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- (71) Applicant: **APPLE INC.** [US/US]; One Apple Park Way, Cupertino, California 95014 (US).
- (72) Inventors: **GUPTA, Vivek**; c/o APPLE INC., One Apple Park Way, Cupertino, California 95014 (US). **JAIN,**

**Puneet**; c/o APPLE INC., One Apple Park Way, Cupertino, California 95014 (US). **KEDALAGUDDE, Meghashree Dattatri**; c/o APPLE INC., One Apple Park Way, Cupertino, California 95014 (US).

(74) Agent: **HELVEY, Jeffrey T.** 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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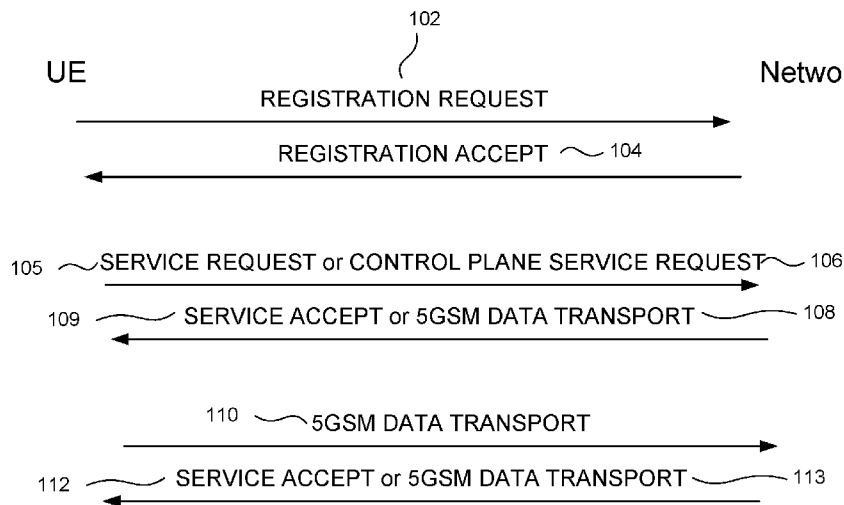


Figure 1

(57) Abstract: Some embodiments of this disclosure include systems, apparatuses, methods, and computer-readable media for use in a wireless network for communicating data over control plane in a 5G system. For example, some embodiments are directed to a user equipment (UE). The UE includes processor circuitry and radio front end circuitry. The processor circuitry can be configured to transmit, using the radio front end circuitry, a first message for connecting to a 5G network and indicating a capability of the UE relating to Cellular Internet of Things (CIOT). The processor circuitry can be further configured to transmit, using the radio front end circuitry and via a control plane to the 5G network, a second message comprising mobile originated data. The processor circuitry can be further configured to receive, using the radio front end circuitry, a third message from the 5G network.



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# METHODS AND SYSTEMS FOR DATA TRANSFER OVER NON-ACCESS STRATUM (NAS) CONTROL PLANE FOR CELLULAR INTERNET OF THINGS (CIOT) IN A 5G SYSTEM (5GS)

## CROSS REFERENCE TO RELATED APPLICATIONS

**[0001]** This application claims the benefit under 35 U.S.C. § 119(e) of U.S. Provisional Application No. 62/797,012, filed January 25, 2019, which is hereby incorporated by reference in its entirety.

## BACKGROUND

**[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 communicating data over control plane in a 5G system.

**[0004]** Some embodiments are directed to a user equipment (UE). The UE includes processor circuitry and radio front end circuitry. The processor circuitry can be configured to transmit, using the radio front end circuitry, a first message for connecting to a 5G network and indicating a capability of the UE relating to Cellular Internet of Things (CIOT). The processor circuitry can be further configured to transmit, using the radio front end circuitry and via a control plane to the 5G network, a second message comprising mobile originated data. The processor circuitry can be further configured to receive, using the radio front end circuitry, a third message from the 5G network.

**[0005]** Some embodiments are directed to a method. The method includes transmitting, by a user equipment (UE), a first message for connecting to a 5G network and indicating a capability of the UE relating to Cellular Internet of Things (CIOT). The method further includes transmitting, via a control plane to the 5G network, a second message comprising mobile originated data and receiving a third message from the 5G network.

**[0006]** Some embodiments are directed to a user equipment (UE). The UE includes a memory configured to store program instructions and a processor. The processor, upon executing the program instructions, can be configured to transmit a first message for connecting to a 5G network and indicating a capability of the UE relating to Cellular Internet of Things (CIOT). The processor can be further configured to transmit, via a control plane to the 5G network, a second message comprising mobile originated data and receive mobile terminated data from the 5G network.

## BRIEF DESCRIPTION OF THE DRAWINGS/FIGURES

- [0007]** Figure 1 depicts data transfer over Non-Access Stratum (NAS) control plane, in accordance with some embodiments.
- [0008]** Figure 2 depicts an exemplary user data container, in accordance with some embodiments.
- [0009]** Figure 3 depicts one exemplary Protocol Data Unit (PDU) session establishment enabling data over NAS-SM, in accordance with some embodiments.
- [0010]** Figure 4 depicts one exemplary mobile originated data transfer via NAS-SM and N6, in accordance with some embodiments.
- [0011]** Figure 5 depicts one exemplary mobile terminated data transport via NAS-SM and N6, in accordance with some embodiments.
- [0012]** Figure 6 depicts one exemplary PDU session establishment procedure for data over NAS (NEF based), in accordance with some embodiments.
- [0013]** Figure 7 depicts an architecture of a system of a network, in accordance with some embodiments.
- [0014]** Figure 8 depicts an architecture of a system including a first core network, in accordance with some embodiments.
- [0015]** Figure 9 depicts an architecture of a system including a second core network in accordance with some embodiments.
- [0016]** Figure 10 depicts an example of infrastructure equipment, in accordance with various embodiments.
- [0017]** Figure 11 depicts example components of a computer platform, in accordance with various embodiments.

- [0018] Figure 12 depicts example components of baseband circuitry and radio frequency circuitry, in accordance with various embodiments.
- [0019] Figure 13 is an illustration of various protocol functions that may be used for various protocol stacks, in accordance with various embodiments.
- [0020] Figure 14 illustrates components of a core network, in accordance with various embodiments.
- [0021] Figure 15 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.
- [0022] Figure 16 depicts an example flowchart for practicing the various embodiments discussed herein, for example, for communicating data over control plane in a 5G system.
- [0023] Figure 17 depicts another example flowchart for practicing the various embodiments discussed herein, for example, for communicating data over control plane in a 5G system.
- [0024] The features and advantages of the embodiments will become more apparent from the detailed description set forth below when taken in conjunction with the drawings, in which like reference characters identify corresponding elements throughout. In the drawings, like reference numbers generally indicate identical, functionally similar, and/or structurally similar elements. The drawing in which an element first appears is indicated by the leftmost digit(s) in the corresponding reference number.

## DETAILED DESCRIPTION

- [0025] 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).

**[0026]** A listing of abbreviations, as well as notes on terminology, is provided at the end of this disclosure.

**[0027]** The 3GPP Rel-16 stage-3 work-item (CIOT-CT) across SA2 and CT1/CT3/CT4/CT6 WGs is intended to carry out architecture enhancements to support highly efficient handling of frequent and infrequent small data transmissions in 5G systems with minimized overhead for system signaling without compromising, for example, security, support power consumption optimizations, simplify mobility and session management procedures and support paging optimizations.

**[0028]** There is currently no mechanism to transfer data over a control plane in a 5G system. The following disclosure describes various mechanisms to transfer data over a control plane in both connected and idle modes. The solutions described herein include, for example, both new messages and enhancements to existing messages in a 5G system to support data over NAS terminating at a user plane function (UPF) and network exposure function (NEF). In one example, a new message 5GSM DATA TRANSPORT is proposed to transfer data in a connected mode from a UE to a UPF/NEF, and from a UPF/NEF to a UE. In an idle mode the UE uses SERVICE REQUEST or CONTROL PLANE SERVICE REQUEST to encapsulate 5GSM DATA TRANSPORT and send the message to the UPF/NEF.

**[0029]** The following aspects are considered for data via NEF/UPF data transfer procedure design.

- 1) Because multiple connections (UE-NEF and UPF connections) can co-exist, a unique ID is needed to distinguish the connections between the UE and the network in order to correctly deliver the data. The combination of a protocol data unit (PDU) session ID and QFI (QoS flow identifier) is used to serve this purpose.
- 2) The Data via NEF/UPF PDU embedded in the NAS message is both integrity protected and encrypted. As the PDU session ID and QFI (QoS Flow Identifier) is used as one of the input parameters in the security operations, it must NOT to be encrypted.
- 3) The Non-Access Stratum (NAS) message to carry the data is similar to the initial NAS message. This means that the message header has to contain a key set

identifier (KSI) to cope with the case that the UE and network have got out-of-sync.

- 4) A new 5GSM message containing the PDU Session ID/QoS Flow is added for data transfer.

**[0030]** Herein, parameters and messages introduced to support Data over NAS are described.

### **1. Transport of user data via the control plane (UE and network impacts TS 24.501)**

**[0031]** If the UE is in a connected mode, the UE initiates the procedure by sending the 5GSM DATA TRANSPORT message including the user data to be sent in the User data container IE. The length of the value part of the User data container IE should not exceed the link MTU size for the respective type of user data (IPv4, IPv6 or Non-IP). If the UE is in an idle mode, the UE initiates the procedure by sending the 5GSM DATA TRANSPORT message included in a SERVICE REQUEST message or a new CONTROL PLANE SERVICE REQUEST message.

**[0032]** Based on information provided by the upper layers, the UE may include a Release assistance indication IE in the 5GSM DATA TRANSPORT message to inform the network that subsequent to the current uplink data transmission no further uplink or downlink data transmission (e.g. an acknowledgement or response) is expected (i.e., the upper layers indicated that data exchanges have completed with the current UL data transfer) or subsequent to the current uplink data transmission only a single downlink data transmission and no further uplink data transmission is expected (i.e., the upper layers indicated that data exchanges will have completed with the next downlink data transmission).

**[0033]** When receiving the 5GSM DATA TRANSPORT message, the session management function (SMF) shall identify the PDN connection to the NEF or to the UPF based on the PDU session ID included in message, and forward the contents of the User data container IE accordingly. If the 5GSM DATA TRANSPORT message includes a Release assistance indication IE indicating that no further uplink or downlink data transmission subsequent to the uplink data transmission is expected, then 5GSM layer indicates to the 5GMM layer to initiate release of the NAS signaling connection. Additionally, or alternatively, upon subsequent delivery of the next received downlink data transmission to the UE if the release assistance indication indicates that only a single

downlink data transmission and no further uplink data transmission subsequent to the uplink data transmission is expected then 5GSM layer indicates to the 5GMM layer to initiate release of the NAS signaling connection.

**[0034]** Figure 1 depicts data transfer over Non-Access Stratum (NAS) control plane, in accordance with some embodiments. As illustrated in, for example, Figure 1, the UE indicates its capability and preferences for CIoT transfer as part of REGISTRATION REQUEST message 102 in initial or mobility and periodic update registration procedure. The network considers the UE request and preferences and responds back with what it can support as part of REGISTRATION ACCEPT message 104 based on network’s own capabilities and what it can support.

**[0035]** Thereafter in idle mode UE sends data using SERVICE REQUEST message 105 or CONTROL PLANE SERVICE REQUEST message 106, which contains an embedded 5GSM DATA TRANSPORT message. The network responds with SERVICE ACCEPT 108 if there is no data to send back to UE or with 5GSM DATA TRANSPORT message 109, if there is data to be sent to UE.

**[0036]** In connected mode, the UE directly uses the 5GSM message 5GS DATA TRANSPORT 110 to send data to network. The network again responds in a similar way (112 or 113) as above.

**[0037]** The 5GSM DATA TRANSPORT message (e.g., 109, 110, and/or 113) is sent by the UE or the SMF in order to carry user data in an encapsulated format.

Table A: 5GSM DATA TRANSPORT message content (e.g., referring to stage three impacts)

IEI	Information Element	Type/Reference	Presence	Format	Length
	Extended Protocol discriminator	Extended Protocol discriminator	M	V	1
	PDU Session ID	PDU session identity 2	M	V	2
	QFI	QFI	M	V	1
	5GSM data transport message identity	Message type	M	V	1
	User data container	User data container	M	LV-E	2-n
F-	Release assistance indication	Release assistance indication	O	TV	1

**[0038]** The QFI is of length one octet and has values in range 0 to 63. The network assigns the QFI value for transfer of user data.

[0039] The User data container, as illustrated in, for example, Figure 2, is a type 6 information element. Figure 2 depicts an exemplary user data container 200, in accordance with some embodiments.

[0040] The SERVICE REQUEST message 105 may be enhanced as follows:

Table B: SERVICE REQUEST message content

IEI	Information Element	Type/Reference	Presence	Format	Length
	Extended protocol discriminator	Extended protocol discriminator 9.2	M	V	1
	Security header type	Security header type 9.3	M	V	1/2
	Spare half octet	Spare half octet 9.5	M	V	1/2
	Service request message identity	Message type 9.7	M	V	1
	ngKSI	NAS key set identifier 9.11.3.32	M	V	1/2
	Service type	Service type 9.11.3.50	M	V	1/2
	5G-S-TMSI	5GS mobile identity 9.11.3.4	M	LV-E	8
40	Uplink data status	Uplink data status 9.11.3.57	O	TLV	4-34
50	PDU session status	PDU session status 9.11.3.44	O	TLV	4-34
25	Allowed PDU session status	Allowed PDU session status 9.11.3.13	O	TLV	4-34
71	NAS message container	NAS message container 9.11.3.33	O	TLV-E	4-n
	Payload container type	Payload container type 9.11.3.40	M	V	1/2
	Payload container	Payload container 9.11.3.39	M	LV-E	3-65537

[0041] The last two rows of Table B can be referring to stage three impacts. The payload container is set to N1 SM information and the Payload container contains the 5GSM DATA TRANSPORT message. In another variant just a Payload container may be included that may be set to 5GSM DATA TRANSPORT message. In yet another variant a new IE may be defined for the purpose of including this 5G SM message.

[0042] Instead of using the existing SERVICE REQUEST message 105 in another variant alternately, a new CONTROL PLANE SERVICE REQUEST message 106 may be defined as follows:

Table C : CONTROL PLANE SERVICE REQUEST message content (e.g., referring to stage three impacts)

IEI	Information Element	Type/Reference	Presence	Format	Length
	Extended protocol discriminator	Extended protocol discriminator 9.2	M	V	1
	Security header type	Security header type 9.3	M	V	1/2
	Spare half octet	Spare half octet 9.5	M	V	1/2
	Control Plane Service request message identity	Message type 9.7	M	V	1
	ngKSI	NAS key set identifier 9.11.3.32	M	V	1/2
	Control plane service type	Service type 9.11.3.50	M	V	1/2
71	NAS message container	NAS message container 9.11.3.33	O	TLV-E	4-n
	Payload container type	Payload container type 9.11.3.40	M	V	1/2
	Payload container	Payload container 9.11.3.39	M	LV-E	3-65537

[0043] The payload container is set to N1 SM information and the Payload container contains the 5GSM DATA TRANSPORT message (e.g., message 109, 110, and/or 113). In another variant just a Payload container may be included that may be set to 5GSM DATA TRANSPORT message (e.g., message 109, 110, and/or 113). In yet another variant a new IE may be defined for the purpose of including this 5G SM message.

**2. Core Network and system level enhancements and impacts PDU session establishment procedure for data over NAS (UPF based):**

[0044] A new container type “SM data transfer “is defined as part of stage 2 specification in TR 23.724 for frequent small data transmission over NAS and the PDU session establishment procedure for data over NAS is described as given below. In this disclosure, stage 3 details of the messages impacted between the UE and the UPF and between the UE and the NEF to enable data transfer over NAS are provided.

- [0045] Figure 3 depicts one exemplary Protocol Data Unit (PDU) session establishment enabling data over NAS-SM, in accordance with some embodiments.
- [0046] 1. The UE 302 sends a PDU session establishment request message 301 as SM payload of a NAS transport message. The NAS transport message contains PDU session ID along with other regular information e.g. DNN, S-NSSAI, etc. if applicable.
- [0047] 2. The AMF 304 determines if the PDU Session uses NAS-SM to transfer PDUs. If the PDU Session will use NAS-SM to transfer PDUs, the AMF 304 selects an SMF 306 in 303 that supports Data over NAS-SM if available for the requested DNN, and S-NSSAI. The AMF 304 stores the association of the PDU Session ID and the selected SMF ID in the UE context. The network chooses to transfer data to the DN via N6.
- [0048] How the AMF 304 determines if the PDU Session uses NAS-SM to transfer PDUs will be determined as discussed below.
- [0049] It is assumed that the exposure of network capabilities towards the SCS/AS is done via NEF. In addition, *when a UE is capable of switching between EPC and 5GC, it shall only be associated with combined SCEF+NEF node(s) for Service Capability Exposure*. Consequently, data towards SCS/AS can be routed via a NEF+SCEF combined node. See also Solution 30.
- [0050] 3. The AMF 304 invokes Nsmf\_PDUSession\_CreateSMContext request 305 including DNN, S-NSSAI and PDU Session ID. The AMF 304 also indicates to the SMF 306 if the PDU Session uses NAS-SM to transfer PDUs. The SMF 306 replies with an Nsmf\_PDUSession\_CreateSMContext Response.
- [0051] 4. The SMF 306 may perform a Session Management Policy Establishment procedure 309.
- [0052] 5. The SMF 306 selects a UPF at 311.
- [0053] 6. The SMF 306 configures the UPF for data transfer via N4 at 313.
- [0054] 7. The SMF 306 sends a PDU Session Establishment Accept 315 providing indication that Data Over NAS-SM is enabled for this PDU session without including the N2 SM container.
- [0055] 8. The AMF 304 forwards the NAS message 317 to the UE 302.
- [0056] In step 3, the AMF 304 invokes the Nsmf\_PDUSession\_CreateSMContext request 305 to create an association between AMF and SMF to support a PDU session.

- [0057] The Nsmf\_PDUSession\_CreateSMContext service operation requires the following modification to indicate to the SMF that the PDU session use NAS-SM to transfer PDUs.
- [0058] Service operation name: Nsmf\_PDUSession\_CreateSMContext.
- [0059] Description: It creates an AMF-SMF association to support a PDU Session.
- [0060] Input, Required: SUPI or PEI, DNN, AMF ID (AMF Instance ID).
- [0061] Input, Optional: PEI, S-NSSAI(s), PDU Session Id, N1 SM container, SM data transfer indication, UE location information, UE Time Zone, AN type, H-SMF identifier/address, list of alternative H-SMF(s) if available, old PDU Session ID (if the AMF also received an old PDU Session ID from the UE as specified in clause 4.3.5.2), Subscription For PDU Session Status Notification, indication that the SUPI has not been authenticated, PCF ID, DNN Selection Mode, UE PDN Connection Context, GPSI, UE presence in LADN service area, GUAMI, backup AMF(s) (if NF Type is AMF), Trace Requirements. Backup AMF(s) sent only once by the AMF to the SMF in its first interaction with the SMF, UE's Routing Indicator or UDM Group ID for the UE.
- [0062] Output, Required: Result Indication
- [0063] Output, Optional: Cause, PDU Session ID, N2 SM information, N1 SM container, S-NSSAI(s), SM data transfer supported.
- [0064] When the PDU Session is for Emergency services for a UE without USIM, the AMF provides the PEI and not the SUPI as identifier of the UE. When the PDU Session is for Emergency services of an unauthenticated UE with an USIM, the AMF shall provide both the SUPI and the PEI and shall provide an indication that the SUPI has not been authenticated.
- [0065] In some embodiments, the SMContextCreateData request data structure creates an individual SM context resource in SMF. The SMContextCreateData data type as defined in 29.502 is updated as follows to allow for Data over NAS indication:

supi	Supi	C	0..1	This IE shall be present, except if the UE is emergency registered and UICCless. When present, it shall contain the subscriber permanent identify.
unauthenticatedSupi	boolean	C	0..1	This IE shall be present if the SUPI is present in the message but is not authenticated and is for an emergency registered UE.

				When present, it shall be set as follows: - true: unauthenticated SUPI; - false (default): authenticated SUPI.
pei	Pei	C	0..1	This IE shall be present if the UE is emergency registered and it is either UICless or the SUPI is not authenticated. For all other cases, this IE shall be present if it is available. When present, it shall contain the permanent equipment identifier.
gpsi	Gpsi	C	0..1	This IE shall be present if it is available. When present, it shall contain the user's GPSI.
pduSessionId	PduSessionId	C	0..1	This IE shall be present, except during an EPS to 5GS Idle mode mobility or handover using the N26 interface. When present, it shall contain the PDU Session ID.
dnn	Dnn	C	0..1	This IE shall be present, except during an EPS to 5GS Idle mode mobility or handover using the N26 interface. When present, it shall contain the requested DNN.
sNssai	Snsai	C	0..1	This IE shall be present during the PDU session establishment procedure. In this case, it shall contain the requested S-NSSAI for the serving PLMN. This corresponds to an S-NSSAI from the allowed NSSAI.  This IE shall also be present during an EPS to 5GS idle mode mobility or handover using the N26 interface. In this case, it shall contain the S-NSSAI configured in the AMF for EPS interworking.
hplmnSnsai	Snsai	C	0..1	This IE shall be present for a HR PDU session, except during an EPS to 5GS idle mode mobility or handover using the N26 interface. When present, it shall contain the requested S-NSSAI for the HPLMN. This corresponds to an S-NSSAI from the subscribed S-NSSAI corresponding to the SNSSAI value included in the sNssai IE.
servingNfId	NfInstanceId	M	1	This IE shall contain the identifier of the

				serving NF (e.g. serving AMF).
guami	Guami	C	0..1	This IE shall contain the serving AMF's GUAMI. It shall be included if the NF service consumer is an AMF.
serviceName	ServiceName	O	0..1	When present, this IE shall contain the name of the AMF service to which SM context status notifications are to be sent (see subclause 6.5.2.2 of 3GPP TS 29.500 [4]). This IE may be included if the NF service consumer is an AMF.
servingNetwork	PlmnId	M	1	This IE shall contain the serving core network operator PLMN ID.
requestType	RequestType	C	0..1	This IE shall be present if the request relates to an existing PDU session or an existing emergency PDU session, except during an EPS to 5GS idle mode mobility or handover using the N26 interface. It may be present otherwise. When present, it shall indicate whether the request refers to a new PDU session or emergency PDU session, or to an existing PDU session or emergency PDU session.
n1SmMsg	RefToBinaryData	C	0..1	This IE shall be present and reference the N1 SM Message binary data (see subclause 6.1.6.4.2), except during an EPS to 5GS Idle mode mobility or handover using N26.
anType	AccessType	M	1	This IE shall indicate the Access Network Type to which the PDU session is to be associated.
ratType	RatType	C	0..1	This IE shall be present and indicate the RAT Type used by the UE, if available.
presenceInLadn	PresenceState	C	0..1	This IE shall be present if the DNN corresponds to a LADN. When present, it shall be set to "IN" or "OUT" to indicate that the UE is in or out of the LADN service area.
ueLocation	UserLocation	C	0..1	This IE shall contain the UE location information, if it is available. See NOTE.
ueTimeZone	TimeZone	C	0..1	This IE shall contain the UE Time Zone, if it is available.
addUeLocation	UserLocation	O	0..1	Additional UE location. This IE may be present, if anType indicates a non-3GPP access and valid 3GPP access user location information

				<p>is available.</p> <p>When present, it shall contain:</p> <ul style="list-style-type: none"> <li>- the last known 3GPP access user location; and</li> <li>- the timestamp, if available, indicating the UTC time when the addUeLocation information was acquired.</li> </ul> <p>(NOTE)</p>
smContextStatusUri	Uri	M	1	This IE shall include the callback URI to receive notification of SM context status.
hSmfUri	Uri	C	0..1	This IE shall be present in HR roaming scenarios. When present, it shall contain the URI of the Nsmf_PDUSession service of the selected H-SMF. The URI shall be formatted as specified in subclause 6.1.1.
oldPduSessionId	PduSessionId	C	0..1	This IE shall be present if this information is received from the UE. When present, it shall contain the old PDU Session ID received from the UE. See subclauses 4.3.2.2.1 and 4.3.5.2 of 3GPP TS 23.502 [3].
pduSessionsActivateList	array(PduSessionId)	C	1..N	This IE shall be present, during an EPS to 5GS Idle mode mobility using the N26 interface, if the UE indicated PDU session(s) to be activated in the Registration Request. When present, it shall indicate all the PDU session(s) requested to be re-activated by the UE.
ueEpsPdnConnection	EpsPdnCnxContainer	C	0..1	This IE shall be present, during an EPS to 5GS Idle mode mobility or handover using the N26 interface. When present, it shall contain an MME/SGSN UE EPS PDN connection including the EPS bearer context(s).
hoState	HoState	C	0..1	This IE shall be present during an EPS to 5GS handover using N26 interface, to request the preparation of a handover of the PDU session. When present, it shall be set as specified in subclause 5.2.2.2.3.
additionalHsmfUri	array(Uri)	O	1..N	This IE may be present in HR roaming scenarios. When present, it shall contain an array of URI of the Nsmf_PDUSession service of the additional H-SMFs discovered by the

				<p>AMF for the given DNN, hplmnSnsai and for this PDU session. If provided, the V-SMF shall use these additional H-SMF(s) if the V-SMF is not able to receive any response from the H-SMF identified by hSmfUri.</p> <p>The URI shall be formatted as specified in subclause 6.1.1.</p>
pcfId	NfInstanceId	O	0..1	When present, this IE shall contain the identifier of the PCF selected by the AMF for the UE (for Access and Mobility Policy Control); it shall be the V-PCF in LBO roaming and the H-PCF in HR roaming.
nrfUri	Uri	O	0..1	This IE may be present to indicate the NRF to use for PCF selection within the same network slice instance. When present, the SMF shall use the NRF URI to select the PCF.
supportedFeatures	SupportedFeatures	C	0..1	This IE shall be present if at least one optional feature defined in subclause 6.1.8 is supported.
selMode	DnnSelectionMode	C	0..1	This IE shall be present if it is available. When present, it shall indicate whether the requested DNN corresponds to an explicitly subscribed DNN or to the usage of a wildcard subscription.
backupAmfInfo	array(BackupAmfInfo)	C	1..N	This IE shall be included if the NF service consumer is an AMF and the AMF supports the AMF management without UDSF for the following cases: <ul style="list-style-type: none"> <li>- First interaction with SMF.</li> <li>- Modification of the BackupAmfInfo.</li> </ul>
traceData	TraceData	C	0..1	This IE shall be included if trace is required to be activated (see 3GPP TS 32.422 [22]).
udmGroupId	NfGroupId	O	0..1	When present, it shall indicate the identity of the UDM group serving the UE.
routingIndicator	string	O	0..1	When present, it shall indicate the Routing Indicator of the UE.
epsInterworkingInd	EpsInterworkingIndication	O	0..1	<p>The AMF may provide the indication when a PGW-C+SMF is selected to serve the PDU Session.</p> <p>When present, this IE shall indicate whether the PDU session may possibly</p>

				<p>be moved to EPS and whether N26 interface to be used during EPS interworking procedures.</p> <p>The AMF may derive the value of the indication from different sources, like UE radio capabilities (e.g. "S1 mode supported"), UE subscription data (e.g. "Core Network Type Restriction to EPC" and "Interworking with EPS Indication" for the DNN) and configurations.</p>
indirectForwardingFlag	boolean	C	0..1	<p>The AMF shall include this indication during N26 based Handover procedure from EPS to 5GS (see 3GPP TS 23.502 [3], subclause 4.11.1.2.2), to inform the SMF of the applicability or non-applicability of indirect data forwarding.</p> <p>When present, it shall be set as follows:</p> <ul style="list-style-type: none"> <li>- True: indirect data forwarding is applicable</li> <li>- False: indirect data forwarding is not applicable</li> </ul>
smDataTransferIndication	Boolean	O	1	<p>The AMF may provide the indication to the SMF when a PDU session uses NAS-SM to transfer PDUs.</p> <p>When present, it shall be set as follows:</p> <ul style="list-style-type: none"> <li>- True: NAS-SM data transfer supported</li> <li>- False: NAS-SM data transfer not supported</li> </ul>
<p>NOTE: In shared networks, when the message is sent from the VPLMN to the HPLMN, the PLMN ID that is communicated in this IE shall be that of the selected Core Network Operator.</p> <p>In shared networks, when the AMF and SMF pertain to the same PLMN, the Primary PLMN ID shall be communicated in the ECGI or NCGI to the SMF. The Core Network Operator PLMN ID shall be communicated in the TAI and the Serving Network.</p>				

**[0066]** In some embodiments, the smDataTransferIndication can refer to stage tree impacts. The SMContextCreatedData response data structure represents successful creation of an SM context in SMF. The SMContextCreatedData data type as defined in 29.502 is updated as follows to allow for Data over NAS indication:

Attribute name	Data type	P	Cardinality	Description
hsmfUri	Uri	C	0..1	This IE shall be present in HR roaming scenarios if the additionalHsmfUri IE was received in the request and the V-SMF established the PDU session towards an

				alternative SMF listed in the additionalHsmfUri IE. When present, it shall contain the URI of the H-SMF towards which the PDU session was established.
pduSessionId	PduSessionId	C	0..1	This IE shall be present, during an EPS to 5GS Idle mode mobility or handover using the N26 interface. When present, it shall be set to the PDU Session ID.
sNssai	Snsai	C	0..1	This IE shall be present during an EPS to 5GS Idle mode mobility or handover using the N26 interface. When present, it shall contain the S-NSSAI assigned to the PDU session.
upCnxState	UpCnxState	C	0..1	This IE shall be present if the SMF was requested to activate the user plane connection of the PDU session in the corresponding request. When present, it shall be set as specified in subclause 5.2.2.2.2.
n2SmlInfo	RefToBinaryData	C	0..1	This IE shall be present if N2 SM Information needs to be sent to the AN.
n2SmlInfoType	N2SmlInfoType	C	0..1	This IE shall be present if "n2SmlInfo" attribute is present. When present, this IE shall indicate the NG AP IE type for the NG AP SMF related IE container carried in "n2SmlInfo" attribute.
allocatedEbiList	array(EbiArpmapping)	C	1..N	This IE shall be present if the consumer NF is an AMF and Inter-system mobility happens. When present, it shall contain an array of EBI to ARP mappings currently allocated to the PDU session.
hoState	HoState	C	0..1	This IE shall be present if the SMF was requested to prepare an EPS to 5GS handover for the PDU session in the corresponding request. When present, it shall be set as specified in subclause 5.2.2.2.3.
smfServiceInstanceId	string	O	0..1	When present, this IE shall contain the serviceInstanceId of the SMF service instance serving the PDU session Context. This IE may be used by the AMF to identify PDU session contexts affected by a failure or restart of the SMF service instance (see subclause 6.2 of

				3GPP TS 23.527 [24]).
recoveryTime	DateTime	O	0..1	Timestamp when the SMF service instance serving the PDU session was (re)started (see subclause 6.3 of 3GPP TS 23.527 [24]).
supportedFeatures	SupportedFeatures	C	0..1	This IE shall be present if at least one optional feature defined in subclause 6.1.8 is supported.
smDataTransferSupported	Boolean	O	1	This IE shall be present if the SMF supports data transfer over NAS.

- [0067]** In some embodiments, the smDataTransferSupported can refer to stage three impacts
- [0068]** In other embodiment, the AMF 304 may indicate SM data transfer indication in the SupportedFeatures IE of the SMContextCreateData data type request to indicate to the SMF that SM data transfer feature is required to be supported for the PDU session.
- [0069]** The SMF 306 may indicate that the SM data transfer is supported in the supportedFeatures IE in the SMContextCreatedData data type response.
- [0070]** In step 5, the SMF 306 selects the UPF 308. Among other parameters listed in clause 6.3.3.3 TS 23.501, the SMF 306 may use the SM data transfer indication to select an UPF 308 for a particular PDU session. According to some embodiments, this step can refer to stage three impacts.
- [0071]** In step 6, the SMF 306 configures the UPF 308 for data transfer over N4.
- [0072]** As described in TS 23.502, the N4 Session Establishment procedure is used to create the initial N4 session context for a PDU Session at the UPF 308. The SMF 306 assigns a new N4 Session ID and provides it to the UPF 308. The N4 Session ID is stored by both entities and used to identify the N4 session context during their interaction. The SMF also stores the relation between the N4 Session ID and PDU Session for a UE.
- [0073]** To enable small data transfer between SMF 306 and UPF 308, an N4-U tunnel is established between SMF 306 and UPF 308. The SMF 306 sends its own N4-U IP address and SMF downlink data TEID for downlink data transfer from the UPF 308 in the N4 Session Establishment/Modification request. The UPF sends its own N4-U IP address and UPF TEID for N4-U in the N4 Session Establishment/Modification response. According to some embodiments, this step can refer to stage three impacts.

[0074] In step 7, the SMF 306 sends a PDU Session Establishment Accept providing indication that Data Over NAS-SM is enabled for this PDU session without including the N2 SM container.

[0075] Namf\_Communication\_N1N2MessageTransfer service operation  
**Service operation name:** Namf\_Communication\_N1N2MessageTransfer.  
**Description:** CN NF request to transfer downlink N1 and/or N2 message to the UE and/or AN through the AMF.  
**Input, Required:** CN NF ID, Message type (N1 or N2 or both), Message Container (s) where at least one of the message containers (N1 or N2) is required.  
**Input, Optional:** last message indication, Session ID, Paging Policy Indicator, ARP, Area of validity for the N2 SM information, 5QI, N1N2TransferFailure Notification Target Address, type of N2 SM information, SM Data Transfer Result Indication. According to some embodiments, SM Data Transfer Result Indication can refer to stage three impacts.  
**Output, Required:** Result indication.  
**Output, Optional:** Redirection information.

[0076] The N1N2MessageTransferReqData request data structure initiates a N1 message and/or N2 message transfer at the AMF and may create a resource to store the N1 message if the UE is not reachable or if the UE is paged. The N1N2MessageTransferReqData data type as defined in 29.518 is updated as follows to indicate Data over NAS is supported for the PDU session:

Attribute name	Data type	P	Cardinality	Description
n1MessageContainer	N1MessageContainer	C	0..1	This IE shall be included if a N1 message needs to be transferred.
n2InfoContainer	N2InfoContainer	C	0..1	This IE shall be included if a N2 information needs to be transferred.
skipInd	boolean	C	0..1	This IE shall be present and set to "true" if the service consumer (e.g. SMF) requires the N1 message to be sent to the UE only when UE is in CM-CONNECTED, e.g. during SMF initiated PDU session release procedure (see subclause 4.3.4.2 of 3GPP TS 23.502 [2]).  When present, this IE shall be set as following: - true: AMF should skip sending N1 message to UE, when the UE is in CM-

				IDLE. - false (default): the AMF shall send the N1 message to the UE.
lastMsgIndication	boolean	O	0..1	This flag when present shall indicate that the message transferred is the last message. (See subclause 4.13.3.3 of 3GPP TS 23.502 [2]).
pduSessionId	PduSessionId	O	0..1	PDU Session ID for which the N1 / N2 message is sent, if the N1 / N2 message class is SM.
lcsCorrelationId	CorrelationID	O	0..1	LCS Correlation ID, for which the N1 message is sent, if the N1 message class is LPP (see subclause 4.13.5.4 of 3GPP TS 23.502 [2]).
ppi	Ppi	O	0..1	This IE when present shall indicate the Paging policy to be applied. The paging policies are configured at the AMF.
arp	Arp	O	0..1	This IE when present shall indicate the Allocation and Retention Priority of the PDU session for which the N1/N2 message transfer is initiated. This IE shall not be present when the N1/N2 message class is not SM.
5qi	5Qi	O	0..1	This IE when present shall indicate the 5QI associated with the PDU session for which the N1 / N2 message transfer is initiated. This IE shall not be present when the N1/N2 message class is not SM.
n1n2FailureTxfNotifURI	Uri	O	0..1	If included, this IE represents the callback URI on which the AMF shall notify the N1/N2 message transfer failure.
smfReallocationInd	boolean	O	0..1	This IE shall indicate that the SMF is requested to be reallocated (see subclause 4.3.5.2 of 3GPP TS 23.502 [2]). When present, this IE shall be set as follows: - true: the SMF is requested to be reallocated. - false (default): the SMF is not requested to be reallocated.
areaOfValidity	AreaOfValidity	O	0..1	This IE represents the list of TAs where the provided N2 information is valid. See subclause 5.2.2.2.7 and 4.2.3.3 of 3GPP TS 23.502 [3].
supportedFeatures	SupportedFeatures	C	0..1	This IE shall be present if at least one optional feature defined in subclause

				6.1.8 is supported.
smDataTransferResult	Boolean	O	1	This IE shall indicate that the SM data transfer is supported when set to True.
NOTE: For N1 message class "UPDP", as per 3GPP TS 24.501 [11] Annex D, the messages between UE and PCF carry PTI which is used by the PCF to correlate the received N1 message in the notification with a prior transaction initiated by the PCF.				

[0077] In some embodiments, the smDataTransferResult can refer to stage three impacts.

**A. Mobile Originated Data Transfer via NAS-SM and N6**

[0078] In embodiments, a new service operation of SMF Nsmf\_SMDDataTransfer is defined over N11 interface to enable the SM data transfer. These embodiments can refer to stage two impacts.

[0079] Figure 4 depicts one exemplary mobile originated data transfer via NAS-SM and N6, in accordance with some embodiments.

[0080] Data structure supported by the POST Request Body on this resource (this can refer to stage three impacts):

Data type	P	Cardinality	Description
SMDDataTransferReqData	M	1	This contains: - N1 message, if the NF Service Consumer requests to transfer an N1 message to the UPF ;

[0081] Data structure supported by the POST Response Body on this resource (this can refer to stage three impacts):

Data type	P	Cardinality	Response codes	Description
SMDDataTransferRspData	C	0..1	200 OK	This case represents a successful transfer of SM Data.
SMDDataTransferError	M	1	404 Not Found	The "cause" attribute shall be set to one of the following application error: - CONTEXT_NOT_FOUND See table 6.1.7.3-1 TS 29.502 for the description of these errors.

[0082] Data type: SMDDataTransferReqData (this can refer to stage three impacts)

Attribute name	Data type	P	Cardinality	Description
n1MessageContainer	N1MessageContainer	C	0..1	This IE shall be included if a N1 message needs to be transferred.
pduSessionId	PduSessionId	O	0..1	PDU Session ID for which the N1 / N2 message is sent, if the N1 / N2 message class is SM.

[0083] N1MessageContainer type as defined in TS 29.518 applies for SMDDataTransferReqData

Attribute name	Data type	P	Cardinality	Description
n1MessageClass	N1MessageClass	M	1	This IE shall contain the N1 message class for the message content specified in n1MessageContent.
n1MessageContent	RefToBinaryData	M	1	This IE shall reference the N1 message binary data corresponding to the n1MessageClass. See 3GPP TS 24.501 [11]. See subclause 6.1.6.4.2.
nflid	NflInstanceId	C	0..1	This IE shall be present when the n1MessageClass IE is set to "LPP". When present, this IE shall carry the identifier of the Network Function (e.g. LMF) instance sending or receiving the LPP data.

[0084] A new message class is introduced to differentiate SM data transfer from SM signaling messages as shown below:

Enumeration value	Description
"5GMM"	The whole NAS message as received (for e.g. used in forwarding the Registration message to target AMF during Registration procedure with AMF redirection).
"SM"	The N1 message of SM type
"LPP"	The N1 message of LPP type.
"SMS"	The N1 message of SMS type.
"UPDP"	The N1 messages for UE policy delivery (See Annex D of 3GPP TS 24.501 [11]).
"SM Data Transfer"	The N1 message of small data type

[0085] In some embodiments, SM Data Transfer can refer to stage three impacts.

[0086] In step 7, the SMF 406 encapsulates the DL data as payload in an SM data transfer message and forwards this message along with PDU session ID to the AMF using Namf\_Communication\_N1N2MessageTransfer service operation.

[0087] The Namf\_Communication\_N1N2MessageTransfer service operation is reused with a new message class to indicate that the N1 message container carries DL data as payload.

[0088] A new message class is defined to indicate SM data transfer message. This can refer to stage three impacts.

**N1MessageClass**

Table D: Enumeration N1MessageClass

Enumeration value	Description
"5GMM"	The whole NAS message as received (for e.g. used in forwarding the Registration message to target AMF during Registration procedure with AMF redirection).
"SM"	The N1 message of SM type
"LPP"	The N1 message of LPP type.
"SMS"	The N1 message of SMS type.
"UPDP"	The N1 messages for UE policy delivery (See Annex D of 3GPP TS 24.501 [11]).
"SM Data Transfer"	The N1 message of small data type

[0089] In some embodiments, the SM Data Transfer can refer to stage three impacts.

**B. Mobile terminated Data transport vis NAS-SM and N6**

[0090] Figure 5 depicts one exemplary mobile terminated data transport via NAS-SM and N6, in accordance with some embodiments

[0091] In step 1, the UPF 508 forwards DL data to the SMF 506.

[0092] For step 2 and step 13, the new message and parameters defined above apply.

**C. PDU session establishment procedure for data over NAS (NEF based):**

[0093] Figure 6 depicts one exemplary PDU session establishment procedure for data over NAS (NEF based), in accordance with some embodiments.

[0094] In step 4, the SMF 606 retrieves the Session Management Subscription data for the corresponding SUPI, DNN and S-NSSAI. If the subscription includes an Invoke NEF Selection indication for the DNN and S-NSSAI indicated by UE 602, the SMF 606 retrieves the NIDD information such as External Group Identifier, External Identifier or MSISDN, AF ID and decides to transfer data to the DN via NEF. The SMF 606 selects the NEF based on the UE subscription profile.

[0095] Subscription data types used in Nudm\_SubscriberDataManagement (SDM) Service for session management is given below.

Session Management Subscription data (data needed for PDU Session	GPSI List	List of the GPSI (Generic Public Subscription Identifier) used both inside and outside of the 3GPP system to address a 3GPP subscription.
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Establishment)

Internal Group ID-list	List of the subscribed internal group(s) that the UE belongs to.
Trace Requirements	Trace requirements about a UE (e.g. trace reference, address of the Trace Collection Entity, etc...) is defined in TS 32.421 [39]. This information is only sent to a SMF in the HPLMN or one of its equivalent PLMN(s).
<b>Session Management Subscription data contains one or more S-NSSAI level subscription data:</b>	
S-NSSAI	Indicates the value of the S-NSSAI.
Subscribed DNN list	List of the subscribed DNNs for the S-NSSAI (NOTE 1).
<b>For each DNN in S-NSSAI level subscription data:</b>	
DNN	DNN for the PDU Session.
UE Address	Indicates the subscribed static IP address(es) for the IPv4 or IPv6 or IPv4v6 type PDU Sessions accessing the DNN, S-NSSAI.
Allowed PDU Session Types	Indicates the allowed PDU Session Types (IPv4, IPv6, IPv4v6, Ethernet, and Unstructured) for the DNN, S-NSSAI.
Default PDU Session Type	Indicates the default PDU Session Type for the DNN, S-NSSAI.
Allowed SSC modes	Indicates the allowed SSC modes for the DNN, S-NSSAI.
Default SSC mode	Indicate the default SSC mode for the DNN, S-NSSAI.
Interworking with EPS indication	Indicates whether interworking with EPS is supported for this DNN and S-NSSAI.
5GS Subscribed QoS profile	The QoS Flow level QoS parameter values (5QI and ARP) for the DNN, S-NSSAI (see clause 5.7.2.7 of TS 23.501 [2]).
Charging Characteristics	This information is defined in TS 32.240 [34]; it may e.g. contain information on how to contact the Charging Function. This information, when provided shall override any corresponding predefined information at the SMF
Subscribed-Session-AMBR	The maximum aggregated uplink and downlink MBRs to be shared across all Non-GBR QoS Flows in each PDU Session, which are established for the DNN, S-NSSAI.
Static IP address/prefix	Indicate the static IP address/prefix for the DNN, S-NSSAI.
User Plane Security Policy	Indicates the security policy for integrity protection and encryption for the user plane.
Invoke NEF Selection indicator	Indicates non-IP data delivery via the NEF is supported.

	NEF ID	Indicates the FQDN or IP address of the NEF which is to be selected. It is required if "Invoke NEF Selection" indicator is set.
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[0096] In some embodiments, Invoke NEF Selection indicator and NEF ID can refer to stage two impacts.

[0097] In step 5, two new service operations from NEF are defined Nnef\_PDUSession\_CreateSMContext request and response. The SMF 606 invokes the Nnef\_PDUSession\_CreateSMContext request (which can refer to stage three impacts) including the User Identity, PDU session ID, NEF ID, NIDD information, S-NSSAI, DNN. The NEF replies with an Nnef\_PDUSession\_CreateSMContext response (which can refer to stage three impacts) including User Identity, PDU session ID, NEF ID, S-NSSAI, DNN.

[0098] The data structure supported by the POST Request for SmContextCreateData data type is:

Data type	P	Cardinality	Description
SmContextCreateData	M	1	Representation of the SM context to be created in the SMF.

[0099] The data structure supported by the POST Response for SmContextCreateData data type is:

Data type	P	Cardinality	Response codes	Description
SmContextCreatedData	M	1	201 Created	Successful creation of an SM context.
SmContextCreateError	M	1	400 Bad Request	The "cause" attribute shall be set to one of the errors defined in Table 5.2.7.2-1 of 3GPP TS 29.500 [4].
SmContextCreateError	M	1	403 Forbidden	The "cause" attribute shall be set to one of the following application error: - N1_SM_ERROR - SNSSAI_DENIED - DNN_DENIED - PDUTYPE_DENIED - SSC_DENIED - SUBSCRIPTION_DENIED - DNN_NOT_SUPPORTED - PDUTYPE_NOT_SUPPORTED - SSC_NOT_SUPPORTED - HOME_ROUTED_ROAMING_REQUIRED - OUT_OF_LADN_SERVICE_AREA - NO_EPS_5GS_CONTINUITY - INTEGRITY_PROTECTED_MDR_NOT_ACCEPTABLE See table 6.1.7.3-1 for the description of these errors.
SmContextCreateError	M	1	404 Not Found	The "cause" attribute shall be set to one of the following application error:

				- CONTEXT_NOT_FOUND See table 6.1.7.3-1 for the description of these errors.
SmContextCreateError	M	1	500 Internal Server Error	The "cause" attribute shall be set to one of the errors defined in Table 5.2.7.2-1 of 3GPP TS 29.500 [4] or to one of the following application errors: - INSUFFICIENT_RESOURCES_SLICE - INSUFFICIENT_RESOURCES_SLICE_DNN See table 6.1.7.3-1 for the description of these errors.
SmContextCreateError	M	1	503 Service Unavailable	The "cause" attribute shall be set to one of the errors defined in Table 5.2.7.2-1 of 3GPP TS 29.500 [4] or to one of the following application errors: - DNN_CONGESTION - S-NSSAI_CONGESTION See table 6.1.7.3-1 for the description of these errors.
SmContextCreateError	M	1	504 Gateway Timeout	The "cause" attribute shall be set to one of the following application error: - PEER_NOT_RESPONDING - NETWORK_FAILURE See table 6.1.7.3-1 for the description of these errors.
NOTE: The mandatory HTTP error status codes for the POST method listed in Table 5.2.7.1-1 of 3GPP TS 29.500 [4] other than those specified in the table above also apply, with a ProblemDetails data type (see subclause 5.2.7 of 3GPP TS 29.500 [4]).				

[0100] Data type SmContextCreateData is defined as given below (which can refer to stage three impacts):

Attribute name	Data type	P	Cardinality	Description
supi	Supi	C	0..1	This IE shall be present, except if the UE is emergency registered and UICCless. When present, it shall contain the subscriber permanent identify.
pduSessionId	PduSessionId	C	0..1	This IE shall be present, except during an EPS to 5GS Idle mode mobility or handover using the N26 interface. When present, it shall contain the PDU Session ID.
dnn	Dnn	C	0..1	This IE shall be present, except during an EPS to 5GS Idle mode mobility or handover using the N26 interface. When present, it shall contain the requested DNN.
sNssai	Snsai	C	0..1	This IE shall be present during the PDU session establishment procedure. In this case, it shall contain the requested S-NSSAI for the serving PLMN. This corresponds to an S-NSSAI from the allowed NSSAI.  This IE shall also be present during an EPS to 5GS idle mode mobility or handover using the N26 interface. In this case, it shall contain the S-

				NSSAI configured in the AMF for EPS interworking.
servingNfId	NfInstanceId	M	1	This IE shall contain the identifier of the serving NF (e.g. serving AMF).
nefId	NfInstanceId	O	0..1	When present, this IE shall contain the identifier of the NEF selected by the SMF for the UE
nidInformation		O	0..1	When present, this IE shall contain External Group Identifier, External Identifier or MSISDN

[0101] Data type SmContextCreatedData is defined as given below:

Attribute name	Data type	P	Cardinality	Description
Supi	Supi	C	0..1	This IE shall be present, except if the UE is emergency registered and UICCless. When present, it shall contain the subscriber permanent identify.
pduSessionId	PduSessionId	C	0..1	This IE shall be present, except during an EPS to 5GS Idle mode mobility or handover using the N26 interface. When present, it shall contain the PDU Session ID.
dnn	Dnn	C	0..1	This IE shall be present, except during an EPS to 5GS Idle mode mobility or handover using the N26 interface. When present, it shall contain the requested DNN.
sNssai	Snsai	C	0..1	This IE shall be present during the PDU session establishment procedure. In this case, it shall contain the requested S-NSSAI for the serving PLMN. This corresponds to an S-NSSAI from the allowed NSSAI.  This IE shall also be present during an EPS to 5GS idle mode mobility or handover using the N26 interface. In this case, it shall contain the S-NSSAI configured in the AMF for EPS interworking.
nefId	NfInstanceId	O	0..1	When present, this IE shall contain the identifier of the NEF selected by the SMF for the UE

### Systems and Implementations

[0102] Figure 7 illustrates an example architecture of a system 700 of a network, in accordance with various embodiments. The following description is provided for an example system 700 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.

**[0103]** As shown by Figure 7, the system 700 includes UE 701a and UE 701b (collectively referred to as “UEs 701” or “UE 701”). In this example, UEs 701 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.

**[0104]** In some embodiments, any of the UEs 701 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.

**[0105]** The UEs 701 may be configured to connect, for example, communicatively couple, with an or RAN 710. In embodiments, the RAN 710 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 710 that operates in an NR or 5G system 700, and the term “E-UTRAN” or the like may refer to a RAN 710 that operates

in an LTE or 4G system 700. The UEs 701 utilize connections (or channels) 703 and 704, respectively, each of which comprises a physical communications interface or layer (discussed in further detail below).

**[0106]** In this example, the connections 703 and 704 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 701 may directly exchange communication data via a ProSe interface 705. The ProSe interface 705 may alternatively be referred to as a SL interface 705 and may comprise one or more logical channels, including but not limited to a PSCCH, a PSSCH, a PSDCH, and a PSBCH.

**[0107]** The UE 701b is shown to be configured to access an AP 706 (also referred to as “WLAN node 706,” “WLAN 706,” “WLAN Termination 706,” “WT 706” or the like) via connection 707. The connection 707 can comprise a local wireless connection, such as a connection consistent with any IEEE 802.11 protocol, wherein the AP 706 would comprise a wireless fidelity (Wi-Fi®) router. In this example, the AP 706 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 701b, RAN 710, and AP 706 may be configured to utilize LWA operation and/or LWIP operation. The LWA operation may involve the UE 701b in RRC\_CONNECTED being configured by a RAN node 711a-b to utilize radio resources of LTE and WLAN. LWIP operation may involve the UE 701b using WLAN radio resources (e.g., connection 707) via IPsec protocol tunneling to authenticate and encrypt packets (e.g., IP packets) sent over the connection 707. 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.

**[0108]** The RAN 710 can include one or more AN nodes or RAN nodes 711a and 711b (collectively referred to as “RAN nodes 711” or “RAN node 711”) that enable the connections 703 and 704. 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 711 that operates in an NR or 5G system 700 (for example, a gNB), and the term “E-UTRAN node” or the like may refer to a RAN node 711 that operates in an LTE or 4G system 700 (e.g., an eNB). According to various embodiments, the RAN nodes 711 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.

**[0109]** In some embodiments, all or parts of the RAN nodes 711 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 711; 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 711; 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 711. This virtualized framework allows the freed-up processor cores of the RAN nodes 711 to perform other virtualized applications. In some implementations, an individual RAN node 711 may represent individual gNB-DUs that are connected to a gNB-CU via individual F1 interfaces (not shown by Figure 7). In these implementations, the gNB-DUs may include one or more remote radio heads or RFEMs (see, e.g., Figure 10), and the gNB-CU may be operated by a server that is located in the RAN 710 (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 711 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 701, and are connected to a 5GC (e.g., CN 920 of Figure 9) via an NG interface (discussed infra).

**[0110]** In V2X scenarios one or more of the RAN nodes 711 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 701 (vUEs 701). 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.

**[0111]** Any of the RAN nodes 711 can terminate the air interface protocol and can be the first point of contact for the UEs 701. In some embodiments, any of the RAN nodes 711 can fulfill various logical functions for the RAN 710 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.

**[0112]** In embodiments, the UEs 701 can be configured to communicate using OFDM communication signals with each other or with any of the RAN nodes 711 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.

**[0113]** In some embodiments, a downlink resource grid can be used for downlink transmissions from any of the RAN nodes 711 to the UEs 701, 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.

**[0114]** According to various embodiments, the UEs 701, 702 and the RAN nodes 711, 712 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.

**[0115]** To operate in the unlicensed spectrum, the UEs 701, 702 and the RAN nodes 711, 712 may operate using LAA, eLAA, and/or feLAA mechanisms. In these implementations, the UEs 701, 702 and the RAN nodes 711, 712 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.

**[0116]** LBT is a mechanism whereby equipment (for example, UEs 701, 702, RAN nodes 711, 712, 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.

**[0117]** 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 701 or 702, AP 706, 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 ( $\mu\text{s}$ ); however, the size of the CWS and a MCOT (for example, a transmission burst) may be based on governmental regulatory requirements.

**[0118]** 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.

**[0119]** 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 701, 702 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.

**[0120]** The PDSCH carries user data and higher-layer signaling to the UEs 701. 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 701 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 701b within a cell) may be performed at any of the RAN nodes 711 based on channel quality information fed back from any of the UEs 701. The downlink resource assignment information may be sent on the PDCCH used for (e.g., assigned to) each of the UEs 701.

**[0121]** 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,  $L=1, 2, 4, \text{ or } 8$ ).

- [0122]** 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.
- [0123]** The RAN nodes 711 may be configured to communicate with one another via interface 712. In embodiments where the system 700 is an LTE system (e.g., when CN 720 is an EPC 820 as in Figure 8), the interface 712 may be an X2 interface 712. The X2 interface may be defined between two or more RAN nodes 711 (e.g., two or more eNBs and the like) that connect to EPC 720, and/or between two eNBs connecting to EPC 720. 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 701 from an SeNB for user data; information of PDCP PDUs that were not delivered to a UE 701; 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.
- [0124]** In embodiments where the system 700 is a 5G or NR system (e.g., when CN 720 is an 5GC 920 as in Figure 9), the interface 712 may be an Xn interface 712. The Xn interface is defined between two or more RAN nodes 711 (e.g., two or more gNBs and the like) that connect to 5GC 720, between a RAN node 711 (e.g., a gNB) connecting to 5GC 720 and an eNB, and/or between two eNBs connecting to 5GC 720. 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 701 in a connected mode (e.g., CM-CONNECTED) including functionality to manage the UE mobility for connected mode between one or more RAN nodes 711. The mobility support may include context transfer from an old (source) serving RAN node 711 to new (target) serving RAN node 711; and control of user plane tunnels between old (source) serving RAN node 711 to new (target) serving RAN node 711. 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.

**[0125]** The RAN 710 is shown to be communicatively coupled to a core network—in this embodiment, core network (CN) 720. The CN 720 may comprise a plurality of network elements 722, which are configured to offer various data and telecommunications services to customers/subscribers (e.g., users of UEs 701) who are connected to the CN 720 via the RAN 710. The components of the CN 720 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 720 may be referred to as a network slice, and a logical instantiation of a portion of the CN 720 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.

**[0126]** Generally, the application server 730 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 730 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 701 via the EPC 720.

**[0127]** In embodiments, the CN 720 may be a 5GC (referred to as “5GC 720” or the like), and the RAN 710 may be connected with the CN 720 via an NG interface 713. In embodiments, the NG interface 713 may be split into two parts, an NG user plane (NG-U) interface 714, which carries traffic data between the RAN nodes 711 and a UPF, and the S1 control plane (NG-C) interface 715, which is a signaling interface between the RAN nodes 711 and AMFs. Embodiments where the CN 720 is a 5GC 720 are discussed in more detail with regard to Figure 9.

**[0128]** In embodiments, the CN 720 may be a 5G CN (referred to as “5GC 720” or the like), while in other embodiments, the CN 720 may be an EPC). Where CN 720 is an EPC (referred to as “EPC 720” or the like), the RAN 710 may be connected with the CN 720 via an S1 interface 713. In embodiments, the S1 interface 713 may be split into two parts, an S1 user plane (S1-U) interface 714, which carries traffic data between the RAN nodes 711 and the S-GW, and the S1-MME interface 715, which is a signaling interface between the RAN nodes 711 and MMEs. An example architecture wherein the CN 720 is an EPC 720 is shown by Figure 8.

**[0129]** Figure 8 illustrates an example architecture of a system 800 including a first CN 820, in accordance with various embodiments. In this example, system 800 may implement the LTE standard wherein the CN 820 is an EPC 820 that corresponds with CN 720 of Figure 7. Additionally, the UE 801 may be the same or similar as the UEs 701 of Figure 7, and the E-UTRAN 810 may be a RAN that is the same or similar to the RAN 710 of Figure 7, and which may include RAN nodes 711 discussed previously. The CN 820 may comprise MMEs 821, an S-GW 822, a P-GW 823, a HSS 824, and a SGSN 825.

**[0130]** The MMEs 821 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 801. The

MMEs 821 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 801, provide user identity confidentiality, and/or perform other like services to users/subscribers. Each UE 801 and the MME 821 may include an MM or EMM sublayer, and an MM context may be established in the UE 801 and the MME 821 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 801. The MMEs 821 may be coupled with the HSS 824 via an S6a reference point, coupled with the SGSN 825 via an S3 reference point, and coupled with the S-GW 822 via an S11 reference point.

**[0131]** The SGSN 825 may be a node that serves the UE 801 by tracking the location of an individual UE 801 and performing security functions. In addition, the SGSN 825 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 821; handling of UE 801 time zone functions as specified by the MMEs 821; and MME selection for handovers to E-UTRAN 3GPP access network. The S3 reference point between the MMEs 821 and the SGSN 825 may enable user and bearer information exchange for inter-3GPP access network mobility in idle and/or active states.

**[0132]** The HSS 824 may comprise a database for network users, including subscription-related information to support the network entities’ handling of communication sessions. The EPC 820 may comprise one or several HSSs 824, depending on the number of mobile subscribers, on the capacity of the equipment, on the organization of the network, etc. For example, the HSS 824 can provide support for routing/roaming, authentication, authorization, naming/addressing resolution, location dependencies, etc. An S6a reference point between the HSS 824 and the MMEs 821 may enable transfer of subscription and authentication data for authenticating/authorizing user access to the EPC 820 between HSS 824 and the MMEs 821.

**[0133]** The S-GW 822 may terminate the S1 interface 713 (“S1-U” in Figure 8) toward the RAN 810, and routes data packets between the RAN 810 and the EPC 820. In addition, the S-GW 822 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 822 and the MMEs 821 may provide a control plane between the MMEs 821 and the S-GW 822. The S-GW 822 may be coupled with the P-GW 823 via an S5 reference point.

**[0134]** The P-GW 823 may terminate an SGi interface toward a PDN 830. The P-GW 823 may route data packets between the EPC 820 and external networks such as a network including the application server 730 (alternatively referred to as an “AF”) via an IP interface 725 (see e.g., Figure 7). In embodiments, the P-GW 823 may be communicatively coupled to an application server (application server 730 of Figure 7 or PDN 830 in Figure 8) via an IP communications interface 725 (see, e.g., Figure 7). The S5 reference point between the P-GW 823 and the S-GW 822 may provide user plane tunneling and tunnel management between the P-GW 823 and the S-GW 822. The S5 reference point may also be used for S-GW 822 relocation due to UE 801 mobility and if the S-GW 822 needs to connect to a non-collocated P-GW 823 for the required PDN connectivity. The P-GW 823 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 823 and the packet data network (PDN) 830 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 823 may be coupled with a PCRF 826 via a Gx reference point.

**[0135]** PCRF 826 is the policy and charging control element of the EPC 820. In a non-roaming scenario, there may be a single PCRF 826 in the Home Public Land Mobile Network (HPLMN) associated with a UE 801’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 801’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 826 may be communicatively coupled to the application server 830 via the P-GW 823. The application server 830 may signal the PCRF 826 to indicate a new service flow and select the appropriate QoS and charging parameters. The PCRF 826 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 830. The Gx reference point between the PCRF 826 and the P-GW 823

may allow for the transfer of QoS policy and charging rules from the PCRF 826 to PCEF in the P-GW 823. An Rx reference point may reside between the PDN 830 (or “AF 830”) and the PCRF 826.

**[0136]** Figure 9 illustrates an architecture of a system 900 including a second CN 920 in accordance with various embodiments. The system 900 is shown to include a UE 901, which may be the same or similar to the UEs 701 and UE 801 discussed previously; a (R)AN 910, which may be the same or similar to the RAN 710 and RAN 810 discussed previously, and which may include RAN nodes 711 discussed previously; and a DN 903, which may be, for example, operator services, Internet access or 3rd party services; and a 5GC 920. The 5GC 920 may include an AUSF 922; an AMF 921; a SMF 924; a NEF 923; a PCF 926; a NRF 925; a UDM 927; an AF 928; a UPF 902; and a NSSF 929.

**[0137]** The UPF 902 may act as an anchor point for intra-RAT and inter-RAT mobility, an external PDU session point of interconnect to DN 903, and a branching point to support multi-homed PDU session. The UPF 902 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 902 may include an uplink classifier to support routing traffic flows to a data network. The DN 903 may represent various network operator services, Internet access, or third party services. DN 903 may include, or be similar to, application server 730 discussed previously. The UPF 902 may interact with the SMF 924 via an N4 reference point between the SMF 924 and the UPF 902.

**[0138]** The AUSF 922 may store data for authentication of UE 901 and handle authentication-related functionality. The AUSF 922 may facilitate a common authentication framework for various access types. The AUSF 922 may communicate with the AMF 921 via an N12 reference point between the AMF 921 and the AUSF 922; and may communicate with the UDM 927 via an N13 reference point between the UDM 927 and the AUSF 922. Additionally, the AUSF 922 may exhibit an Nausf service-based interface.

- [0139] The AMF 921 may be responsible for registration management (e.g., for registering UE 901, etc.), connection management, reachability management, mobility management, and lawful interception of AMF-related events, and access authentication and authorization. The AMF 921 may be a termination point for the N11 reference point between the AMF 921 and the SMF 924. The AMF 921 may provide transport for SM messages between the UE 901 and the SMF 924, and act as a transparent proxy for routing SM messages. AMF 921 may also provide transport for SMS messages between UE 901 and an SMSF (not shown by Figure 9). AMF 921 may act as SEAF, which may include interaction with the AUSF 922 and the UE 901, receipt of an intermediate key that was established as a result of the UE 901 authentication process. Where USIM based authentication is used, the AMF 921 may retrieve the security material from the AUSF 922. AMF 921 may also include a SCM function, which receives a key from the SEA that it uses to derive access-network specific keys. Furthermore, AMF 921 may be a termination point of a RAN CP interface, which may include or be an N2 reference point between the (R)AN 910 and the AMF 921; and the AMF 921 may be a termination point of NAS (N1) signalling, and perform NAS ciphering and integrity protection.
- [0140] AMF 921 may also support NAS signalling with a UE 901 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 910 and the AMF 921 for the control plane, and may be a termination point for the N3 reference point between the (R)AN 910 and the UPF 902 for the user plane. As such, the AMF 921 may handle N2 signalling from the SMF 924 and the AMF 921 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 901 and AMF 921 via an N1 reference point between the UE 901 and the AMF 921, and relay uplink and downlink user-plane packets between the UE 901 and UPF 902. The N3IWF also provides mechanisms for IPsec tunnel establishment with the UE 901. The AMF 921 may exhibit an Namf service-based interface, and may be a termination point for an N14 reference point between two AMFs 921 and an N17 reference point between the AMF 921 and a 5G-EIR (not shown by Figure 9).

- [0141] The UE 901 may need to register with the AMF 921 in order to receive network services. RM is used to register or deregister the UE 901 with the network (e.g., AMF 921), and establish a UE context in the network (e.g., AMF 921). The UE 901 may operate in an RM-REGISTERED state or an RM-DEREGISTERED state. In the RM-DEREGISTERED state, the UE 901 is not registered with the network, and the UE context in AMF 921 holds no valid location or routing information for the UE 901 so the UE 901 is not reachable by the AMF 921. In the RM-REGISTERED state, the UE 901 is registered with the network, and the UE context in AMF 921 may hold a valid location or routing information for the UE 901 so the UE 901 is reachable by the AMF 921. In the RM-REGISTERED state, the UE 901 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 901 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.
- [0142] The AMF 921 may store one or more RM contexts for the UE 901, 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 921 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 921 may store a CE mode B Restriction parameter of the UE 901 in an associated MM context or RM context. The AMF 921 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).
- [0143] CM may be used to establish and release a signaling connection between the UE 901 and the AMF 921 over the N1 interface. The signaling connection is used to enable NAS signaling exchange between the UE 901 and the CN 920, 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 901 between the AN (e.g., RAN 910) and the AMF 921. The UE 901 may operate in one of two CM states, CM-IDLE mode or CM-CONNECTED mode. When the UE 901 is operating in the CM-IDLE state/mode, the UE 901 may have no NAS signaling connection established with the AMF 921 over the N1 interface, and there may be (R)AN 910 signaling connection

(e.g., N2 and/or N3 connections) for the UE 901. When the UE 901 is operating in the CM-CONNECTED state/mode, the UE 901 may have an established NAS signaling connection with the AMF 921 over the N1 interface, and there may be a (R)AN 910 signaling connection (e.g., N2 and/or N3 connections) for the UE 901. Establishment of an N2 connection between the (R)AN 910 and the AMF 921 may cause the UE 901 to transition from CM-IDLE mode to CM-CONNECTED mode, and the UE 901 may transition from the CM-CONNECTED mode to the CM-IDLE mode when N2 signaling between the (R)AN 910 and the AMF 921 is released.

**[0144]** The SMF 924 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 901 and a data network (DN) 903 identified by a Data Network Name (DNN). PDU sessions may be established upon UE 901 request, modified upon UE 901 and 5GC 920 request, and released upon UE 901 and 5GC 920 request using NAS SM signaling exchanged over the N1 reference point between the UE 901 and the SMF 924. Upon request from an application server, the 5GC 920 may trigger a specific application in the UE 901. In response to receipt of the trigger message, the UE 901 may pass the trigger message (or relevant parts/information of the trigger message) to one or more identified applications in the UE 901. The identified application(s) in the UE 901 may establish a PDU session to a specific DNN. The SMF 924 may check whether the UE 901 requests are compliant with user subscription information associated with the UE 901. In this regard, the SMF 924 may retrieve and/or request to receive update notifications on SMF 924 level subscription data from the UDM 927.

**[0145]** The SMF 924 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 924 may be included in the system 900, which may be between another SMF 924 in a visited network and the SMF 924 in the home network in roaming scenarios. Additionally, the SMF 924 may exhibit the Nsmf service-based interface.

**[0146]** The NEF 923 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 928), edge computing or fog computing systems, etc. In such embodiments, the NEF 923 may authenticate, authorize, and/or throttle the AFs. NEF 923 may also translate information exchanged with the AF 928 and information exchanged with internal network functions. For example, the NEF 923 may translate between an AF-Service-Identifier and an internal 5GC information. NEF 923 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 923 as structured data, or at a data storage NF using standardized interfaces. The stored information can then be re-exposed by the NEF 923 to other NFs and AFs, and/or used for other purposes such as analytics. Additionally, the NEF 923 may exhibit an Nnef service-based interface.

**[0147]** The NRF 925 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 925 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 925 may exhibit the Nnrf service-based interface.

**[0148]** The PCF 926 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 926 may also implement an FE to access subscription information relevant for policy decisions in a UDR of the UDM 927. The PCF 926 may communicate with the AMF 921 via an N15 reference point between the PCF 926 and the AMF 921, which may include a PCF 926 in a visited network and the AMF 921 in case of roaming scenarios. The PCF

926 may communicate with the AF 928 via an N5 reference point between the PCF 926 and the AF 928; and with the SMF 924 via an N7 reference point between the PCF 926 and the SMF 924. The system 900 and/or CN 920 may also include an N24 reference point between the PCF 926 (in the home network) and a PCF 926 in a visited network. Additionally, the PCF 926 may exhibit an Npcf service-based interface.

**[0149]** The UDM 927 may handle subscription-related information to support the network entities' handling of communication sessions, and may store subscription data of UE 901. For example, subscription data may be communicated between the UDM 927 and the AMF 921 via an N8 reference point between the UDM 927 and the AMF. The UDM 927 may include two parts, an application FE and a UDR (the FE and UDR are not shown by Figure 9). The UDR may store subscription data and policy data for the UDM 927 and the PCF 926, and/or structured data for exposure and application data (including PFDs for application detection, application request information for multiple UEs 901) for the NEF 923. The Nudr service-based interface may be exhibited by the UDR 221 to allow the UDM 927, PCF 926, and NEF 923 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 924 via an N10 reference point between the UDM 927 and the SMF 924. UDM 927 may also support SMS management, wherein an SMS-FE implements the similar application logic as discussed previously. Additionally, the UDM 927 may exhibit the Nudm service-based interface.

**[0150]** The AF 928 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 920 and AF 928 to provide information to each other via NEF 923, 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 901 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 902 close to the UE 901 and execute traffic steering from the UPF 902 to DN 903 via the N6 interface. This may be based on the UE subscription data, UE location, and information provided by the AF 928. In this way, the AF 928 may influence UPF (re)selection and traffic routing. Based on operator deployment, when AF 928 is considered to be a trusted entity, the network operator may permit AF 928 to interact directly with relevant NFs. Additionally, the AF 928 may exhibit an Naf service-based interface.

**[0151]** The NSSF 929 may select a set of network slice instances serving the UE 901. The NSSF 929 may also determine allowed NSSAI and the mapping to the subscribed S-NSSAIs, if needed. The NSSF 929 may also determine the AMF set to be used to serve the UE 901, or a list of candidate AMF(s) 921 based on a suitable configuration and possibly by querying the NRF 925. The selection of a set of network slice instances for the UE 901 may be triggered by the AMF 921 with which the UE 901 is registered by interacting with the NSSF 929, which may lead to a change of AMF 921. The NSSF 929 may interact with the AMF 921 via an N22 reference point between AMF 921 and NSSF 929; and may communicate with another NSSF 929 in a visited network via an N31 reference point (not shown by Figure 9). Additionally, the NSSF 929 may exhibit an Nnssf service-based interface.

**[0152]** As discussed previously, the CN 920 may include an SMSF, which may be responsible for SMS subscription checking and verification, and relaying SM messages to/from the UE 901 to/from other entities, such as an SMS-GMSC/IW MSC/SMS-router. The SMSF may also interact with AMF 921 and UDM 927 for a notification procedure that the UE 901 is available for SMS transfer (e.g., set a UE not reachable flag, and notifying UDM 927 when UE 901 is available for SMS).

**[0153]** The CN 120 may also include other elements that are not shown by Figure 9, such as a Data Storage system/architecture, a 5G-EIR, a SEPP, and the like. The Data Storage system may include a SDSF, an UDSF, and/or the like. Any NF may store and retrieve unstructured data into/from the UDSF (e.g., UE contexts), via N18 reference point between any NF and the UDSF (not shown by Figure 9). Individual NFs may share a UDSF for storing their respective unstructured data or individual NFs may each have their own UDSF located at or near the individual NFs. Additionally, the UDSF may

exhibit an Nudsf service-based interface (not shown by Figure 9). 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.

**[0154]** Additionally, there may be many more reference points and/or service-based interfaces between the NF services in the NFs; however, these interfaces and reference points have been omitted from Figure 9 for clarity. In one example, the CN 920 may include an Nx interface, which is an inter-CN interface between the MME (e.g., MME 821) and the AMF 921 in order to enable interworking between CN 920 and CN 820. 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.

**[0155]** Figure 10 illustrates an example of infrastructure equipment 1000 in accordance with various embodiments. The infrastructure equipment 1000 (or “system 1000”) may be implemented as a base station, radio head, RAN node such as the RAN nodes 711 and/or AP 706 shown and described previously, application server(s) 730, and/or any other element/device discussed herein. In other examples, the system 1000 could be implemented in or by a UE.

**[0156]** The system 1000 includes application circuitry 1005, baseband circuitry 1010, one or more radio front end modules (RFEMs) 1015, memory circuitry 1020, power management integrated circuitry (PMIC) 1025, power tee circuitry 1030, network controller circuitry 1035, network interface connector 1040, satellite positioning circuitry 1045, and user interface 1050. In some embodiments, the device 1000 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.

**[0157]** Application circuitry 1005 includes circuitry such as, but not limited to one or more processors (or processor cores), cache memory, and one or more of low drop-out voltage regulators (LDOs), interrupt controllers, serial interfaces such as SPI, I<sup>2</sup>C 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 1005 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 1000. 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.

**[0158]** The processor(s) of application circuitry 1005 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 1005 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 1005 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 1000 may not utilize application circuitry 1005, and instead may include a special-purpose processor/controller to process IP data received from an EPC or 5GC, for example.

**[0159]** In some implementations, the application circuitry 1005 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 1005 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 1005 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.

**[0160]** The baseband circuitry 1010 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 1010 are discussed infra with regard to Figure 12.

**[0161]** User interface circuitry 1050 may include one or more user interfaces designed to enable user interaction with the system 1000 or peripheral component interfaces designed to enable peripheral component interaction with the system 1000. 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.

**[0162]** The radio front end modules (RFEMs) 1015 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 1211 of Figure 12 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 1015, which incorporates both mmWave antennas and sub-mmWave.

- [0163]** The memory circuitry 1020 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 1020 may be implemented as one or more of solder down packaged integrated circuits, socketed memory modules and plug-in memory cards.
- [0164]** The PMIC 1025 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 1030 may provide for electrical power drawn from a network cable to provide both power supply and data connectivity to the infrastructure equipment 1000 using a single cable.
- [0165]** The network controller circuitry 1035 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 1000 via network interface connector 1040 using a physical connection, which may be electrical (commonly referred to as a “copper interconnect”), optical, or wireless. The network controller circuitry 1035 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 1035 may include multiple controllers to provide connectivity to other networks using the same or different protocols.
- [0166]** The positioning circuitry 1045 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 1045 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 1045 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 1045 may also be part of, or interact with, the baseband circuitry 1010 and/or RFEMs 1015 to communicate with the nodes and components of the positioning network. The positioning circuitry 1045 may also provide position data and/or time data to the application circuitry 1005, which may use the data to synchronize operations with various infrastructure (e.g., RAN nodes 711, etc.), or the like.

**[0167]** The components shown by Figure 10 may communicate with one another using interface circuitry, which may include any number of bus and/or interconnect (IX) technologies such as industry standard architecture (ISA), extended ISA (EISA), peripheral component interconnect (PCI), peripheral component interconnect extended (PCIx), PCI express (PCIe), or any number of other technologies. The bus/IX may be a proprietary bus, for example, used in a SoC based system. Other bus/IX systems may be included, such as an I<sup>2</sup>C interface, an SPI interface, point to point interfaces, and a power bus, among others.

**[0168]** Figure 11 illustrates an example of a platform 1100 (or "device 1100") in accordance with various embodiments. In embodiments, the computer platform 1100 may be suitable for use as UEs 701, 702, 801, application servers 730, and/or any other element/device discussed herein. The platform 1100 may include any combinations of the components shown in the example. The components of platform 1100 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 1100, or as components otherwise incorporated within a chassis of a larger system. The block diagram of Figure 11 is intended to show a high level view of components of the computer platform 1100. 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.

**[0169]** Application circuitry 1105 includes circuitry such as, but not limited to one or more processors (or processor cores), cache memory, and one or more of LDOs, interrupt controllers, serial interfaces such as SPI, I<sup>2</sup>C 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 1105 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 1100. 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.

**[0170]** The processor(s) of application circuitry 1005 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 1005 may comprise, or may be, a special-purpose processor/controller to operate according to the various embodiments herein.

**[0171]** As examples, the processor(s) of application circuitry 1105 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 1105 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 1105 may be a part of a system on a chip (SoC) in which the application circuitry 1105 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.

**[0172]** Additionally or alternatively, application circuitry 1105 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 1105 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 1105 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.

**[0173]** The baseband circuitry 1110 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 1110 are discussed *infra* with regard to Figure 12.

**[0174]** The RFEMs 1115 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 1211 of Figure 12 *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 1115, which incorporates both mmWave antennas and sub-mmWave.

**[0175]** The memory circuitry 1120 may include any number and type of memory devices used to provide for a given amount of system memory. As examples, the memory circuitry 1120 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 1120 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 1120 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 1120 may be on-die memory or registers associated with the application circuitry 1105. To provide for persistent storage of information such as data, applications, operating systems and so forth, memory circuitry 1120 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 1100 may incorporate the three-dimensional (3D) cross-point (XPOINT) memories from Intel® and Micron®.

**[0176]** Removable memory circuitry 1123 may include devices, circuitry, enclosures/housings, ports or receptacles, etc. used to couple portable data storage devices with the platform 1100. 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.

- [0177] The platform 1100 may also include interface circuitry (not shown) that is used to connect external devices with the platform 1100. The external devices connected to the platform 1100 via the interface circuitry include sensor circuitry 1121 and electro-mechanical components (EMCs) 1122, as well as removable memory devices coupled to removable memory circuitry 1123.
- [0178] The sensor circuitry 1121 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.
- [0179] EMCs 1122 include devices, modules, or subsystems whose purpose is to enable platform 1100 to change its state, position, and/or orientation, or move or control a mechanism or (sub)system. Additionally, EMCs 1122 may be configured to generate and send messages/signalling to other components of the platform 1100 to indicate a current state of the EMCs 1122. Examples of the EMCs 1122 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 1100 is configured to operate one or more EMCs 1122 based on one or more captured events and/or instructions or control signals received from a service provider and/or various clients.
- [0180] In some implementations, the interface circuitry may connect the platform 1100 with positioning circuitry 1145. The positioning circuitry 1145 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 1145 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 1145 may include a Micro-PNT IC that uses a master timing clock to perform position tracking/estimation without GNSS assistance. The positioning circuitry 1145 may also be part of, or interact with, the baseband circuitry 1010 and/or RFEMs 1115 to communicate with the nodes and components of the positioning network. The positioning circuitry 1145 may also provide position data and/or time data to the application circuitry 1105, 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

**[0181]** In some implementations, the interface circuitry may connect the platform 1100 with Near-Field Communication (NFC) circuitry 1140. NFC circuitry 1140 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 1140 and NFC-enabled devices external to the platform 1100 (e.g., an "NFC touchpoint"). NFC circuitry 1140 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 1140 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 1140, or initiate data transfer between the NFC circuitry 1140 and another active NFC device (e.g., a smartphone or an NFC-enabled POS terminal) that is proximate to the platform 1100.

- [0182]** The driver circuitry 1146 may include software and hardware elements that operate to control particular devices that are embedded in the platform 1100, attached to the platform 1100, or otherwise communicatively coupled with the platform 1100. The driver circuitry 1146 may include individual drivers allowing other components of the platform 1100 to interact with or control various input/output (I/O) devices that may be present within, or connected to, the platform 1100. For example, driver circuitry 1146 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 1100, sensor drivers to obtain sensor readings of sensor circuitry 1121 and control and allow access to sensor circuitry 1121, EMC drivers to obtain actuator positions of the EMCs 1122 and/or control and allow access to the EMCs 1122, 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.
- [0183]** The power management integrated circuitry (PMIC) 1125 (also referred to as “power management circuitry 1125”) may manage power provided to various components of the platform 1100. In particular, with respect to the baseband circuitry 1110, the PMIC 1125 may control power-source selection, voltage scaling, battery charging, or DC-to-DC conversion. The PMIC 1125 may often be included when the platform 1100 is capable of being powered by a battery 1130, for example, when the device is included in a UE 701, 702, 801.
- [0184]** In some embodiments, the PMIC 1125 may control, or otherwise be part of, various power saving mechanisms of the platform 1100. For example, if the platform 1100 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 1100 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 1100 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 1100 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 1100 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.

- [0185]** A battery 1130 may power the platform 1100, although in some examples the platform 1100 may be mounted deployed in a fixed location, and may have a power supply coupled to an electrical grid. The battery 1130 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 1130 may be a typical lead-acid automotive battery.
- [0186]** In some implementations, the battery 1130 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 1100 to track the state of charge (SoCh) of the battery 1130. The BMS may be used to monitor other parameters of the battery 1130 to provide failure predictions, such as the state of health (SoH) and the state of function (SoF) of the battery 1130. The BMS may communicate the information of the battery 1130 to the application circuitry 1105 or other components of the platform 1100. The BMS may also include an analog-to-digital (ADC) convertor that allows the application circuitry 1105 to directly monitor the voltage of the battery 1130 or the current flow from the battery 1130. The battery parameters may be used to determine actions that the platform 1100 may perform, such as transmission frequency, network operation, sensing frequency, and the like.
- [0187]** A power block, or other power supply coupled to an electrical grid may be coupled with the BMS to charge the battery 1130. In some examples, the power block 1130 may be replaced with a wireless power receiver to obtain the power wirelessly, for example, through a loop antenna in the computer platform 1100. 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 1130, 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.

**[0188]** User interface circuitry 1150 includes various input/output (I/O) devices present within, or connected to, the platform 1100, and includes one or more user interfaces designed to enable user interaction with the platform 1100 and/or peripheral component interfaces designed to enable peripheral component interaction with the platform 1100. The user interface circuitry 1150 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 1100. 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 1121 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.

**[0189]** Although not shown, the components of platform 1100 may communicate with one another using a suitable bus or interconnect (IX) technology, which may include any number of technologies, including ISA, EISA, PCI, PCIX, PCIe, a Time-Trigger Protocol (TTP) system, a FlexRay system, or any number of other technologies. The bus/IX may

be a proprietary bus/IX, for example, used in a SoC based system. Other bus/IX systems may be included, such as an I<sup>2</sup>C interface, an SPI interface, point-to-point interfaces, and a power bus, among others.

**[0190]** Figure 12 illustrates example components of baseband circuitry 1210 and radio front end modules (RFEM) 1215 in accordance with various embodiments. The baseband circuitry 1210 corresponds to the baseband circuitry 1010 and 1110 of Figures 10 and 11, respectively. The RFEM 1215 corresponds to the RFEM 1015 and 1115 of Figures 10 and 11, respectively. As shown, the RFEMs 1215 may include Radio Frequency (RF) circuitry 1206, front-end module (FEM) circuitry 1208, antenna array 1211 coupled together at least as shown.

**[0191]** The baseband circuitry 1210 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 1206. 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 1210 may include Fast-Fourier Transform (FFT), precoding, or constellation mapping/demapping functionality. In some embodiments, encoding/decoding circuitry of the baseband circuitry 1210 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 1210 is configured to process baseband signals received from a receive signal path of the RF circuitry 1206 and to generate baseband signals for a transmit signal path of the RF circuitry 1206. The baseband circuitry 1210 is configured to interface with application circuitry 1005/1105 (see Figures 10 and 11) for generation and processing of the baseband signals and for controlling operations of the RF circuitry 1206. The baseband circuitry 1210 may handle various radio control functions.

**[0192]** The aforementioned circuitry and/or control logic of the baseband circuitry 1210 may include one or more single or multi-core processors. For example, the one or more processors may include a 3G baseband processor 1204A, a 4G/LTE baseband processor 1204B, a 5G/NR baseband processor 1204C, or some other baseband processor(s) 1204D

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 1204A-D may be included in modules stored in the memory 1204G and executed via a Central Processing Unit (CPU) 1204E. In other embodiments, some or all of the functionality of baseband processors 1204A-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 1204G may store program code of a real-time OS (RTOS), which when executed by the CPU 1204E (or other baseband processor), is to cause the CPU 1204E (or other baseband processor) to manage resources of the baseband circuitry 1210, schedule tasks, etc. Examples of the RTOS may include Operating System Embedded (OSE)<sup>™</sup> provided by Enea®, Nucleus RTOS<sup>™</sup> provided by Mentor Graphics®, Versatile Real-Time Executive (VRTX) provided by Mentor Graphics®, ThreadX<sup>™</sup> 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 1210 includes one or more audio digital signal processor(s) (DSP) 1204F. The audio DSP(s) 1204F include elements for compression/decompression and echo cancellation and may include other suitable processing elements in other embodiments.

**[0193]** In some embodiments, each of the processors 1204A-1204E include respective memory interfaces to send/receive data to/from the memory 1204G. The baseband circuitry 1210 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 1210; an application circuitry interface to send/receive data to/from the application circuitry 1005/1105 of Figures 10-12); an RF circuitry interface to send/receive data to/from RF circuitry 1206 of Figure 12; 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 1125.

**[0194]** In alternate embodiments (which may be combined with the above described embodiments), baseband circuitry 1210 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 1210 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 1215).

**[0195]** Although not shown by Figure 12, in some embodiments, the baseband circuitry 1210 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 1210 and/or RF circuitry 1206 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 1210 and/or RF circuitry 1206 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., 1204G) 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 1210 may also support radio communications for more than one wireless protocol.

**[0196]** The various hardware elements of the baseband circuitry 1210 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 1210 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 1210 and RF circuitry 1206 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 1210 may be implemented as a separate SoC that is communicatively coupled with and RF circuitry 1206 (or multiple instances of RF circuitry 1206). In yet another example, some or all of the constituent components of the baseband circuitry 1210 and the application circuitry 1005/1105 may be implemented together as individual SoCs mounted to a same circuit board (e.g., a “multi-chip package”).

**[0197]** In some embodiments, the baseband circuitry 1210 may provide for communication compatible with one or more radio technologies. For example, in some embodiments, the baseband circuitry 1210 may support communication with an E-UTRAN or other WMAN, a WLAN, a WPAN. Embodiments in which the baseband circuitry 1210 is configured to support radio communications of more than one wireless protocol may be referred to as multi-mode baseband circuitry.

**[0198]** RF circuitry 1206 may enable communication with wireless networks using modulated electromagnetic radiation through a non-solid medium. In various embodiments, the RF circuitry 1206 may include switches, filters, amplifiers, etc. to facilitate the communication with the wireless network. RF circuitry 1206 may include a receive signal path, which may include circuitry to down-convert RF signals received from the FEM circuitry 1208 and provide baseband signals to the baseband circuitry 1210. RF circuitry 1206 may also include a transmit signal path, which may include circuitry to up-convert baseband signals provided by the baseband circuitry 1210 and provide RF output signals to the FEM circuitry 1208 for transmission.

- [0199]** In some embodiments, the receive signal path of the RF circuitry 1206 may include mixer circuitry 1206a, amplifier circuitry 1206b and filter circuitry 1206c. In some embodiments, the transmit signal path of the RF circuitry 1206 may include filter circuitry 1206c and mixer circuitry 1206a. RF circuitry 1206 may also include synthesizer circuitry 1206d for synthesizing a frequency for use by the mixer circuitry 1206a of the receive signal path and the transmit signal path. In some embodiments, the mixer circuitry 1206a of the receive signal path may be configured to down-convert RF signals received from the FEM circuitry 1208 based on the synthesized frequency provided by synthesizer circuitry 1206d. The amplifier circuitry 1206b may be configured to amplify the down-converted signals and the filter circuitry 1206c 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 1210 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 1206a of the receive signal path may comprise passive mixers, although the scope of the embodiments is not limited in this respect.
- [0200]** In some embodiments, the mixer circuitry 1206a of the transmit signal path may be configured to up-convert input baseband signals based on the synthesized frequency provided by the synthesizer circuitry 1206d to generate RF output signals for the FEM circuitry 1208. The baseband signals may be provided by the baseband circuitry 1210 and may be filtered by filter circuitry 1206c.
- [0201]** In some embodiments, the mixer circuitry 1206a of the receive signal path and the mixer circuitry 1206a 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 1206a of the receive signal path and the mixer circuitry 1206a 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 1206a of the receive signal path and the mixer circuitry 1206a of the transmit signal path may be arranged for direct downconversion and direct upconversion, respectively. In some embodiments, the mixer circuitry 1206a of the receive signal path

and the mixer circuitry 1206a of the transmit signal path may be configured for super-heterodyne operation.

- [0202]** 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 1206 may include analog-to-digital converter (ADC) and digital-to-analog converter (DAC) circuitry and the baseband circuitry 1210 may include a digital baseband interface to communicate with the RF circuitry 1206.
- [0203]** 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.
- [0204]** In some embodiments, the synthesizer circuitry 1206d 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 1206d may be a delta-sigma synthesizer, a frequency multiplier, or a synthesizer comprising a phase-locked loop with a frequency divider.
- [0205]** The synthesizer circuitry 1206d may be configured to synthesize an output frequency for use by the mixer circuitry 1206a of the RF circuitry 1206 based on a frequency input and a divider control input. In some embodiments, the synthesizer circuitry 1206d may be a fractional  $N/N+1$  synthesizer.
- [0206]** 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 1210 or the application circuitry 1005/1105 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 1005/1105.
- [0207]** Synthesizer circuitry 1206d of the RF circuitry 1206 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.

**[0208]** In some embodiments, synthesizer circuitry 1206d 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 1206 may include an IQ/polar converter.

**[0209]** FEM circuitry 1208 may include a receive signal path, which may include circuitry configured to operate on RF signals received from antenna array 1211, amplify the received signals and provide the amplified versions of the received signals to the RF circuitry 1206 for further processing. FEM circuitry 1208 may also include a transmit signal path, which may include circuitry configured to amplify signals for transmission provided by the RF circuitry 1206 for transmission by one or more of antenna elements of antenna array 1211. In various embodiments, the amplification through the transmit or receive signal paths may be done solely in the RF circuitry 1206, solely in the FEM circuitry 1208, or in both the RF circuitry 1206 and the FEM circuitry 1208.

**[0210]** In some embodiments, the FEM circuitry 1208 may include a TX/RX switch to switch between transmit mode and receive mode operation. The FEM circuitry 1208 may include a receive signal path and a transmit signal path. The receive signal path of the FEM circuitry 1208 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 1206). The transmit signal path of the FEM circuitry 1208 may include a power amplifier (PA) to amplify input RF signals (e.g., provided by RF circuitry 1206), and one or more filters to generate RF signals for subsequent transmission by one or more antenna elements of the antenna array 1211.

- [0211] The antenna array 1211 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 1210 is converted into analog RF signals (e.g., modulated waveform) that will be amplified and transmitted via the antenna elements of the antenna array 1211 including one or more antenna elements (not shown). The antenna elements may be omnidirectional, direction, or a combination thereof. The antenna elements may be formed in a multitude of arranges as are known and/or discussed herein. The antenna array 1211 may comprise microstrip antennas or printed antennas that are fabricated on the surface of one or more printed circuit boards. The antenna array 1211 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 1206 and/or FEM circuitry 1208 using metal transmission lines or the like.
- [0212] Processors of the application circuitry 1005/1105 and processors of the baseband circuitry 1210 may be used to execute elements of one or more instances of a protocol stack. For example, processors of the baseband circuitry 1210, alone or in combination, may be used execute Layer 3, Layer 2, or Layer 1 functionality, while processors of the application circuitry 1005/1105 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.
- [0213] Figure 13 illustrates various protocol functions that may be implemented in a wireless communication device according to various embodiments. In particular, Figure 13 includes an arrangement 1300 showing interconnections between various protocol layers/entities. The following description of Figure 13 is provided for various protocol layers/entities that operate in conjunction with the 5G/NR system standards and LTE system standards, but some or all of the aspects of Figure 13 may be applicable to other wireless communication network systems as well.
- [0214] The protocol layers of arrangement 1300 may include one or more of PHY 1310, MAC 1320, RLC 1330, PDCP 1340, SDAP 1347, RRC 1355, and NAS layer 1357, in

addition to other higher layer functions not illustrated. The protocol layers may include one or more service access points (e.g., items 1359, 1356, 1350, 1349, 1345, 1335, 1325, and 1315 in Figure 13) that may provide communication between two or more protocol layers.

- [0215]** The PHY 1310 may transmit and receive physical layer signals 1305 that may be received from or transmitted to one or more other communication devices. The physical layer signals 1305 may comprise one or more physical channels, such as those discussed herein. The PHY 1310 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 1355. The PHY 1310 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 1310 may process requests from and provide indications to an instance of MAC 1320 via one or more PHY-SAP 1315. According to some embodiments, requests and indications communicated via PHY-SAP 1315 may comprise one or more transport channels.
- [0216]** Instance(s) of MAC 1320 may process requests from, and provide indications to, an instance of RLC 1330 via one or more MAC-SAPs 1325. These requests and indications communicated via the MAC-SAP 1325 may comprise one or more logical channels. The MAC 1320 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 1310 via the transport channels, de-multiplexing MAC SDUs to one or more logical channels from TBs delivered from the PHY 1310 via transport channels, multiplexing MAC SDUs onto TBs, scheduling information reporting, error correction through HARQ, and logical channel prioritization.
- [0217]** Instance(s) of RLC 1330 may process requests from and provide indications to an instance of PDCP 1340 via one or more radio link control service access points (RLC-SAP) 1335. These requests and indications communicated via RLC-SAP 1335 may comprise one or more RLC channels. The RLC 1330 may operate in a plurality of modes of operation, including: Transparent Mode (TM), Unacknowledged Mode (UM), and Acknowledged Mode (AM). The RLC 1330 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 1330 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.

**[0218]** Instance(s) of PDCP 1340 may process requests from and provide indications to instance(s) of RRC 1355 and/or instance(s) of SDAP 1347 via one or more packet data convergence protocol service access points (PDCP-SAP) 1345. These requests and indications communicated via PDCP-SAP 1345 may comprise one or more radio bearers. The PDCP 1340 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.).

**[0219]** Instance(s) of SDAP 1347 may process requests from and provide indications to one or more higher layer protocol entities via one or more SDAP-SAP 1349. These requests and indications communicated via SDAP-SAP 1349 may comprise one or more QoS flows. The SDAP 1347 may map QoS flows to DRBs, and vice versa, and may also mark QFIs in DL and UL packets. A single SDAP entity 1347 may be configured for an individual PDU session. In the UL direction, the NG-RAN 710 may control the mapping of QoS Flows to DRB(s) in two different ways, reflective mapping or explicit mapping. For reflective mapping, the SDAP 1347 of a UE 701 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 1347 of the UE 701 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 910 may mark DL packets over the Uu interface with a QoS flow ID. The explicit mapping may involve the RRC 1355 configuring the SDAP 1347 with an explicit QoS flow to DRB mapping rule, which may be stored and followed by the SDAP 1347. In embodiments, the SDAP

1347 may only be used in NR implementations and may not be used in LTE implementations.

- [0220]** The RRC 1355 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 1310, MAC 1320, RLC 1330, PDCP 1340 and SDAP 1347. In embodiments, an instance of RRC 1355 may process requests from and provide indications to one or more NAS entities 1357 via one or more RRC-SAPs 1356. The main services and functions of the RRC 1355 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 701 and RAN 710 (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.
- [0221]** The NAS 1357 may form the highest stratum of the control plane between the UE 701 and the AMF 921. The NAS 1357 may support the mobility of the UEs 701 and the session management procedures to establish and maintain IP connectivity between the UE 701 and a P-GW in LTE systems.
- [0222]** According to various embodiments, one or more protocol entities of arrangement 1300 may be implemented in UEs 701, RAN nodes 711, AMF 921 in NR implementations or MME 821 in LTE implementations, UPF 902 in NR implementations or S-GW 822 and P-GW 823 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 701, gNB 711, AMF 921, 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 711 may host the RRC 1355, SDAP 1347, and PDCP 1340 of the gNB that controls the operation of one or more gNB-DUs, and the

gNB-DUs of the gNB 711 may each host the RLC 1330, MAC 1320, and PHY 1310 of the gNB 711.

**[0223]** In a first example, a control plane protocol stack may comprise, in order from highest layer to lowest layer, NAS 1357, RRC 1355, PDCP 1340, RLC 1330, MAC 1320, and PHY 1310. In this example, upper layers 1360 may be built on top of the NAS 1357, which includes an IP layer 1361, an SCTP 1362, and an application layer signaling protocol (AP) 1363.

**[0224]** In NR implementations, the AP 1363 may be an NG application protocol layer (NGAP or NG-AP) 1363 for the NG interface 713 defined between the NG-RAN node 711 and the AMF 921, or the AP 1363 may be an Xn application protocol layer (XnAP or Xn-AP) 1363 for the Xn interface 712 that is defined between two or more RAN nodes 711.

**[0225]** The NG-AP 1363 may support the functions of the NG interface 713 and may comprise Elementary Procedures (EPs). An NG-AP EP may be a unit of interaction between the NG-RAN node 711 and the AMF 921. The NG-AP 1363 services may comprise two groups: UE-associated services (e.g., services related to a UE 701, 702) and non-UE-associated services (e.g., services related to the whole NG interface instance between the NG-RAN node 711 and AMF 921). These services may include functions including, but not limited to: a paging function for the sending of paging requests to NG-RAN nodes 711 involved in a particular paging area; a UE context management function for allowing the AMF 921 to establish, modify, and/or release a UE context in the AMF 921 and the NG-RAN node 711; a mobility function for UEs 701 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 701 and AMF 921; a NAS node selection function for determining an association between the AMF 921 and the UE 701; 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 711 via CN 720; and/or other like functions.

- [0226]** The XnAP 1363 may support the functions of the Xn interface 712 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 711 (or E-UTRAN 810), 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 701, such as Xn interface setup and reset procedures, NG-RAN update procedures, cell activation procedures, and the like.
- [0227]** In LTE implementations, the AP 1363 may be an S1 Application Protocol layer (S1-AP) 1363 for the S1 interface 713 defined between an E-UTRAN node 711 and an MME, or the AP 1363 may be an X2 application protocol layer (X2AP or X2-AP) 1363 for the X2 interface 712 that is defined between two or more E-UTRAN nodes 711.
- [0228]** The S1 Application Protocol layer (S1-AP) 1363 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 711 and an MME 821 within an LTE CN 720. The S1-AP 1363 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.
- [0229]** The X2AP 1363 may support the functions of the X2 interface 712 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 720, 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 701, such as X2 interface setup and reset procedures, load indication procedures, error indication procedures, cell activation procedures, and the like.
- [0230]** The SCTP layer (alternatively referred to as the SCTP/IP layer) 1362 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 1362 may ensure reliable delivery of signaling messages between the RAN node 711 and the AMF 921/MME 821 based, in part, on the IP protocol, supported by the IP 1361. The Internet Protocol layer (IP) 1361 may be used to perform packet addressing and routing functionality. In some implementations the IP layer 1361 may use point-to-point transmission to deliver and convey PDUs. In this regard, the RAN node 711 may comprise L2 and L1 layer communication links (e.g., wired or wireless) with the MME/AMF to exchange information.

**[0231]** In a second example, a user plane protocol stack may comprise, in order from highest layer to lowest layer, SDAP 1347, PDCP 1340, RLC 1330, MAC 1320, and PHY 1310. The user plane protocol stack may be used for communication between the UE 701, the RAN node 711, and UPF 902 in NR implementations or an S-GW 822 and P-GW 823 in LTE implementations. In this example, upper layers 1351 may be built on top of the SDAP 1347, and may include a user datagram protocol (UDP) and IP security layer (UDP/IP) 1352, a General Packet Radio Service (GPRS) Tunneling Protocol for the user plane layer (GTP-U) 1353, and a User Plane PDU layer (UP PDU) 1363.

**[0232]** The transport network layer 1354 (also referred to as a “transport layer”) may be built on IP transport, and the GTP-U 1353 may be used on top of the UDP/IP layer 1352 (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.

**[0233]** The GTP-U 1353 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 1352 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 711 and the S-GW 822 may utilize an S1-U interface to exchange user plane data via a protocol stack comprising an L1 layer (e.g., PHY 1310), an L2 layer (e.g., MAC 1320, RLC 1330, PDCP 1340, and/or SDAP 1347), the UDP/IP layer 1352, and the GTP-U 1353. The S-GW 822 and the P-GW 823 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 1352, and the GTP-U 1353. As discussed previously, NAS protocols may support the mobility of the UE 701 and the session management procedures to establish and maintain IP connectivity between the UE 701 and the P-GW 823.

**[0234]** Moreover, although not shown by Figure 13, an application layer may be present above the AP 1363 and/or the transport network layer 1354. The application layer may be a layer in which a user of the UE 701, RAN node 711, or other network element interacts with software applications being executed, for example, by application circuitry 1005 or application circuitry 1105, respectively. The application layer may also provide one or more interfaces for software applications to interact with communications systems of the UE 701 or RAN node 711, such as the baseband circuitry 1210. 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).

**[0235]** Figure 14 illustrates components of a core network in accordance with various embodiments. The components of the CN 820 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 920 may be implemented in a same or similar manner as discussed herein with regard to the components of CN 820. 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 820 may be referred to as a network slice 1401, and individual logical instantiations of the CN 820 may provide specific network capabilities and network characteristics. A logical instantiation of a portion of the CN 820 may be referred to as a network sub-slice 1402 (e.g., the network sub-slice 1402 is shown to include the P-GW 823 and the PCRF 826).

**[0236]** 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.

**[0237]** With respect to 5G systems (see, e.g., Figure 9), 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 901 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.

**[0238]** A network slice may include the CN 920 control plane and user plane NFs, NG-RANs 910 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 901 (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 921 instance serving an individual UE 901 may belong to each of the network slice instances serving that UE.

**[0239]** Network Slicing in the NG-RAN 910 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 910 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 910 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 910 selects the RAN part of the network slice using assistance information provided by the UE 901 or the 5GC 920, which unambiguously identifies one or more of the pre-configured network slices in the PLMN. The NG-RAN 910 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 910 may also apply an appropriate RRM policy for the SLA in place to each supported slice. The NG-RAN 910 may also support QoS differentiation within a slice.

**[0240]** The NG-RAN 910 may also use the UE assistance information for the selection of an AMF 921 during an initial attach, if available. The NG-RAN 910 uses the assistance information for routing the initial NAS to an AMF 921. If the NG-RAN 910 is unable to select an AMF 921 using the assistance information, or the UE 901 does not provide any such information, the NG-RAN 910 sends the NAS signaling to a default AMF 921, which may be among a pool of AMFs 921. For subsequent accesses, the UE 901 provides a temp ID, which is assigned to the UE 901 by the 5GC 920, to enable the NG-RAN 910 to route the NAS message to the appropriate AMF 921 as long as the temp ID is valid. The NG-RAN 910 is aware of, and can reach, the AMF 921 that is associated with the temp ID. Otherwise, the method for initial attach applies.

**[0241]** The NG-RAN 910 supports resource isolation between slices. NG-RAN 910 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 910 resources to a certain slice. How NG-RAN 910 supports resource isolation is implementation dependent.

**[0242]** Some slices may be available only in part of the network. Awareness in the NG-RAN 910 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 910 and the 5GC 920 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 910.

- [0243]** The UE 901 may be associated with multiple network slices simultaneously. In case the UE 901 is associated with multiple slices simultaneously, only one signaling connection is maintained, and for intra-frequency cell reselection, the UE 901 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 901 camps. The 5GC 920 is to validate that the UE 901 has the rights to access a network slice. Prior to receiving an Initial Context Setup Request message, the NG-RAN 910 may be allowed to apply some provisional/local policies, based on awareness of a particular slice that the UE 901 is requesting to access. During the initial context setup, the NG-RAN 910 is informed of the slice for which resources are being requested.
- [0244]** 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.
- [0245]** Figure 15 is a block diagram illustrating components, according to some example embodiments, able to read instructions from a machine-readable or computer-readable medium (e.g., a non-transitory machine-readable storage medium) and perform any one or more of the methodologies discussed herein. Specifically, Figure 15 shows a diagrammatic representation of hardware resources 1500 including one or more processors (or processor cores) 1510, one or more memory/storage devices 1520, and one or more communication resources 1530, each of which may be communicatively coupled via a bus 1540. For embodiments where node virtualization (e.g., NFV) is utilized, a hypervisor 1502 may be executed to provide an execution environment for one or more network slices/sub-slices to utilize the hardware resources 1500.
- [0246]** The processors 1510 may include, for example, a processor 1512 and a processor 1514. The processor(s) 1510 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.

- [0247] The memory/storage devices 1520 may include main memory, disk storage, or any suitable combination thereof. The memory/storage devices 1520 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.
- [0248] The communication resources 1530 may include interconnection or network interface components or other suitable devices to communicate with one or more peripheral devices 1504 or one or more databases 1506 via a network 1508. For example, the communication resources 1530 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..
- [0249] Instructions 1550 may comprise software, a program, an application, an applet, an app, or other executable code for causing at least any of the processors 1510 to perform any one or more of the methodologies discussed herein. The instructions 1550 may reside, completely or partially, within at least one of the processors 1510 (e.g., within the processor's cache memory), the memory/storage devices 1520, or any suitable combination thereof. Furthermore, any portion of the instructions 1550 may be transferred to the hardware resources 1500 from any combination of the peripheral devices 1504 or the databases 1506. Accordingly, the memory of processors 1510, the memory/storage devices 1520, the peripheral devices 1504, and the databases 1506 are examples of computer-readable and machine-readable media.

### **Example Procedures**

- [0250] In some embodiments, the electronic device(s), network(s), system(s), chip(s) or component(s), or portions or implementations thereof, of Figures 7-15, or some other figure herein, may be configured to perform one or more processes, techniques, or methods as described herein, or portions thereof. One such process is depicted in Figure 16. Figure 16 illustrates a flowchart 1600 that describes a UE, such as UE 302, 602, 701, 801, 901, 1100, for communicating data over control plane in a 5G system, according to embodiments of the disclosure. In embodiments, the flowchart 1600 can be performed or controlled by a processor or processor circuitry described in the various embodiments

herein, including the processor shown in Figure 15, and/or the application circuitry 1005 or 1105, and/or baseband circuitry 1010 or 1110 shown in Figures 10-11.

**[0251]** For example, at 1602 features and capabilities of the UE relating to Cellular Internet of Things (CIoT) for connecting to a 5GS network that is also enhanced for CIoT features are enhanced and optimized. At 1604, a first message for connecting to a 5G network and indicating the capabilities and features are transmitted. For example, step 1604 can include the UE transmitting REGISTRATION ACCEPT message 104 as illustrated in Figure 1. For example, the UE transmits the first message indicating the capability of the UE relating to Cellular Internet of Things (CIoT) for connecting to the 5G network. At 1606, a second message including mobile originated data is transmitted via a control plane of to the 5G network. In some embodiments, step 1606 can include, in an idle mode, the UE sending data using SERVICE REQUEST message 105 or CONTROL PLANE SERVICE REQUEST message 106, which contains an embedded 5GSM DATA TRANSPORT message, as discussed, for example, with respect to Figure 1. Additionally, or alternatively, step 1606 can include, in a connected mode, the UE directly using the 5GSM message 5GS DATA TRANSPORT 110 to send data to network, as discussed, for example, with respect to Figure 1. For example, the UE transmits (e.g., transfers or causes to transfer) the mobile originated (MO) data via the control plane to NEF or UPF. At 1608, a third message is received from the 5G network. According to some embodiments, step 1608 can include the UE receiving a response with SERVICE ACCEPT 108 if there is no data to send back to UE or with 5GSM DATA TRANSPORT message 109, if there is data to be sent to UE, as discussed, for example, with respect to Figure 1. Additionally, or alternatively, step 1608 can include receiving messages 112 or 113 from the 5G network, as discussed above. For example, the UE receives or causes to receive, from the network, mobile terminated (MT) data.

**[0252]** According to some embodiments, the first message can include a registration request message as part of an initial registration procedure. Additionally, or alternatively, the first message can include a registration request message as part of a periodic update registration procedure. According to some embodiments, the UE is also configured to receive a registration accept message in response to transmitting the first message, where the registration accept message is based on capabilities of the 5G network.

- [0253] According to some embodiments, transmitting the second message can include sending or causing to send a SERVICE REQUEST or CONTROL PLANE SERVICE REQUEST (CPSR) message, to operate when in idle mode.
- [0254] In some examples, the SERVICE REQUEST or CPSR message includes an 5GSM container message IE which includes data to be sent in a 5GSM DATA TRANSPORT message. In some embodiments, a data service type of the SERVICE REQUEST or CPSR message indicates "mobile originating request."
- [0255] According to some embodiments, transmitting the second message can include sending or causing to send the SERVICE REQUEST or CPSR message as part of a security protected initial NAS message, including a security header type that indicates "integrity protected and ciphered initial NAS message".
- [0256] According to some embodiments, method 1600 can also include receiving or causing to receive a request to transfer user data via the control plane. When the UE is in connected mode, transmitting the second message can include sending or causing to send a stand-alone 5GSM DATA TRANSPORT message.
- [0257] According to some embodiments, upon receipt of the 5GSM DATA TRANSPORT message, the NEF or UPF identifies a NEF/UPF connection on which to transfer user data inside the core network based on a PDU session ID and QFI included in the 5GSM DATA TRANSPORT message and then forwards the contents of a user data container IE accordingly.
- [0258] According to some embodiments, method 1600 can further include receiving or causing to receive a network page indicating that MT data is available. The page can indicate at least one of: "transfer the data via control plane" or "transfer the data via user plane" based on the preferences and capabilities of the UE.
- [0259] According to some embodiments, method 1600 can also include responding or causing to respond to a network page. In some examples, upon receiving a paging message indicating a "transfer user data via the control plane", method 1600 can further include sending or causing to send a SERVICE REQUEST or CPSR message, where the data service type of the SERVICE REQUEST or CPSR message indicates "mobile terminating request".
- [0260] According to some embodiments, method 1600 can also include sending or causing to send the SERVICE REQUEST or CPSR message as part of a security

protected initial NAS message. The security header type indicates "Integrity protected and ciphered initial NAS message."

- [0261]** According to some embodiments, method 1600 can further include receiving or causing to receive a 5GSM DATA TRANSPORT message and forwarding, or causing to forward, in response to the 5GSM DATA TRANSPORT, contents of a user data container IE to an upper layer, using a PDU session ID and QFI entity.
- [0262]** According to some embodiments, transmitting the second message can include transmitting, in an idle mode, a service request message or a control plane service request message comprising a first 5G system session management (5GSM) data transport message. Also, receiving the third message can include at least one of receiving a service accept message in response to no data being transmitted to the UE, or receiving a second 5G system session management (5GSM) data transport message in response to data being transmitted to the UE.
- [0263]** According to some embodiments, transmitting the second message can include transmitting, in a connected mode, a first 5G system session management (5GSM) data transport message. Also, receiving the third message can include at least one of receiving a service accept message in response to no data being transmitted to the UE, or receiving a second 5G system session management (5GSM) data transport message in response to data being transmitted to the UE.
- [0264]** In some embodiments, the electronic device(s), network(s), system(s), chip(s) or component(s), or portions or implementations thereof, of Figures 7-15, or some other figure herein, may be configured to perform one or more processes, techniques, or methods as described herein, or portions thereof. One such process is depicted in Figure 17. Figure 17 illustrates a flowchart 1700 that describes an apparatus (e.g., a network node) for communicating data over control plane in a 5G system, according to embodiments of the disclosure. The apparatus can be a gNB, a base station, radio head, RAN node such as infrastructure equipment 1000, the RAN nodes 711 and/or AP 706, according to some embodiments of the disclosure. In embodiments, the flowchart 1700 can be performed or controlled by a processor or processor circuitry described in the various embodiments herein, including the processor shown in Figure 15, and/or the application circuitry 1005 or 1105, and/or baseband circuitry 1010 or 1110 shown in Figures 10-11.

- [0265] For example, at 1702, an individual session management (SM) context resource is created in SMF. For example, the SMF can create or cause to create, via a SMContextCreateData request data structure, the individual SM context resource. In some embodiments, the data structure includes a SM data transfer indication, when a PDU session uses NAS-SM to transfer data PDUs.
- [0266] At 1704, a successful creation of the SM context in SMF is represented. For example, SMF can be configured to represent or cause to represent, via a SMContextCreatedData response data structure, the successful creation of the SM context in SMF with a smDataTransferSupported attribute.
- [0267] At 1706, a SM data transfer is indicated. For example, SMF can be configured to indicate or cause to indicate the SM data transfer indication in a supported features IE of the SMContextCreateData data type request that SM data transfer feature is required to be supported for the PDU session. Additionally or alternatively, method 1700 can include indicating or causing to indicate that the SM data transfer is supported in a supportedFeatures IE in a SMContextCreatedData data type response. Additionally or alternatively, method 1700 can include using or causing to use a SM data transfer indication to select a UPF for a particular PDU session.
- [0268] For one or more embodiments, at least one of the components set forth in one or more of the preceding figures may be configured to perform one or more operations, techniques, processes, and/or methods as set forth in the example section below. For example, the baseband circuitry as described above in connection with one or more of the preceding figures may be configured to operate in accordance with one or more of the examples set forth below. For another example, circuitry associated with a UE, base station, network element, etc. as described above in connection with one or more of the preceding figures may be configured to operate in accordance with one or more of the examples set forth below in the example section.

## EXAMPLES

- [0269] Example 1 may include an apparatus, comprising:  
means for enhancing and optimizing features and capabilities relating to Cellular Internet of Things (CIoT) for connecting to a 5GS network that is also enhanced for CIoT features;

means for transferring mobile originated (MO) data via control plane to NEF or UPF; and

means for receiving from the network mobile terminated (MT) data.

**[0270]** Example 2 may include the apparatus of example 1 or some other example herein, further comprising means for initiating a data transfer procedure via control plane, including means for sending a SERVICE REQUEST or CONTROL PLANE SERVICE REQUEST (CPSR) message, to operate when the apparatus is in idle mode.

**[0271]** Example 3 may include the apparatus of example 2 or some other example herein wherein the SERVICE REQUEST or CPSR message includes a 5GSM container message IE which includes data to be sent in a 5GSM DATA TRANSPORT message, and wherein a data service type of the SERVICE REQUEST or CPSR message indicates "mobile originating request."

**[0272]** Example 4 may include the apparatus of example 1 or some other example herein, wherein the means for sending sends the SERVICE REQUEST or CPSR message as part of a security protected initial NAS message, including a security header type that indicates "integrity protected and ciphered initial NAS message".

**[0273]** Example 5 may include the apparatus of example 1 or some other example herein, further comprising means for receiving a request to transfer user data via the control plane, and wherein when the apparatus is in connected mode, the means for initiating the data transfer procedure sends, via the means for sending, a stand-alone 5GSM DATA TRANSPORT message.

**[0274]** Example 6 may include the apparatus of example 1 or some other example herein, wherein upon receipt of the 5GSM DATA TRANSPORT message, the NEF or UPF identifies a NEF/UPF connection on which to transfer user data inside the core network based on a PDU session ID and QFI included in the 5GSM DATA TRANSPORT message, and then forwards the contents of a user data container IE accordingly.

**[0275]** Example 7 may include the apparatus of example 1 or some other example herein, further comprising means for receiving a network page indicating that MT data is available, wherein the page indicates at least one of: "transfer the data via control plane" or "transfer the data via user plane" based on apparatus preferences and capabilities

**[0276]** Example 8 may include the apparatus of example 7 or some other example herein, further comprising means for responding to a network page, wherein upon receipt of a

paging message indicating a "transfer user data via the control plane", the means for responding sends a SERVICE REQUEST or CPSR message, wherein the data service type of the SERVICE REQUEST or CPSR message indicates "mobile terminating request".

**[0277]** Example 9 may include the apparatus of example 8 or some other example herein, wherein the means for responding sends the SERVICE REQUEST or CPSR message as part of a security protected initial NAS message, and wherein the security header type indicates "Integrity protected and ciphered initial NAS message."

**[0278]** Example 10 may include the apparatus of example 9 or some other example herein, further comprising means for receiving a 5GSM DATA TRANSPORT message; and means for forwarding, in response to the 5GSM DATA TRANSPORT, contents of a user data container IE to an upper layer, using a PDU session ID and QFI entity.

**[0279]** Example 11 may include an apparatus, comprising: means for creating, via a SMContextCreateData request data structure, an individual SM context resource in SMF, including a SM data transfer indication, when a PDU session uses NAS-SM to transfer data PDUs.

**[0280]** Example 12 may include the apparatus of example 11 or some other example herein, further comprising means for representing, via a SMContextCreatedData response data structure, a successful creation of the SM context in SMF with a smDataTransferSupported attribute.

**[0281]** Example 13 may include the apparatus of example 11 or some other example herein, wherein the means for creating further includes means for indicating a SM data transfer indication, in a supported features IE of the SMContextCreateData data type request, that the SM data transfer feature is required to be supported for the PDU session.

**[0282]** Example 14 may include an apparatus, comprising: means for indicating that a SM data transfer is supported in a supportedFeatures IE in a SMContextCreatedData data type response.

**[0283]** Example 15 may include an apparatus, comprising: means for using a SM data transfer indication to select a UPF for a particular PDU session.

**[0284]** Example 16 may include an apparatus, to:  
enhance and optimize features and capabilities relating to Cellular Internet of Things (CIoT) for connecting to an 5GS network that is also enhanced for CIoT features;

transfer mobile originated (MO) data via control plane to NEF or UPF; and receive from the network mobile terminated (MT) data.

**[0285]** Example 17 may include the apparatus of example 16 or some other example herein, further to

initiate a data transfer procedure via control plane, including to send a SERVICE REQUEST or CONTROL PLANE SERVICE REQUEST (CPSR) message, to operate when the apparatus is in idle mode.

**[0286]** Example 18 may include the apparatus of example 17 or some other example herein wherein the SERVICE REQUEST or CPSR message includes a 5GSM container message IE which includes data to be sent in a 5GSM DATA TRANSPORT message, and wherein a data service type of the SERVICE REQUEST or CPSR message indicates "mobile originating request."

**[0287]** Example 19 may include the apparatus of example 16 or some other example herein, further to send the SERVICE REQUEST or CPSR message as part of a security protected initial NAS message, the message to include a security header type that indicates "integrity protected and ciphered initial NAS message".

**[0288]** Example 20 may include the apparatus of example 16 or some other example herein, further to receive a request to transfer user data via the control plane, and wherein when the apparatus is in a connected mode, further to send a stand-alone 5GSM DATA TRANSPORT message.

**[0289]** Example 21 may include the apparatus of example 16 or some other example herein, wherein upon receipt of the 5GSM DATA TRANSPORT message, the NEF or UPF identifies a NEF/UPF connection on which to transfer user data inside the core network based on a PDU session ID and QFI included in the 5GSM DATA TRANSPORT message, and then forwards the contents of a user data container IE accordingly.

**[0290]** Example 22 may include the apparatus of example 16 or some other example herein, further to receive a network page indicating that MT data is available, wherein the page indicates at least one of: "transfer the data via control plane" or "transfer the data via user plane", based on apparatus preferences and capabilities

**[0291]** Example 23 may include the apparatus of example 22 or some other example herein, further to respond to a network page, wherein, upon receipt of a paging message

indicating a "transfer user data via the control plane", further to send a SERVICE REQUEST or CPSR message, wherein the data service type of the SERVICE REQUEST or CPSR message indicates "mobile terminating request".

**[0292]** Example 24 may include the apparatus of example 23 or some other example herein, wherein the SERVICE REQUEST or CPSR message is sent as part of a security protected initial NAS message, wherein the security header type indicates "Integrity protected and ciphered initial NAS message."

**[0293]** Example 25 may include the apparatus of example 24 or some other example herein, further to:

receive a 5GSM DATA TRANSPORT message; and

forward, in response to the 5GSM DATA TRANSPORT, contents of a user data container IE to an upper layer, using a PDU session ID and QFI entity.

**[0294]** Example 26 may include an apparatus, to: create, via a SMContextCreateData request data structure, an individual SM context resource in SMF, including a SM data transfer indication, when a PDU session uses NAS-SM to transfer data PDUs.

**[0295]** Example 27 may include the apparatus of example 26 or some other example herein, further to represent, via a SMContextCreatedData response data structure, a successful creation of the SM context in SMF with a smDataTransferSupported attribute.

**[0296]** Example 28 may include the apparatus of example 26 or some other example herein, further to include, a SM data transfer indication in a supported features IE of the SMContextCreateData data type request, to indicate that the SM data transfer feature is required to be supported for the PDU session.

**[0297]** Example 29 may include an apparatus, to: indicate that a SM data transfer is supported in a supportedFeatures IE in a SMContextCreatedData data type response.

**[0298]** Example 30 may include an apparatus, to: use a SM data transfer indication to select a UPF for a particular PDU session.

**[0299]** Example 31 may include a method, comprising:

enhancing and optimizing, or causing to enhance and optimize, features and capabilities relating to Cellular Internet of Things (CIoT) for connecting to an 5GS network that is also enhanced for CIoT features; transferring or causing to transfer mobile originated (MO) data via control plane to NEF or UPF; and receiving or causing to receive from the network mobile terminated (MT) data.

- [0300]** Example 32 may include the method of example 31 or some other example herein, further comprising: initiating or causing to initiate a data transfer procedure via control plane, including sending or causing to send a SERVICE REQUEST or CONTROL PLANE SERVICE REQUEST (CPSR) message, to operate when in idle mode.
- [0301]** Example 33 may include the method of example 32 or some other example herein wherein the SERVICE REQUEST or CPSR message includes a 5GSM container message IE which includes data to be sent in a 5GSM DATA TRANSPORT message, and wherein a data service type of the SERVICE REQUEST or CPSR message indicates "mobile originating request."
- [0302]** Example 34 may include the method of example 31 or some other example herein, further comprising sending or causing to send the SERVICE REQUEST or CPSR message as part of a security protected initial NAS message, including a security header type that indicates "integrity protected and ciphered initial NAS message".
- [0303]** Example 35 may include the method of example 31 or some other example herein, further comprising receiving or causing to a request to transfer user data via the control plane, and wherein when the apparatus is in connected mode, further comprising sending or causing to send a stand-alone 5GSM DATA TRANSPORT message.
- [0304]** Example 36 may include the method of example 31 or some other example herein, wherein upon receipt of the 5GSM DATA TRANSPORT message, the NEF or UPF identifies a NEF/UPF connection on which to transfer user data inside the core network based on a PDU session ID and QFI included in the 5GSM DATA TRANSPORT message, and then forwards the contents of a user data container IE accordingly.
- [0305]** Example 37 may include the method of example 31 or some other example herein, further comprising: receiving or causing to receive a network page indicating that MT data is available, wherein the page indicates at least one of: "transfer the data via control plane" or "transfer the data via user plane", based on device preferences and capabilities.
- [0306]** Example 38 may include the method of example 37 or some other example herein, further comprising responding or causing to respond to a network page, wherein upon receipt of a paging message indicating a "transfer user data via the control plane", further comprising sending or causing to send a SERVICE REQUEST or CPSR message wherein the data service type of the SERVICE REQUEST or CPSR message indicates "mobile terminating request".

- [0307] Example 39 may include the method of example 38 or some other example herein, further comprising sending or causing to send the SERVICE REQUEST or CPSR message as part of a security protected initial NAS message, wherein the security header type indicates "Integrity protected and ciphered initial NAS message."
- [0308] Example 40 may include the method of example 39 or some other example herein, further comprising: receiving or causing to receive a 5GSM DATA TRANSPORT message; and forwarding, or causing to forward, in response to the 5GSM DATA TRANSPORT, contents of a user data container IE to an upper layer, using a PDU session ID and QFI entity.
- [0309] Example 41 may include a method, comprising: creating or causing to create, via a SMContextCreateData request data structure, an individual SM context resource in SMF, including a SM data transfer indication, when a PDU session uses NAS-SM to transfer data PDUs.
- [0310] Example 42 may include the method of example 41 or some other example herein, further comprising representing or causing to represent, via a SMContextCreatedData response data structure, a successful creation of the SM context in SMF with a smDataTransferSupported attribute.
- [0311] Example 43 may include the method of example 41 or some other example herein, further comprising indicating or causing to indicate a SM data transfer indication in a supported features IE of the SMContextCreateData data type request that SM data transfer feature is required to be supported for the PDU session.
- [0312] Example 44 may include a method, comprising: indicating or causing to indicate that a SM data transfer is supported in a supportedFeatures IE in a SMContextCreatedData data type response.
- [0313] Example 45 may include a method, comprising: using or causing to use a SM data transfer indication to select a UPF for a particular PDU session.
- [0314] Example 46 includes the apparatus of examples 1-10 and/or some other examples herein, wherein the apparatus is a user equipment (UE) or a portion thereof.
- [0315] Example 47 includes the apparatus of examples 16-25 and/or some other examples herein, wherein the apparatus is a user equipment (UE) or a portion thereof.
- [0316] Example 48 includes the method of examples 31-40 and/or some other examples herein, wherein the method is performed by a user equipment (UE) or a portion thereof.

- [0317] Example 49 includes the apparatus of examples 11-15 and/or some other examples herein, wherein the apparatus is to be employed as a mobility management entity (MME).
- [0318] Example 50 includes the apparatus of examples 26-30 and/or some other examples herein, wherein the apparatus is to be employed as a mobility management entity (MME).
- [0319] Example 51 includes the method of examples 41-45 and/or some other examples herein, wherein the method is performed by a mobility management entity (MME).
- [0320] Example 52 may include a 5G system which consists of gNB, AMF, SMF, UPF, NEF, UDM, NSSF, AUSF, AF, AS and other essential elements as described in 3GPP TS 23.501 and 3GPP TS 24.501 and a user equipment (UE) device that has enhancements and optimizations for features and capabilities relating to Cellular Internet of Things (CIoT) for connecting to an 5GS network that is also enhanced for CIoT features.
- [0321] Example 53 may include the UE of example 52 or some other example herein, wherein the UE needs to transfer Mobile Originated data via control plane to NEF or UPF and the network needs to transfer Mobile Terminated (MT) data to the UE.
- [0322] Example 54 may include the UE of example 53 or some other example herein, wherein if the UE is in idle mode, the 5GMM entity in the UE initiates the data transfer procedure via control plane by sending a SERVICE REQUEST or CONTROL PLANE SERVICE REQUEST (CPSR) message.
- [0323] Example 55 may include the UE of example 54 or some other example herein wherein the SERVICE REQUEST or CPSR message includes an 5GSM container message IE which contains the data to be sent in the 5GSM DATA TRANSPORT message. The data service type of the SERVICE REQUEST or CPSR message indicates "mobile originating request".
- [0324] Example 56 may include the UE of example 53 or some other example herein, wherein the UE shall send the SERVICE REQUEST or CPSR message as part of a Security protected initial NAS message. The security header type of the Security protected initial NAS message shall indicate "Integrity protected and ciphered initial NAS message".
- [0325] Example 57 may include the UE of example 53 or some other example herein, wherein if the UE is in connected mode, then upon receipt of a request to transfer user

data via the control plane, the 5GSM entity in the UE initiates the data transfer procedure by sending a stand-alone 5GSM DATA TRANSPORT message.

- [0326] Example 58 may include the NEF or UPF of example 53 or some other example herein, which when receiving the 5GSM DATA TRANSPORT message, shall identify the flow (e.g., the NEF/UPF connection) on which to transfer the user data inside the core network based on the PDU session Id and QFI included in 5GSM DATA TRANSPORT message and then forward the contents of the User data container IE accordingly.
- [0327] Example 59 may include the network of example 53 or some other example herein, wherein the network would page the UE if MT data is available for the UE. The network may indicate as to “transfer the data via control plane” or “transfer the data via user plane” based on UE preferences and capabilities
- [0328] Example 60 may include the UE of example 59 or some other example herein, wherein upon receipt of a paging message indicating a "transfer user data via the control plane", the UE shall respond with a SERVICE REQUEST or CPSR message. The data service type of the SERVICE REQUEST or CPSR message shall indicate "mobile terminating request".
- [0329] Example 61 may include the UE of example 60 or some other example herein, wherein the UE shall send the SERVICE REQUEST or CPSR message as part of a Security protected initial NAS message. The security header type of the Security protected initial NAS message shall indicate "Integrity protected and ciphered initial NAS message".
- [0330] Example 62 may include the network of example 60 or some other example herein, wherein upon receipt of the SERVICE REQUEST or CPSR message with data service type indicating "mobile terminating request", the network shall send an 5GSM DATA TRANSPORT message or a SERVICE ACCEPT message.
- [0331] Example 63 may include the UE of example 60 or some other example herein, wherein upon receiving the 5GSM DATA TRANSPORT message, the UE shall forward the contents of the User data container IE to the upper layer, using the PDU session Id and QFI entity.
- [0332] Example 64 may include a method where the SMContextCreateData request data structure creates an individual SM context resource in SMF including the SM data transfer indication when a PDU session uses NAS-SM to transfer data PDUs.

- [0333] Example 65 may include a method where the SMContextCreatedData response data structure represents successful creation of an SM context in SMF with the smDataTransferSupported attribute.
- [0334] Example 66 may include a method where the AMF indicates the SM data transfer indication in the Supported Features IE of the SMContextCreateData data type request to indicate to the SMF that SM data transfer feature is required to be supported for the PDU session.
- [0335] Example 67 may include a method where the SMF may indicate that the SM data transfer is supported in the supportedFeatures IE in the SMContextCreatedData data type response.
- [0336] Example 68 may include a method where the SMF uses the SM data transfer indication to select a UPF for a particular PDU session.
- [0337] Example 69 may include a method where a N4-U tunnel is established between SMF and UPF to enable small data transfer via control plane.
- [0338] Example 70 may include a method where the SMF sends its own N4-U IP address and SMF downlink data TEID for downlink data transfer from the UPF in the N4 Session Establishment/Modification request.
- [0339] Example 71 may include a method where the UPF sends its own N4-U IP address and UPF TEID for N4-U in the N4 Session Establishment/Modification response.
- [0340] Example 72 may include a method where the N1N2MessageTransferReqData data type includes the attribute smDataTransferResult indicated the SM data transfer is supported.
- [0341] Example 73 may include a method where the SMDDataTransferReqData data structure POST request body is defined to support small data transfer on N11 interface.
- [0342] Example 74 may include a method where SMDDataTransferRspData data structure POST response body is defined to represent a successful transfer of SM data or error.
- [0343] Example 75 may include a method of example 73 or some other example herein, where the SMDDataTransferReqData data type consists of n1MessageContainer which is included if N1 message needs to be transferred and pduSessionId
- [0344] Example 76 may include a method of example 75 or some other example herein, where the new message class is introduced "SM data transfer" for the n1Message class attribute to differentiate SM data transfer from SM signalling.

- [0345] Example 77 may include a method where two new service operations from NEF are defined to enable data transfer via control plane - Nnef\_PDUSession\_CreateSMContext request and Nnef\_PDUSession\_CreateSMContext response .
- [0346] Example 78 may include a method of example 77 or some other example herein, where the SMContextCreateData consists of the attributes - SUPI,pdusessionID,DNN,sNASSAI, servingnfID, nefID,niddInformation.
- [0347] Example 79 may include a method of example 77 or some other example herein, where the SmContextCreatedData data type consists of the attributes - SUPI,pdusessionID,DNN,sNSSAI,nefID.
- [0348] Example 80 may include an apparatus comprising means to perform one or more elements of a method described in or related to any of examples 1-45, or any other method or process described herein.
- [0349] Example 81 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 1-45, or any other method or process described herein.
- [0350] Example 82 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 1-45, or any other method or process described herein.
- [0351] Example 83 may include a method, technique, or process as described in or related to any of examples 1-45, or portions or parts thereof.
- [0352] Example 84 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 1-45, or portions thereof.
- [0353] Example 85 may include a signal as described in or related to any of examples 1-45, or portions or parts thereof.
- [0354] Example 86 may include a signal in a wireless network as shown and described herein.

- [0355] Example 87 may include a method of communicating in a wireless network as shown and described herein.
- [0356] Example 88 may include a system for providing wireless communication as shown and described herein.
- [0357] Example 89 may include a device for providing wireless communication as shown and described herein.
- [0358] 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

- [0359] For the purposes of the present document, the following abbreviations may apply to the examples and embodiments discussed herein, but are not meant to be limiting.
- |        |      |  |
|--------|------|--|
| [0360] | 3GPP | Third Generation Partnership Project             |
| [0361] | 4G   | Fourth Generation                                |
| [0362] | 5G   | Fifth Generation                                 |
| [0363] | 5GC  | 5G Core network                                  |
| [0364] | ACK  | Acknowledgement                                  |
| [0365] | AF   | Application Function                             |
| [0366] | AM   | Acknowledged Mode                                |
| [0367] | AMBR | Aggregate Maximum Bit Rate                       |
| [0368] | AMF  | Access and Mobility Management Function          |
| [0369] | AN   | Access Network                                   |
| [0370] | ANR  | Automatic Neighbour Relation                     |
| [0371] | AP   | Application Protocol, Antenna Port, Access Point |
| [0372] | API  | Application Programming Interface                |
| [0373] | APN  | Access Point Name                                |
| [0374] | ARP  | Allocation and Retention Priority                |
| [0375] | ARQ  | Automatic Repeat Request                         |
| [0376] | AS   | Access Stratum                                   |

[0377]	ASN.1	Abstract Syntax Notation One
[0378]	AUSF	Authentication Server Function
[0379]	AWGN	Additive White Gaussian Noise
[0380]	BCH	Broadcast Channel
[0381]	BER	Bit Error Ratio
[0382]	BFD	Beam Failure Detection
[0383]	BLER	Block Error Rate
[0384]	BPSK	Binary Phase Shift Keying
[0385]	BRAS	Broadband Remote Access Server
[0386]	BSS	Business Support System
[0387]	BS	Base Station
[0388]	BSR	Buffer Status Report
[0389]	BW	Bandwidth
[0390]	BWP	Bandwidth Part
[0391]	C-RNTI	Cell Radio Network Temporary Identity
[0392]	CA	Carrier Aggregation, Certification Authority
[0393]	CAPEX	CAPital EXpenditure
[0394]	CBRA	Contention Based Random Access
[0395]	CC	Component Carrier, Country Code, Cryptographic Checksum
[0396]	CCA	Clear Channel Assessment
[0397]	CCE	Control Channel Element
[0398]	CCCH	Common Control Channel
[0399]	CE	Coverage Enhancement
[0400]	CDM	Content Delivery Network
[0401]	CDMA	Code-Division Multiple Access
[0402]	CFRA	Contention Free Random Access
[0403]	CG	Cell Group
[0404]	CI	Cell Identity
[0405]	CID	Cell-ID (e.g., positioning method)
[0406]	CIM	Common Information Model
[0407]	CIR	Carrier to Interference Ratio
[0408]	CK	Cipher Key

[0409]	CM	Connection Management, Conditional Mandatory
[0410]	CMAS	Commercial Mobile Alert Service
[0411]	CMD	Command
[0412]	CMS	Cloud Management System
[0413]	CO	Conditional Optional
[0414]	CoMP	Coordinated Multi-Point
[0415]	CORESET	Control Resource Set
[0416]	COTS	Commercial Off-The-Shelf
[0417]	CP	Control Plane, Cyclic Prefix, Connection Point
[0418]	CPD	Connection Point Descriptor
[0419]	CPE	Customer Premise Equipment
[0420]	CPICH	Common Pilot Channel
[0421]	CQI	Channel Quality Indicator
[0422]	CPU	CSI processing unit, Central Processing Unit
[0423]	C/R	Command/Response field bit
[0424]	CRAN	Cloud Radio Access Network, Cloud RAN
[0425]	CRB	Common Resource Block
[0426]	CRC	Cyclic Redundancy Check
[0427]	CRI	Channel-State Information Resource Indicator, CSI-RS Resource Indicator
[0428]	C-RNTI	Cell RNTI
[0429]	CS	Circuit Switched
[0430]	CSAR	Cloud Service Archive
[0431]	CSI	Channel-State Information
[0432]	CSI-IM	CSI Interference Measurement
[0433]	CSI-RS	CSI Reference Signal
[0434]	CSI-RSRP	CSI reference signal received power
[0435]	CSI-RSRQ	CSI reference signal received quality
[0436]	CSI-SINR	CSI signal-to-noise and interference ratio
[0437]	CSMA	Carrier Sense Multiple Access
[0438]	CSMA/CA	CSMA with collision avoidance
[0439]	CSS	Common Search Space, Cell-specific Search Space

[0440]	CTS	Clear-to-Send
[0441]	CW	Codeword
[0442]	CWS	Contention Window Size
[0443]	D2D	Device-to-Device
[0444]	DC	Dual Connectivity, Direct Current
[0445]	DCI	Downlink Control Information
[0446]	DF	Deployment Flavour
[0447]	DL	Downlink
[0448]	DMTF	Distributed Management Task Force
[0449]	DPDK	Data Plane Development Kit
[0450]	DM-RS, DMRS	Demodulation Reference Signal
[0451]	DN	Data network
[0452]	DRB	Data Radio Bearer
[0453]	DRS	Discovery Reference Signal
[0454]	DRX	Discontinuous Reception
[0455]	DSL	Domain Specific Language. Digital Subscriber Line
[0456]	DSLAM	DSL Access Multiplexer
[0457]	DwPTS	Downlink Pilot Time Slot
[0458]	E-LAN	Ethernet Local Area Network
[0459]	E2E	End-to-End
[0460]	ECCA	extended clear channel assessment, extended CCA
[0461]	ECCE	Enhanced Control Channel Element, Enhanced CCE
[0462]	ED	Energy Detection
[0463]	EDGE	Enhanced Datarates for GSM Evolution (GSM Evolution)
[0464]	EGMF	Exposure Governance Management Function
[0465]	EGPRS	Enhanced GPRS
[0466]	EIR	Equipment Identity Register
[0467]	eLAA	enhanced Licensed Assisted Access, enhanced LAA
[0468]	EM	Element Manager
[0469]	eMBB	Enhanced Mobile Broadband
[0470]	EMS	Element Management System
[0471]	eNB	evolved NodeB, E-UTRAN Node B

[0472]	EN-DC	E-UTRA-NR Dual Connectivity
[0473]	EPC	Evolved Packet Core
[0474]	EPDCCH	enhanced PDCCH, enhanced Physical Downlink Control Channel
[0475]	EPRE	Energy per resource element
[0476]	EPS	Evolved Packet System
[0477]	EREG	enhanced REG, enhanced resource element groups
[0478]	ETSI	European Telecommunications Standards Institute
[0479]	ETWS	Earthquake and Tsunami Warning System
[0480]	eUICC	embedded UICC, embedded Universal Integrated Circuit Card
[0481]	E-UTRA	Evolved UTRA
[0482]	E-UTRAN	Evolved UTRAN
[0483]	EV2X	Enhanced V2X
[0484]	F1AP	F1 Application Protocol
[0485]	F1-C	F1 Control plane interface
[0486]	F1-U	F1 User plane interface
[0487]	FACCH	Fast Associated Control Channel
[0488]	FACCH/F	Fast Associated Control Channel/Full rate
[0489]	FACCH/H	Fast Associated Control Channel/Half rate
[0490]	FACH	Forward Access Channel
[0491]	FAUSCH	Fast Uplink Signalling Channel
[0492]	FB	Functional Block
[0493]	FBI	Feedback Information
[0494]	FCC	Federal Communications Commission
[0495]	FCCH	Frequency Correction Channel
[0496]	FDD	Frequency Division Duplex
[0497]	FDM	Frequency Division Multiplex
[0498]	FDMA	Frequency Division Multiple Access
[0499]	FE	Front End
[0500]	FEC	Forward Error Correction
[0501]	FFS	For Further Study
[0502]	FFT	Fast Fourier Transformation

[0503]	feLAA	further enhanced Licensed Assisted Access, further enhanced LAA
[0504]	FN	Frame Number
[0505]	FPGA	Field-Programmable Gate Array
[0506]	FR	Frequency Range
[0507]	G-RNTI	GERAN Radio Network Temporary Identity
[0508]	GERAN	GSM EDGE RAN, GSM EDGE Radio Access Network
[0509]	GGSN	Gateway GPRS Support Node
[0510]	GLONASS	GLOBAL'naya NAVigatsionnaya Sputnikovaya Sistema (Engl.: Global Navigation Satellite System)
[0511]	gNB	Next Generation NodeB
[0512]	gNB-CU	gNB-centralized unit, Next Generation NodeB centralized unit
[0513]	gNB-DU	gNB-distributed unit, Next Generation NodeB distributed unit
[0514]	GNSS	Global Navigation Satellite System
[0515]	GPRS	General Packet Radio Service
[0516]	GSM	Global System for Mobile Communications, Groupe Spécial Mobile
[0517]	GTP	GPRS Tunneling Protocol
[0518]	GTP-U	GPRS Tunnelling Protocol for User Plane
[0519]	GTS	Go To Sleep Signal (related to WUS)
[0520]	GUMMEI	Globally Unique MME Identifier
[0521]	GUTI	Globally Unique Temporary UE Identity
[0522]	HARQ	Hybrid ARQ, Hybrid Automatic Repeat Request
[0523]	HANDOVER, HO	Handover
[0524]	HFN	HyperFrame Number
[0525]	HHO	Hard Handover
[0526]	HLR	Home Location Register
[0527]	HN	Home Network
[0528]	HO	Handover
[0529]	HPLMN	Home Public Land Mobile Network
[0530]	HSDPA	High Speed Downlink Packet Access
[0531]	HSN	Hopping Sequence Number

[0532]	HSPA	High Speed Packet Access
[0533]	HSS	Home Subscriber Server
[0534]	HSUPA	High Speed Uplink Packet Access
[0535]	HTTP	Hyper Text Transfer Protocol
[0536]	HTTPS	Hyper Text Transfer Protocol Secure (https is http/1.1 over SSL, i.e. port 443)
[0537]	I-Block	Information Block
[0538]	ICCID	Integrated Circuit Card Identification
[0539]	ICIC	Inter-Cell Interference Coordination
[0540]	ID	Identity, identifier
[0541]	IDFT	Inverse Discrete Fourier Transform
[0542]	IE	Information element
[0543]	IBE	In-Band Emission
[0544]	IEEE	Institute of Electrical and Electronics Engineers
[0545]	IEI	Information Element Identifier
[0546]	IEIDL	Information Element Identifier Data Length
[0547]	IETF	Internet Engineering Task Force
[0548]	IF	Infrastructure
[0549]	IM	Interference Measurement, Intermodulation, IP Multimedia
[0550]	IMC	IMS Credentials
[0551]	IMEI	International Mobile Equipment Identity
[0552]	IMGI	International mobile group identity
[0553]	IMPI	IP Multimedia Private Identity
[0554]	IMPU	IP Multimedia PUBlic identity
[0555]	IMS	IP Multimedia Subsystem
[0556]	IMSI	International Mobile Subscriber Identity
[0557]	IoT	Internet of Things
[0558]	IP	Internet Protocol
[0559]	Ipssec	IP Security, Internet Protocol Security
[0560]	IP-CAN	IP-Connectivity Access Network
[0561]	IP-M	IP Multicast
[0562]	IPv4	Internet Protocol Version 4

[0563]	IPv6	Internet Protocol Version 6
[0564]	IR	Infrared
[0565]	IS	In Sync
[0566]	IRP	Integration Reference Point
[0567]	ISDN	Integrated Services Digital Network
[0568]	ISIM	IM Services Identity Module
[0569]	ISO	International Organisation for Standardisation
[0570]	ISP	Internet Service Provider
[0571]	IWF	Interworking-Function
[0572]	I-WLAN	Interworking WLAN
[0573]	K	Constraint length of the convolutional code, USIM Individual key
[0574]	kB	Kilobyte (1000 bytes)
[0575]	kbps	kilo-bits per second
[0576]	Kc	Ciphering key
[0577]	Ki	Individual subscriber authentication key
[0578]	KPI	Key Performance Indicator
[0579]	KQI	Key Quality Indicator
[0580]	KSI	Key Set Identifier
[0581]	ksps	kilo-symbols per second
[0582]	KVM	Kernel Virtual Machine
[0583]	L1	Layer 1 (physical layer)
[0584]	L1-RSRP	Layer 1 reference signal received power
[0585]	L2	Layer 2 (data link layer)
[0586]	L3	Layer 3 (network layer)
[0587]	LAA	Licensed Assisted Access
[0588]	LAN	Local Area Network
[0589]	LBT	Listen Before Talk
[0590]	LCM	LifeCycle Management
[0591]	LCR	Low Chip Rate
[0592]	LCS	Location Services
[0593]	LCID	Logical Channel ID

[0594]	LI	Layer Indicator
[0595]	LLC	Logical Link Control, Low Layer Compatibility
[0596]	LPLMN	Local PLMN
[0597]	LPP	LTE Positioning Protocol
[0598]	LSB	Least Significant Bit
[0599]	LTE	Long Term Evolution
[0600]	LWA	LTE-WLAN aggregation
[0601]	LWIP	LTE/WLAN Radio Level Integration with IPsec Tunnel
[0602]	LTE	Long Term Evolution
[0603]	M2M	Machine-to-Machine
[0604]	MAC	Medium Access Control (protocol layering context)
[0605]	MAC	Message authentication code (security/encryption context)
[0606]	MAC-A	MAC used for authentication and key agreement (TSG T WG3 context)
[0607]	MAC-I	MAC used for data integrity of signalling messages (TSG T WG3 context)
[0608]	MANO	Management and Orchestration
[0609]	MBMS	Multimedia Broadcast and Multicast Service
[0610]	MBSFN	Multimedia Broadcast multicast service Single Frequency Network
[0611]	MCC	Mobile Country Code
[0612]	MCG	Master Cell Group
[0613]	MCOT	Maximum Channel Occupancy Time
[0614]	MCS	Modulation and coding scheme
[0615]	MDAF	Management Data Analytics Function
[0616]	MDAS	Management Data Analytics Service
[0617]	MDT	Minimization of Drive Tests
[0618]	ME	Mobile Equipment
[0619]	MeNB	master eNB
[0620]	MER	Message Error Ratio
[0621]	MGL	Measurement Gap Length
[0622]	MGRP	Measurement Gap Repetition Period

[0623]	MIB	Master Information Block, Management Information Base
[0624]	MIMO	Multiple Input Multiple Output
[0625]	MLC	Mobile Location Centre
[0626]	MM	Mobility Management
[0627]	MME	Mobility Management Entity
[0628]	MN	Master Node
[0629]	MO	Measurement Object, Mobile Originated
[0630]	MPBCH	MTC Physical Broadcast CHannel
[0631]	MPDCCH	MTC Physical Downlink Control CHannel
[0632]	MPDSCH	MTC Physical Downlink Shared CHannel
[0633]	MPRACH	MTC Physical Random Access CHannel
[0634]	MPUSCH	MTC Physical Uplink Shared Channel
[0635]	MPLS	MultiProtocol Label Switching
[0636]	MS	Mobile Station
[0637]	MSB	Most Significant Bit
[0638]	MSC	Mobile Switching Centre
[0639]	MSI	Minimum System Information, MCH Scheduling Information
[0640]	MSID	Mobile Station Identifier
[0641]	MSIN	Mobile Station Identification Number
[0642]	MSISDN	Mobile Subscriber ISDN Number
[0643]	MT	Mobile Terminated, Mobile Termination
[0644]	MTC	Machine-Type Communications
[0645]	mMTC	massive MTC, massive Machine-Type Communications
[0646]	MU-MIMO	Multi User MIMO
[0647]	MWUS	MTC wake-up signal, MTC WUS
[0648]	NACK	Negative Acknowledgement
[0649]	NAI	Network Access Identifier
[0650]	NAS	Non-Access Stratum, Non-Access Stratum layer
[0651]	NCT	Network Connectivity Topology
[0652]	NEC	Network Capability Exposure
[0653]	NE-DC	NR-E-UTRA Dual Connectivity
[0654]	NEF	Network Exposure Function

[0655]	NF	Network Function
[0656]	NFP	Network Forwarding Path
[0657]	NFPD	Network Forwarding Path Descriptor
[0658]	NFV	Network Functions Virtualization
[0659]	NFVI	NFV Infrastructure
[0660]	NFVO	NFV Orchestrator
[0661]	NG	Next Generation, Next Gen
[0662]	NGEN-DC	NG-RAN E-UTRA-NR Dual Connectivity
[0663]	NM	Network Manager
[0664]	NMS	Network Management System
[0665]	N-PoP	Network Point of Presence
[0666]	NMIB, N-MIB	Narrowband MIB
[0667]	NPBCH	Narrowband Physical Broadcast CHannel
[0668]	NPDCCH	Narrowband Physical Downlink Control CHannel
[0669]	NPDSCH	Narrowband Physical Downlink Shared CHannel
[0670]	NPRACH	Narrowband Physical Random Access CHannel
[0671]	NPUSCH	Narrowband Physical Uplink Shared CHannel
[0672]	NPSS	Narrowband Primary Synchronization Signal
[0673]	NSSS	Narrowband Secondary Synchronization Signal
[0674]	NR	New Radio, Neighbour Relation
[0675]	NRF	NF Repository Function
[0676]	NRS	Narrowband Reference Signal
[0677]	NS	Network Service
[0678]	NSA	Non-Standalone operation mode
[0679]	NSD	Network Service Descriptor
[0680]	NSR	Network Service Record
[0681]	NSSAI	Network Slice Selection Assistance Information
[0682]	S-NNSAI	Single-NSSAI
[0683]	NSSF	Network Slice Selection Function
[0684]	NW	Network
[0685]	NWUS	Narrowband wake-up signal, Narrowband WUS
[0686]	NZP	Non-Zero Power

[0687]	O&M	Operation and Maintenance
[0688]	ODU2	Optical channel Data Unit - type 2
[0689]	OFDM	Orthogonal Frequency Division Multiplexing
[0690]	OFDMA	Orthogonal Frequency Division Multiple Access
[0691]	OOB	Out-of-band
[0692]	OOS	Out of Sync
[0693]	OPEX	OPERating EXpense
[0694]	OSI	Other System Information
[0695]	OSS	Operations Support System
[0696]	OTA	over-the-air
[0697]	PAPR	Peak-to-Average Power Ratio
[0698]	PAR	Peak to Average Ratio
[0699]	PBCH	Physical Broadcast Channel
[0700]	PC	Power Control, Personal Computer
[0701]	PCC	Primary Component Carrier, Primary CC
[0702]	PCell	Primary Cell
[0703]	PCI	Physical Cell ID, Physical Cell Identity
[0704]	PCEF	Policy and Charging Enforcement Function
[0705]	PCF	Policy Control Function
[0706]	PCRF	Policy Control and Charging Rules Function
[0707]	PDCP	Packet Data Convergence Protocol, Packet Data Convergence Protocol layer
[0708]	PDCCH	Physical Downlink Control Channel
[0709]	PDCP	Packet Data Convergence Protocol
[0710]	PDN	Packet Data Network, Public Data Network
[0711]	PDSCH	Physical Downlink Shared Channel
[0712]	PDU	Protocol Data Unit
[0713]	PEI	Permanent Equipment Identifiers
[0714]	PFD	Packet Flow Description
[0715]	P-GW	PDN Gateway
[0716]	PHICH	Physical hybrid-ARQ indicator channel
[0717]	PHY	Physical layer

[0718]	PLMN	Public Land Mobile Network
[0719]	PIN	Personal Identification Number
[0720]	PM	Performance Measurement
[0721]	PMI	Precoding Matrix Indicator
[0722]	PNF	Physical Network Function
[0723]	PNFD	Physical Network Function Descriptor
[0724]	PNFR	Physical Network Function Record
[0725]	POC	PTT over Cellular
[0726]	PP, PTP	Point-to-Point
[0727]	PPP	Point-to-Point Protocol
[0728]	PRACH	Physical RACH
[0729]	PRB	Physical resource block
[0730]	PRG	Physical resource block group
[0731]	ProSe	Proximity Services, Proximity-Based Service
[0732]	PRS	Positioning Reference Signal
[0733]	PRR	Packet Reception Radio
[0734]	PS	Packet Services
[0735]	PSBCH	Physical Sidelink Broadcast Channel
[0736]	PSDCH	Physical Sidelink Downlink Channel
[0737]	PSCCH	Physical Sidelink Control Channel
[0738]	PSSCH	Physical Sidelink Shared Channel
[0739]	PSCell	Primary SCell
[0740]	PSS	Primary Synchronization Signal
[0741]	PSTN	Public Switched Telephone Network
[0742]	PT-RS	Phase-tracking reference signal
[0743]	PTT	Push-to-Talk
[0744]	PUCCH	Physical Uplink Control Channel
[0745]	PUSCH	Physical Uplink Shared Channel
[0746]	QAM	Quadrature Amplitude Modulation
[0747]	QCI	QoS class of identifier
[0748]	QCL	Quasi co-location
[0749]	QFI	QoS Flow ID, QoS Flow Identifier

[0750]	QoS	Quality of Service
[0751]	QPSK	Quadrature (Quaternary) Phase Shift Keying
[0752]	QZSS	Quasi-Zenith Satellite System
[0753]	RA-RNTI	Random Access RNTI
[0754]	RAB	Radio Access Bearer, Random Access Burst
[0755]	RACH	Random Access Channel
[0756]	RADIUS	Remote Authentication Dial In User Service
[0757]	RAN	Radio Access Network
[0758]	RAND	RANDom number (used for authentication)
[0759]	RAR	Random Access Response
[0760]	RAT	Radio Access Technology
[0761]	RAU	Routing Area Update
[0762]	RB	Resource block, Radio Bearer
[0763]	RBG	Resource block group
[0764]	REG	Resource Element Group
[0765]	Rel	Release
[0766]	REQ	REQuest
[0767]	RF	Radio Frequency
[0768]	RI	Rank Indicator
[0769]	RIV	Resource indicator value
[0770]	RL	Radio Link
[0771]	RLC	Radio Link Control, Radio Link Control layer
[0772]	RLC AM	RLC Acknowledged Mode
[0773]	RLC UM	RLC Unacknowledged Mode
[0774]	RLF	Radio Link Failure
[0775]	RLM	Radio Link Monitoring
[0776]	RLM-RS	Reference Signal for RLM
[0777]	RM	Registration Management
[0778]	RMC	Reference Measurement Channel
[0779]	RMSI	Remaining MSI, Remaining Minimum System Information
[0780]	RN	Relay Node
[0781]	RNC	Radio Network Controller

[0782]	RNL	Radio Network Layer
[0783]	RNTI	Radio Network Temporary Identifier
[0784]	ROHC	RObust Header Compression
[0785]	RRC	Radio Resource Control, Radio Resource Control layer
[0786]	RRM	Radio Resource Management
[0787]	RS	Reference Signal
[0788]	RSRP	Reference Signal Received Power
[0789]	RSRQ	Reference Signal Received Quality
[0790]	RSSI	Received Signal Strength Indicator
[0791]	RSU	Road Side Unit
[0792]	RSTD	Reference Signal Time difference
[0793]	RTP	Real Time Protocol
[0794]	RTS	Ready-To-Send
[0795]	RTT	Round Trip Time
[0796]	Rx	Reception, Receiving, Receiver
[0797]	S1AP	S1 Application Protocol
[0798]	S1-MME	S1 for the control plane
[0799]	S1-U	S1 for the user plane
[0800]	S-GW	Serving Gateway
[0801]	S-RNTI	SRNC Radio Network Temporary Identity
[0802]	S-TMSI	SAE Temporary Mobile Station Identifier
[0803]	SA	Standalone operation mode
[0804]	SAE	System Architecture Evolution
[0805]	SAP	Service Access Point
[0806]	SAPD	Service Access Point Descriptor
[0807]	SAPI	Service Access Point Identifier
[0808]	SCC	Secondary Component Carrier, Secondary CC
[0809]	SCell	Secondary Cell
[0810]	SC-FDMA	Single Carrier Frequency Division Multiple Access
[0811]	SCG	Secondary Cell Group
[0812]	SCM	Security Context Management
[0813]	SCS	Subcarrier Spacing

[0814]	SCTP	Stream Control Transmission Protocol
[0815]	SDAP	Service Data Adaptation Protocol, Service Data Adaptation Protocol layer
[0816]	SDL	Supplementary Downlink
[0817]	SDNF	Structured Data Storage Network Function
[0818]	SDP	Service Discovery Protocol (Bluetooth related)
[0819]	SDSF	Structured Data Storage Function
[0820]	SDU	Service Data Unit
[0821]	SEAF	Security Anchor Function
[0822]	SeNB	secondary eNB
[0823]	SEPP	Security Edge Protection Proxy
[0824]	SFI	Slot format indication
[0825]	SFTD	Space-Frequency Time Diversity, SFN and frame timing difference
[0826]	SFN	System Frame Number
[0827]	SgNB	Secondary gNB
[0828]	SGSN	Serving GPRS Support Node
[0829]	S-GW	Serving Gateway
[0830]	SI	System Information
[0831]	SI-RNTI	System Information RNTI
[0832]	SIB	System Information Block
[0833]	SIM	Subscriber Identity Module
[0834]	SIP	Session Initiated Protocol
[0835]	SiP	System in Package
[0836]	SL	Sidelink
[0837]	SLA	Service Level Agreement
[0838]	SM	Session Management
[0839]	SMF	Session Management Function
[0840]	SMS	Short Message Service
[0841]	SMSF	SMS Function
[0842]	SMTC	SSB-based Measurement Timing Configuration
[0843]	SN	Secondary Node, Sequence Number

[0844]	SoC	System on Chip
[0845]	SON	Self-Organizing Network
[0846]	SpCell	Special Cell
[0847]	SP-CSI-RNTI	Semi-Persistent CSI RNTI
[0848]	SPS	Semi-Persistent Scheduling
[0849]	SQN	Sequence number
[0850]	SR	Scheduling Request
[0851]	SRB	Signalling Radio Bearer
[0852]	SRS	Sounding Reference Signal
[0853]	SS	Synchronization Signal
[0854]	SSB	Synchronization Signal Block, SS/PBCH Block
[0855]	SSBRI	SS/PBCH Block Resource Indicator, Synchronization Signal Block Resource Indicator
[0856]	SSC	Session and Service Continuity
[0857]	SS-RSRP	Synchronization Signal based Reference Signal Received Power
[0858]	SS-RSRQ	Synchronization Signal based Reference Signal Received Quality
[0859]	SS-SINR	Synchronization Signal based Signal to Noise and Interference Ratio
[0860]	SSS	Secondary Synchronization Signal
[0861]	SSSG	Search Space Set Group
[0862]	SSSIF	Search Space Set Indicator
[0863]	SST	Slice/Service Types
[0864]	SU-MIMO	Single User MIMO
[0865]	SUL	Supplementary Uplink
[0866]	TA	Timing Advance, Tracking Area
[0867]	TAC	Tracking Area Code
[0868]	TAG	Timing Advance Group
[0869]	TAU	Tracking Area Update
[0870]	TB	Transport Block
[0871]	TBS	Transport Block Size
[0872]	TBD	To Be Defined
[0873]	TCI	Transmission Configuration Indicator

[0874]	TCP	Transmission Communication Protocol
[0875]	TDD	Time Division Duplex
[0876]	TDM	Time Division Multiplexing
[0877]	TDMA	Time Division Multiple Access
[0878]	TE	Terminal Equipment
[0879]	TEID	Tunnel End Point Identifier
[0880]	TFT	Traffic Flow Template
[0881]	TMSI	Temporary Mobile Subscriber Identity
[0882]	TNL	Transport Network Layer
[0883]	TPC	Transmit Power Control
[0884]	TPMI	Transmitted Precoding Matrix Indicator
[0885]	TR	Technical Report
[0886]	TRP, TRxP	Transmission Reception Point
[0887]	TRS	Tracking Reference Signal
[0888]	TRx	Transceiver
[0889]	TS	Technical Specifications, Technical Standard
[0890]	TTI	Transmission Time Interval
[0891]	Tx	Transmission, Transmitting, Transmitter
[0892]	U-RNTI	UTRAN Radio Network Temporary Identity
[0893]	UART	Universal Asynchronous Receiver and Transmitter
[0894]	UCI	Uplink Control Information
[0895]	UE	User Equipment
[0896]	UDM	Unified Data Management
[0897]	UDP	User Datagram Protocol
[0898]	UDSF	Unstructured Data Storage Network Function
[0899]	UICC	Universal Integrated Circuit Card
[0900]	UL	Uplink
[0901]	UM	Unacknowledged Mode
[0902]	UML	Unified Modelling Language
[0903]	UMTS	Universal Mobile Telecommunications System
[0904]	UP	User Plane
[0905]	UPF	User Plane Function

[0906]	URI	Uniform Resource Identifier
[0907]	URL	Uniform Resource Locator
[0908]	URLLC	Ultra-Reliable and Low Latency
[0909]	USB	Universal Serial Bus
[0910]	USIM	Universal Subscriber Identity Module
[0911]	USS	UE-specific search space
[0912]	UTRA	UMTS Terrestrial Radio Access
[0913]	UTRAN	Universal Terrestrial Radio Access Network
[0914]	UwPTS	Uplink Pilot Time Slot
[0915]	V2I	Vehicle-to-Infrastructure
[0916]	V2P	Vehicle-to-Pedestrian
[0917]	V2V	Vehicle-to-Vehicle
[0918]	V2X	Vehicle-to-everything
[0919]	VIM	Virtualized Infrastructure Manager
[0920]	VL	Virtual Link,
[0921]	VLAN	Virtual LAN, Virtual Local Area Network
[0922]	VM	Virtual Machine
[0923]	VNF	Virtualized Network Function
[0924]	VNFFG	VNF Forwarding Graph
[0925]	VNFFGD	VNF Forwarding Graph Descriptor
[0926]	VNFM	VNF Manager
[0927]	VoIP	Voice-over-IP, Voice-over-Internet Protocol
[0928]	VPLMN	Visited Public Land Mobile Network
[0929]	VPN	Virtual Private Network
[0930]	VRB	Virtual Resource Block
[0931]	WiMAX	Worldwide Interoperability for Microwave Access
[0932]	WLAN	Wireless Local Area Network
[0933]	WMAN	Wireless Metropolitan Area Network
[0934]	WPAN	Wireless Personal Area Network
[0935]	X2-C	X2-Control plane
[0936]	X2-U	X2-User plane
[0937]	XML	eXtensible Markup Language

[0938]	XRES	EXpected user RESponse
[0939]	XOR	eXclusive OR
[0940]	ZC	Zadoff-Chu
[0941]	ZP	Zero Power

### Terminology

- [0942] For the purposes of the present document, the following terms and definitions are applicable to the examples and embodiments discussed herein, but are not meant to be limiting.
- [0943] 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.
- [0944] 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.”

- [0945] 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.
- [0946] 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.
- [0947] 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.
- [0948] 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.
- [0949] 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.

**[0950]** 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.

**[0951]** 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.

**[0952]** 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.

- [0953] 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.
- [0954] 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.
- [0955] The term “SMTC” refers to an SSB-based measurement timing configuration configured by *SSB-MeasurementTimingConfiguration*.
- [0956] The term “SSB” refers to an SS/PBCH block.
- [0957] 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.
- [0958] 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.
- [0959] The term “Secondary Cell” refers to a cell providing additional radio resources on top of a Special Cell for a UE configured with CA.
- [0960] 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.
- [0961] 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.
- [0962] 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/.

**[0963]** The term “Special Cell” refers to the PCell of the MCG or the PSCell of the SCG for DC operation; otherwise, the term “Special Cell” refers to the Pcell.

## WHAT IS CLAIMED IS:

1. A user equipment (UE), comprising:
  - radio front end circuitry; and
  - processor circuitry configured to:
    - transmit, using the radio front end circuitry, a first message for connecting to a 5G network and indicating a capability of the UE relating to Cellular Internet of Things (CIOT);
    - transmit, using the radio front end circuitry and via a control plane to the 5G network, a second message comprising mobile originated data; and
    - receive, using the radio front end circuitry, a third message from the 5G network.
2. The UE of claim 1, wherein the first message comprises a registration request message as part of an initial registration procedure.
3. The UE of claim 1, wherein the first message comprises a registration request message as part of a periodic update registration procedure.
4. The UE of claim 1, wherein the processor circuitry is further configured to receive, using the radio front end circuitry, a registration accept message in response to transmitting the first message and wherein the registration accept message is based on capabilities of the 5G network.
5. The UE of claim 1, wherein to transmit the second message, the processor circuitry is configured to transmit, in an idle mode, a service request message or a control plane service request message comprising a first 5G system session management (5GSM) data transport message.
6. The UE of claim 5, wherein to receive the third message, the processor circuitry is further configured to receive, using the radio front end circuitry:
  - a service accept message in response to no data being transmitted to the UE, or

a second 5G system session management (5GSM) data transport message in response to data being transmitted to the UE.

7. The UE of claim 1, wherein to transmit the second message, the processor circuitry is configured to transmit, in a connected mode, a first 5G system session management (5GSM) data transport message.
8. The UE of claim 7, wherein to receive the third message, the processor circuitry is further configured to receive, using the radio front end circuitry:
  - a service accept message in response to no data being transmitted to the UE, or
  - a second 5G system session management (5GSM) data transport message in response to data being transmitted to the UE.
9. The UE of claim 1, wherein the second message comprises an information element (IE) indicating that no further uplink or downlink data transmission is expected.
10. The UE of claim 1, wherein the second message comprises an information element (IE) indicating that no further uplink data transmission is expected and a single downlink data transmission is expected.
11. A method, comprising:
  - transmitting, by a user equipment (UE), a first message for connecting to a 5G network and indicating a capability of the UE relating to Cellular Internet of Things (CIOT);
  - transmitting, via a control plane to the 5G network, a second message comprising mobile originated data; and
  - receiving a third message from the 5G network.
12. The method of claim 11, wherein the first message comprises at least one of a registration request message as part of an initial registration procedure or a registration request message as part of a periodic update registration procedure.

13. The method of claim 11, further comprising  
receiving a registration accept message in response to transmitting the first message and wherein the registration accept message is based on capabilities of the 5G network.
14. The method of claim 11, wherein:  
transmitting the second message comprises transmitting, in an idle mode, a service request message or a control plane service request message comprising a first 5G system session management (5GSM) data transport message, and  
receiving the third message comprises:  
receiving a service accept message in response to no data being transmitted to the UE, or  
receiving a second 5G system session management (5GSM) data transport message in response to data being transmitted to the UE.
15. The method of claim 11, wherein:  
transmitting the second message comprises transmitting, in a connected mode, a first 5G system session management (5GSM) data transport message, and  
receiving the third message comprises:  
receiving a service accept message in response to no data being transmitted to the UE, or  
receiving a second 5G system session management (5GSM) data transport message in response to data being transmitted to the UE.
16. The method of claim 11, wherein the second message comprises an information element (IE) indicating that no further uplink or downlink data transmission is expected.
17. The method of claim 11, wherein the second message comprises an information element (IE) indicating that no further uplink data transmission is expected and a single downlink data transmission is expected.
18. A user equipment (UE), comprising:

a memory configured to store program instructions; and  
a processor, upon executing the program instructions, configured to:  
transmit a first message for connecting to a 5G network and indicating a capability of the UE relating to Cellular Internet of Things (CIOT);  
transmit, via a control plane to the 5G network, a second message comprising mobile originated data; and  
receive mobile terminated data from the 5G network.

19. The UE of claim 18, wherein:

to transmit the second message, the processor is further configured to transmit, in an idle mode, a service request message or a control plane service request message comprising a first 5G system session management (5GSM) data transport message, and  
to receive the mobile terminated data, the processor is further configured to receive a second 5G system session management (5GSM) data transport message in response to data being transmitted to the UE.

20. The UE of claim 18, wherein:

to transmit the second message, the processor is further configured to transmit, in a connected mode, a first 5G system session management (5GSM) data transport message, and  
to receive the mobile terminated data, the processor is further configured to receive a second 5G system session management (5GSM) data transport message in response to data being transmitted to the UE.

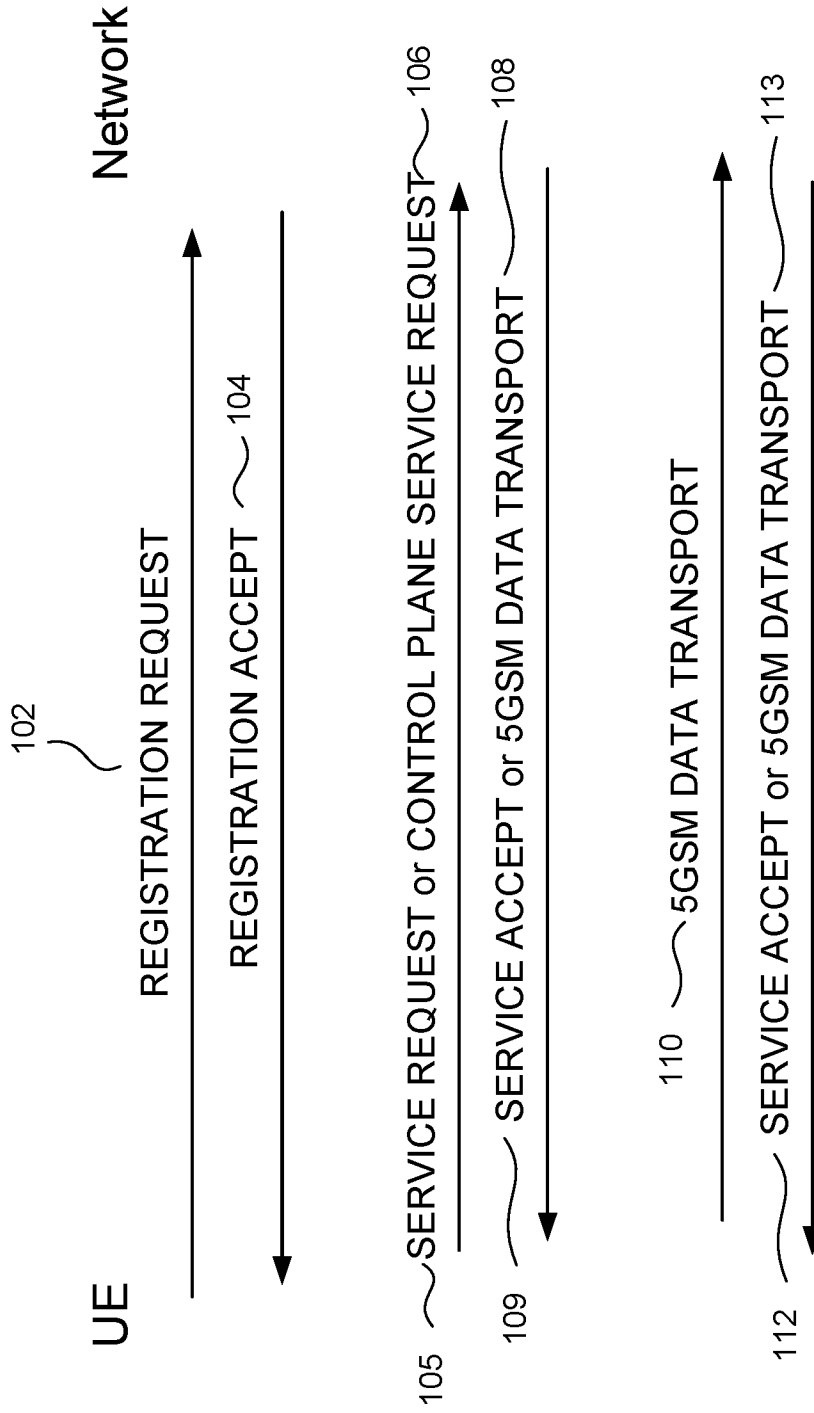


Figure 1

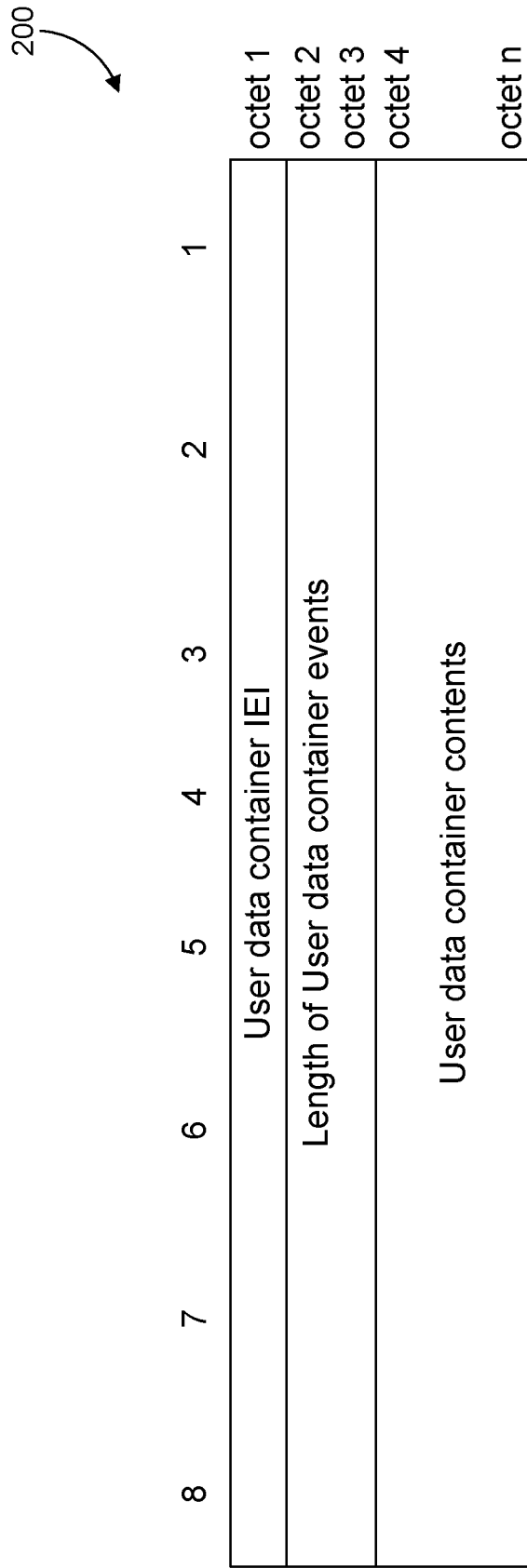


Figure 2

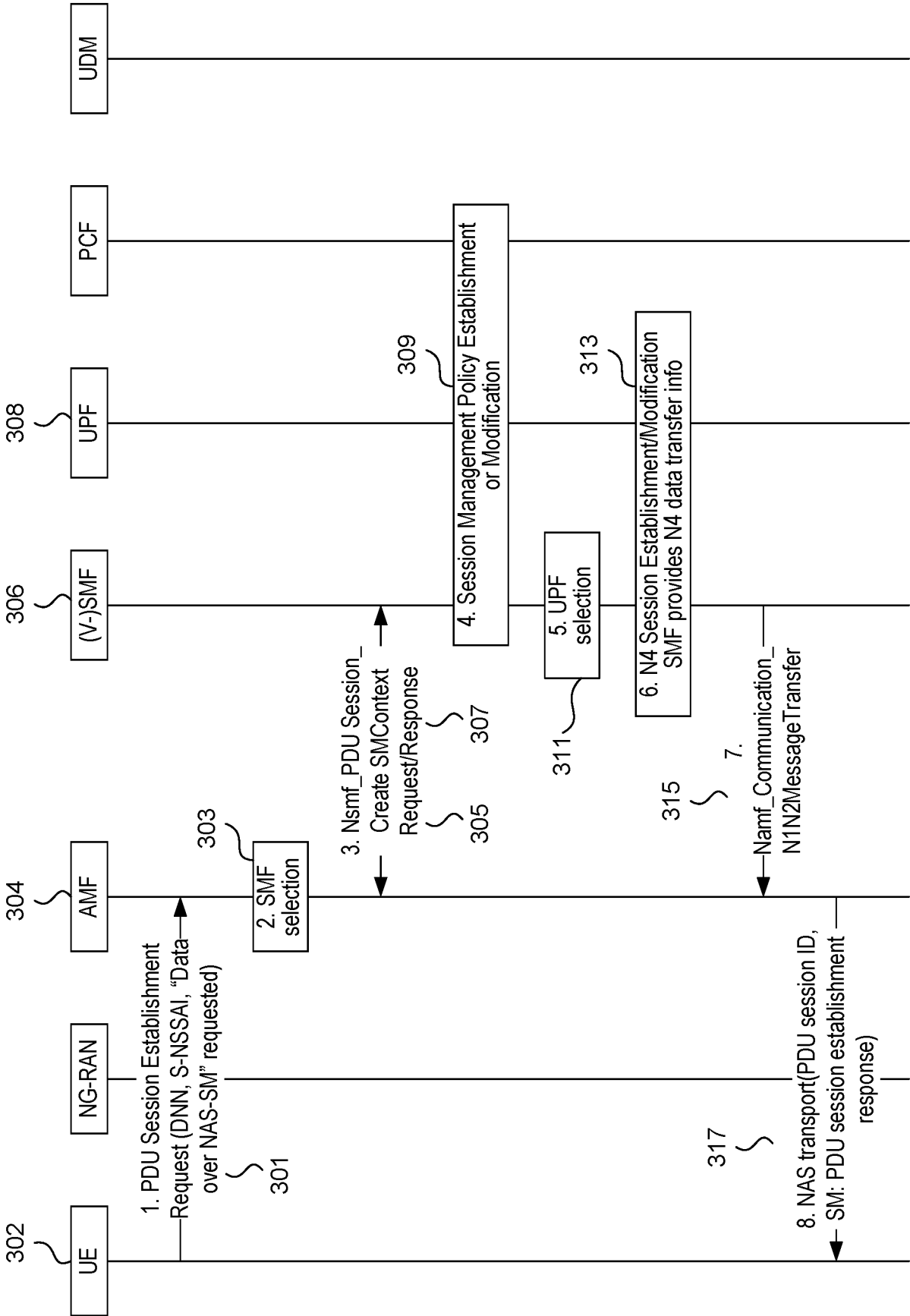


Figure 3

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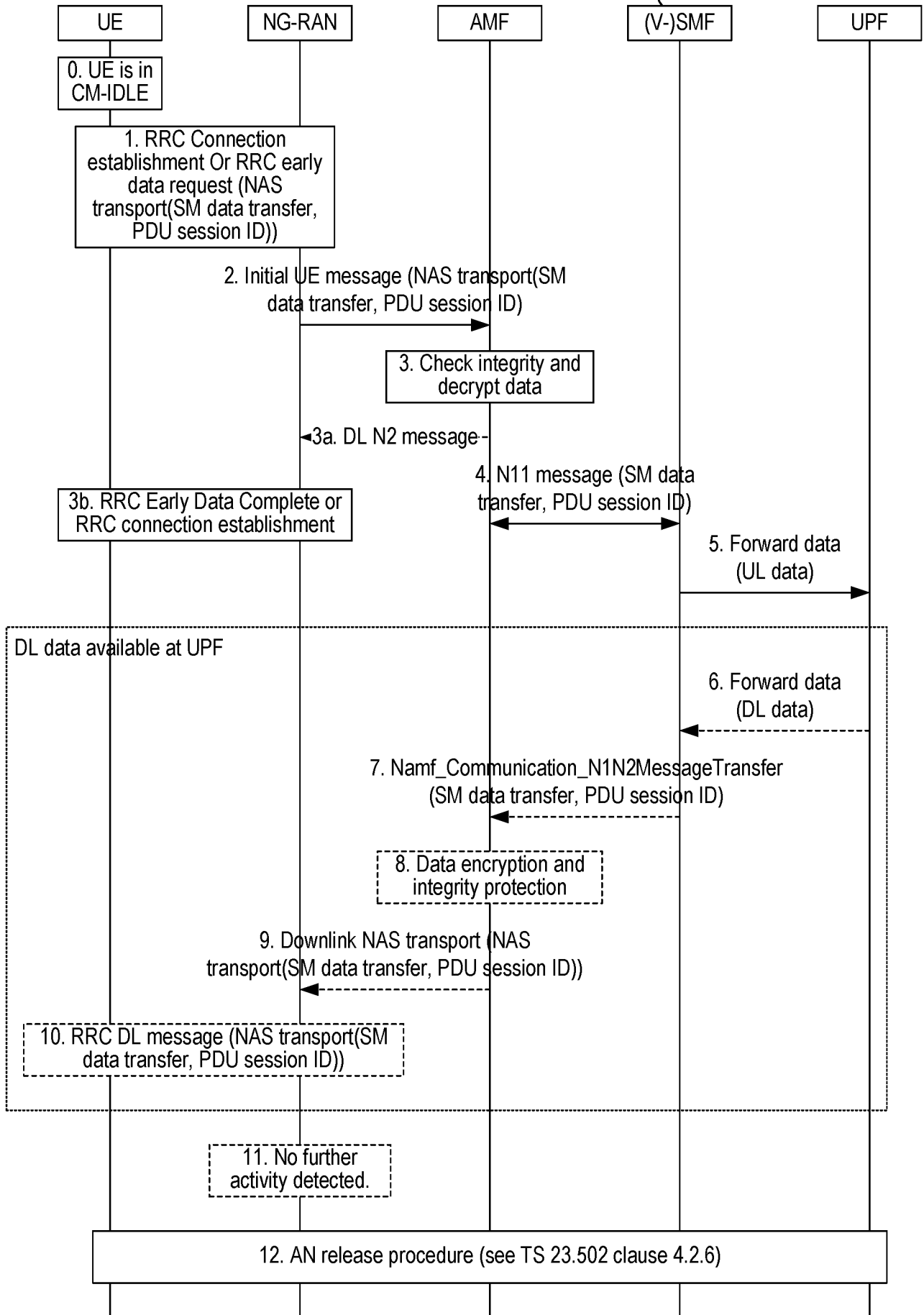


Figure 4

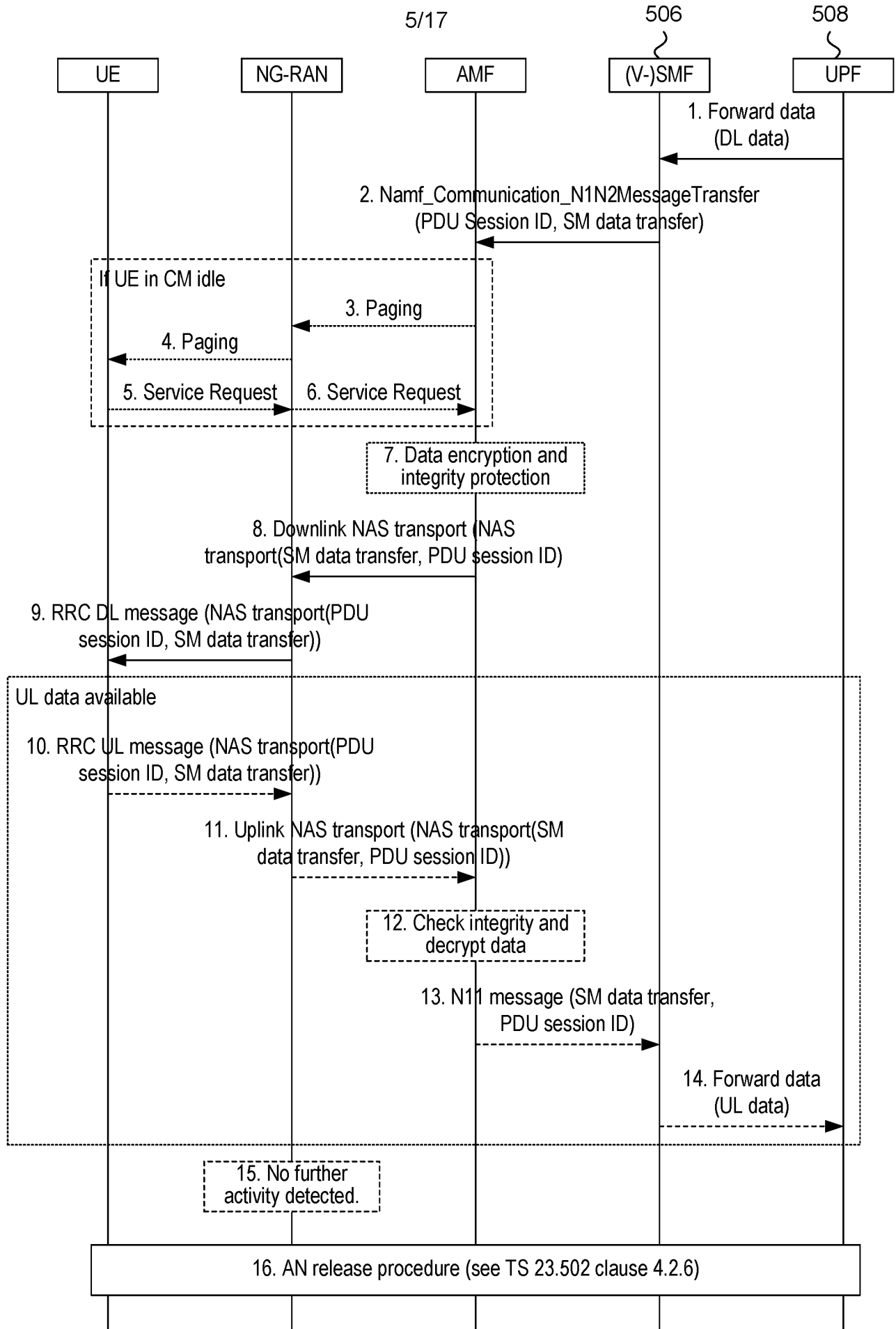


Figure 5

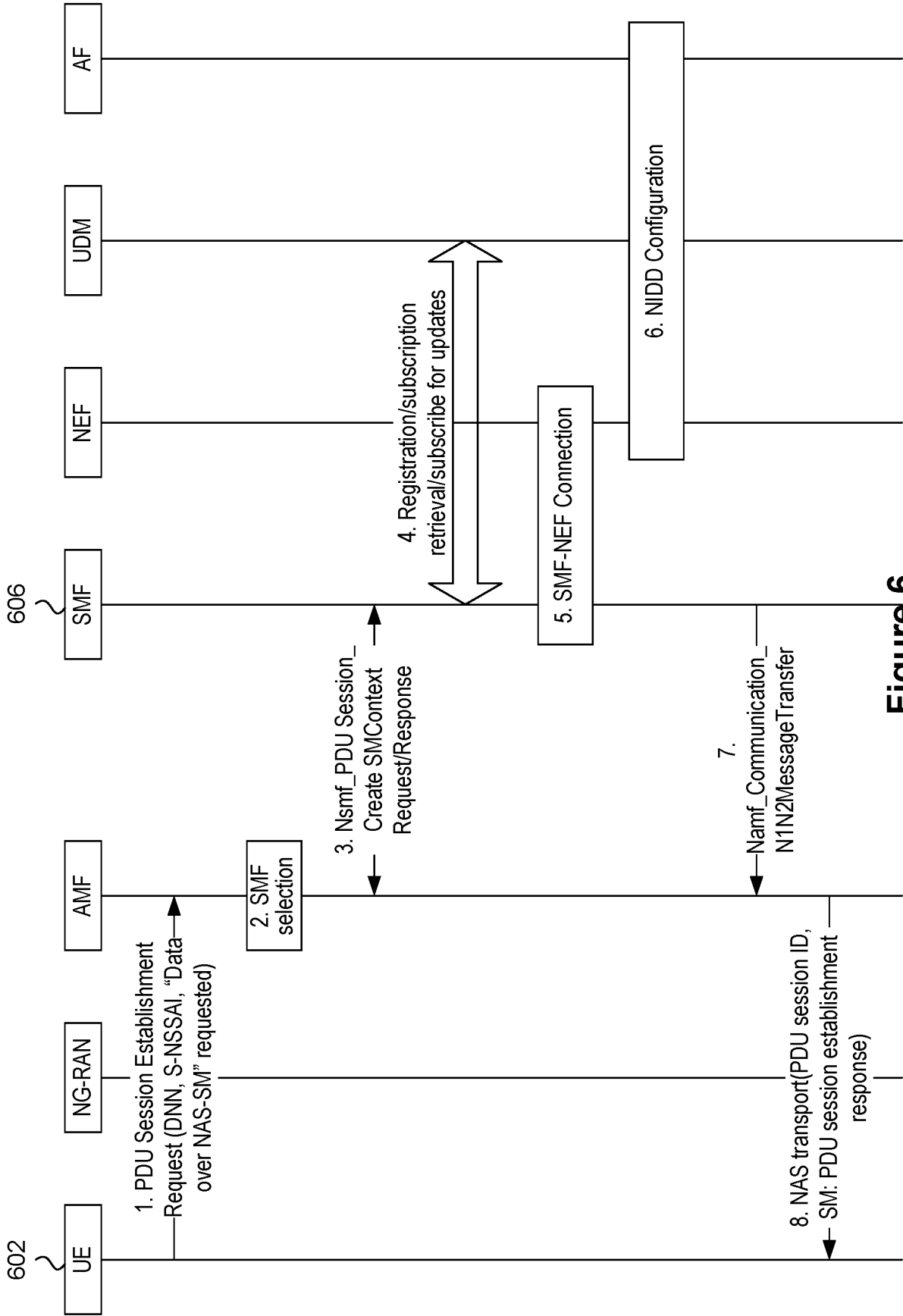


Figure 6

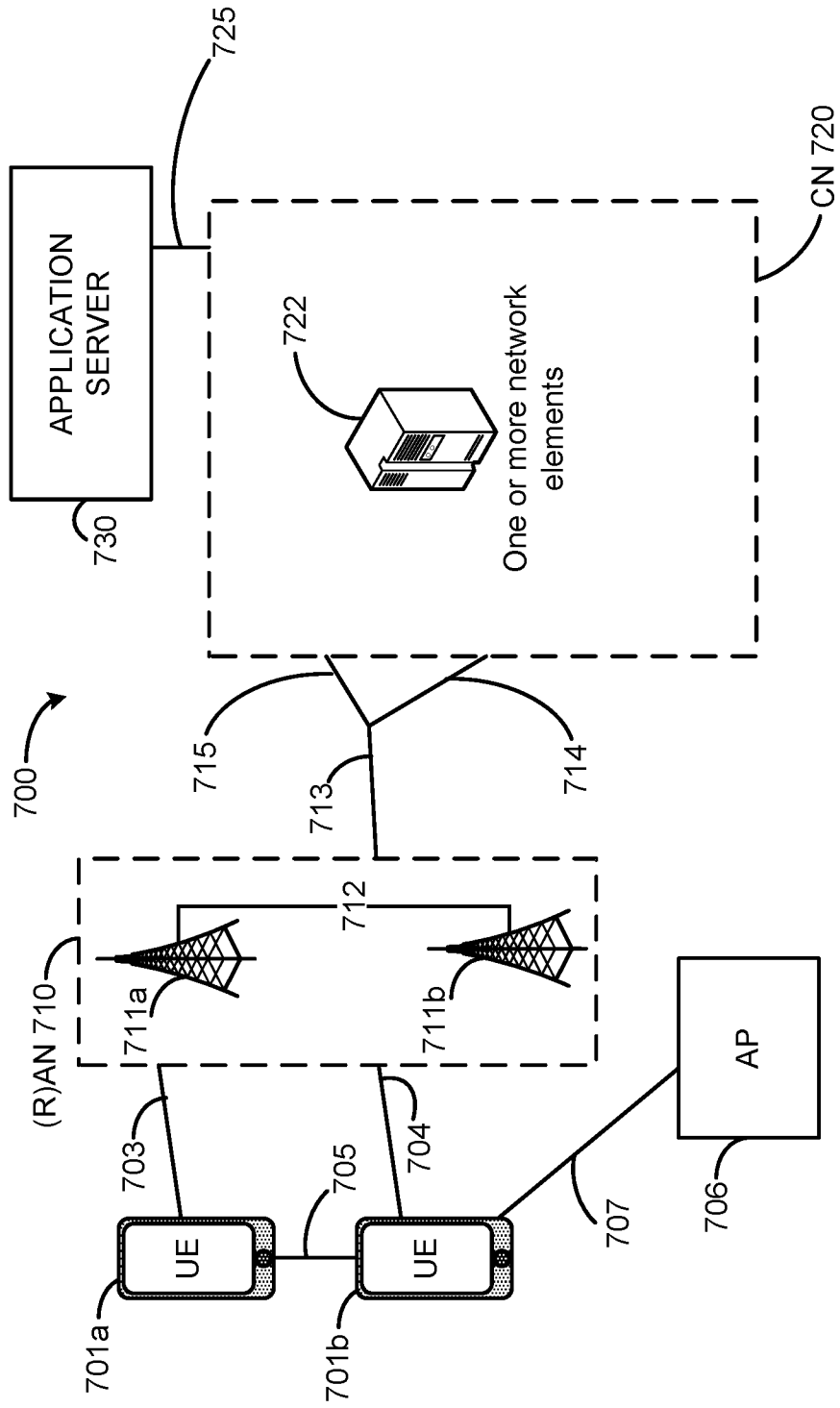


Figure 7

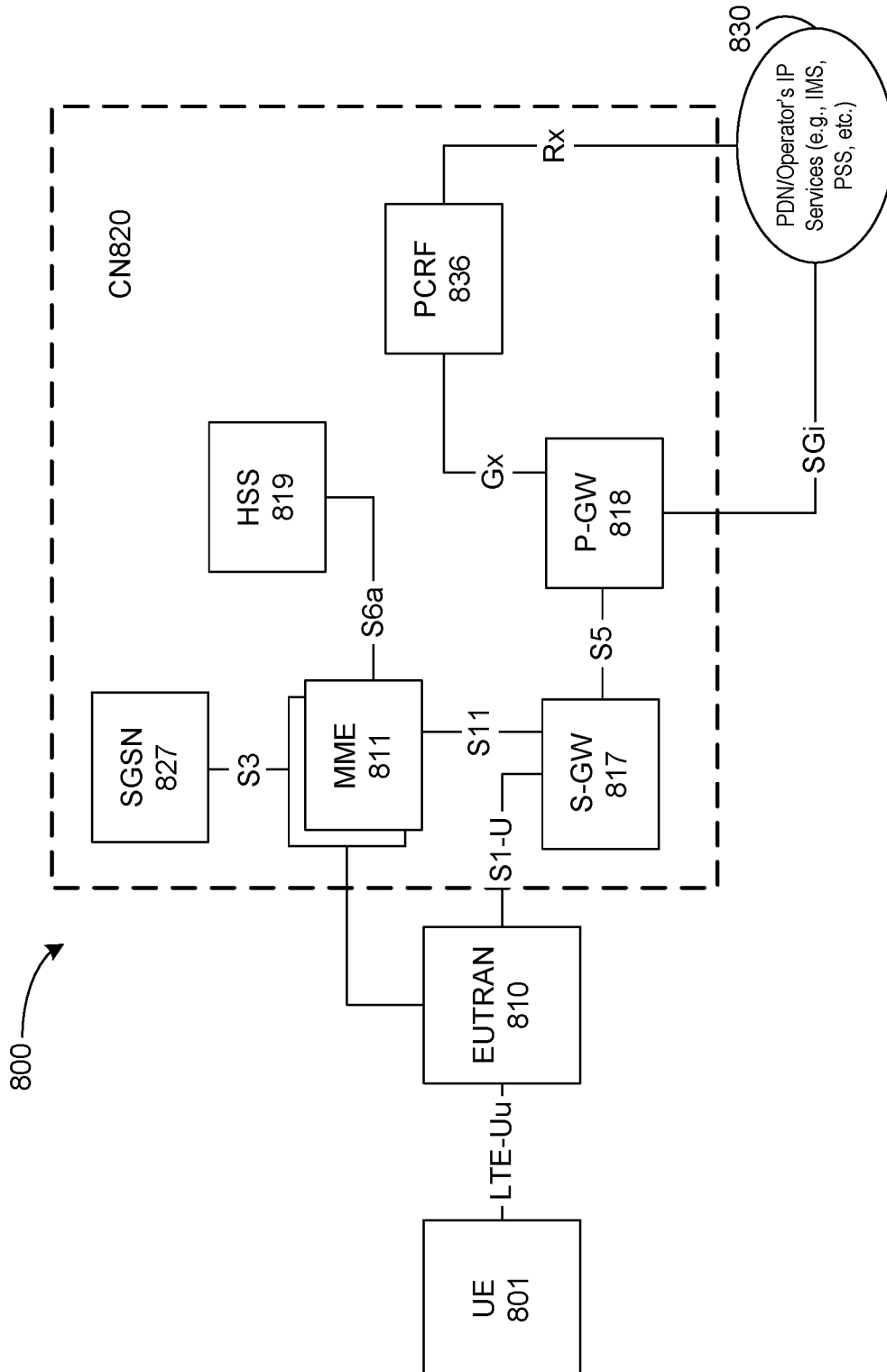


Figure 8

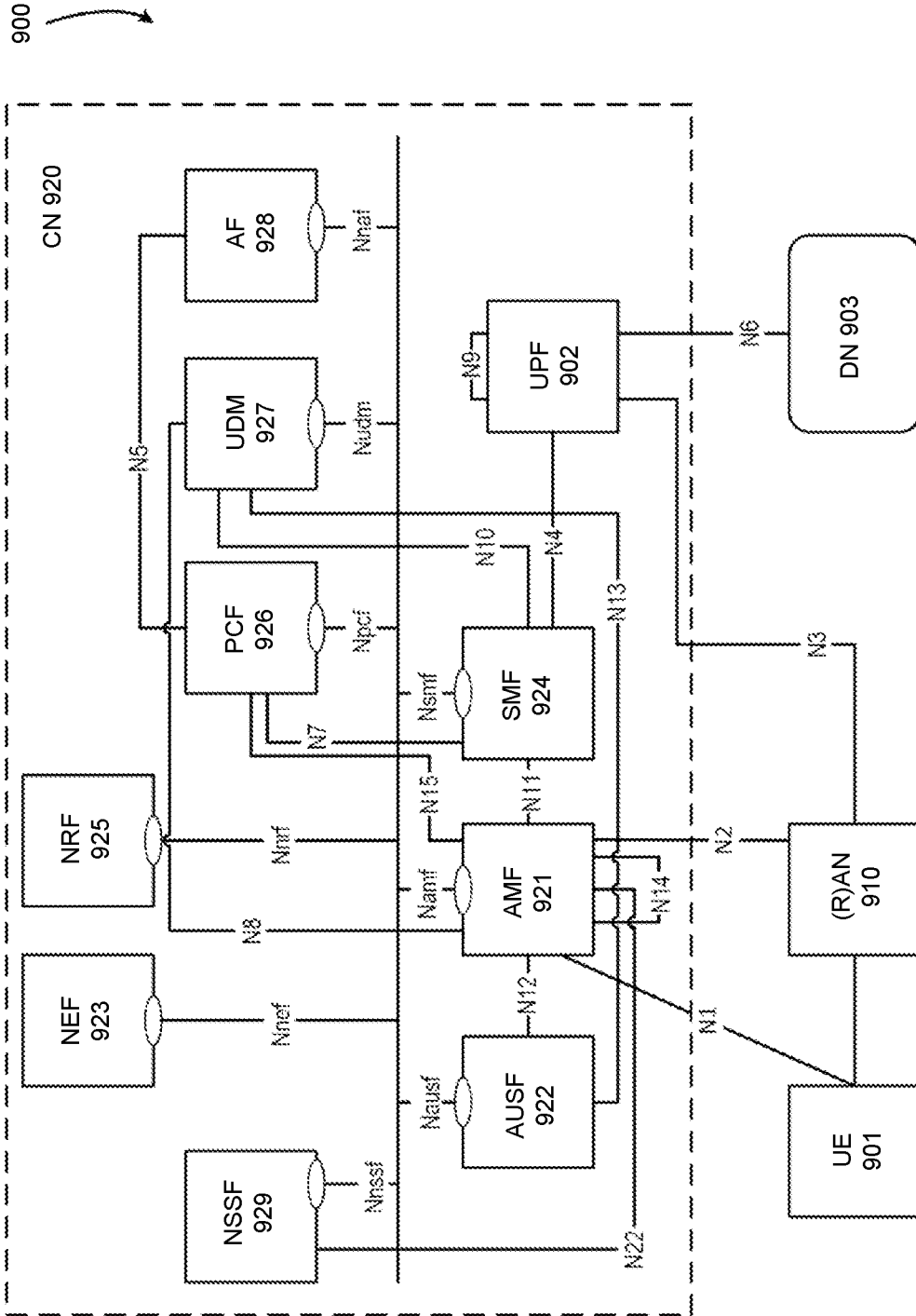


Figure 9

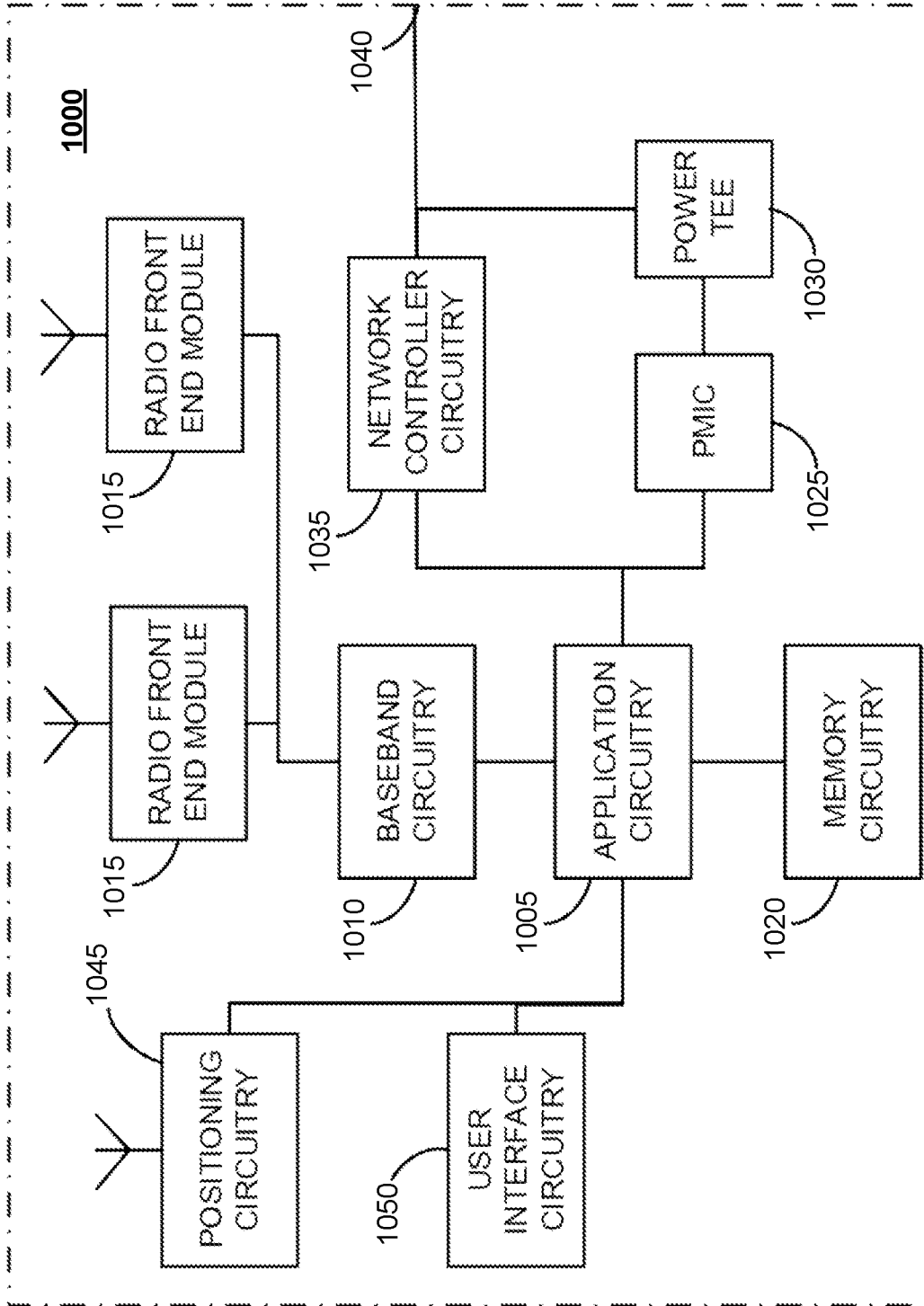


Figure 10

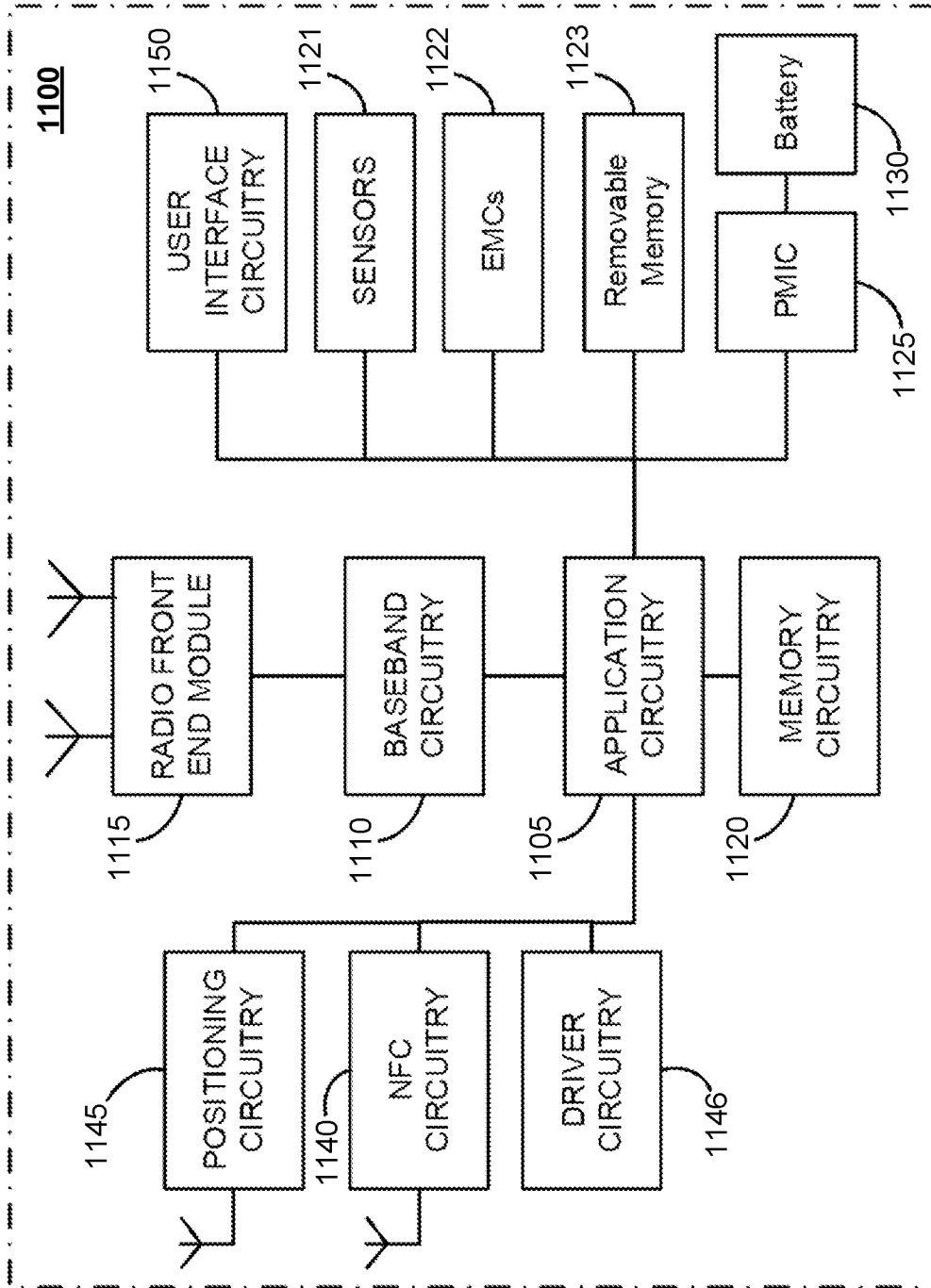


Figure 11

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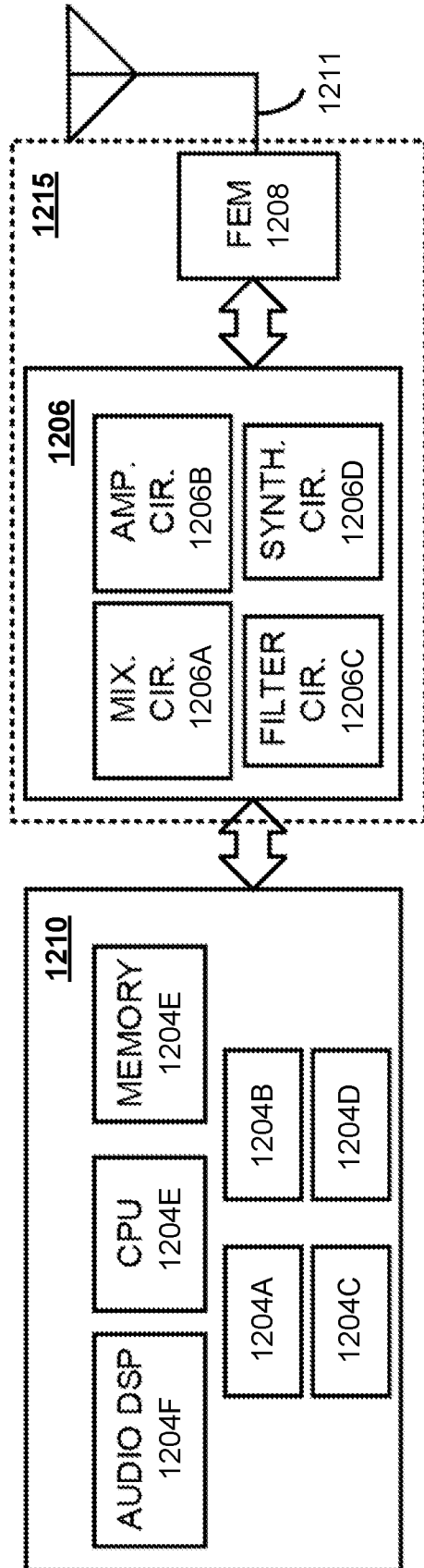


Figure 12

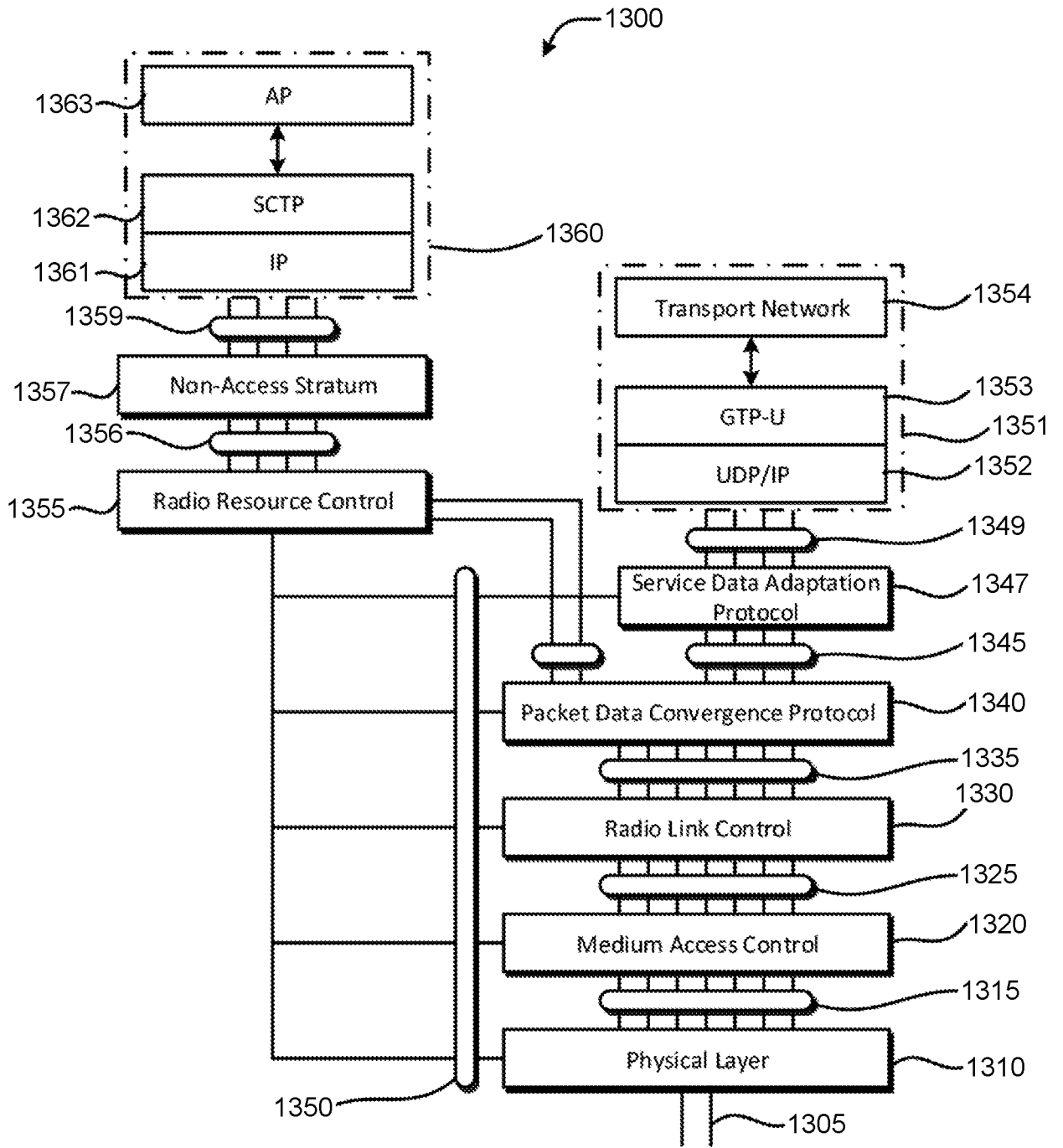


Figure 13

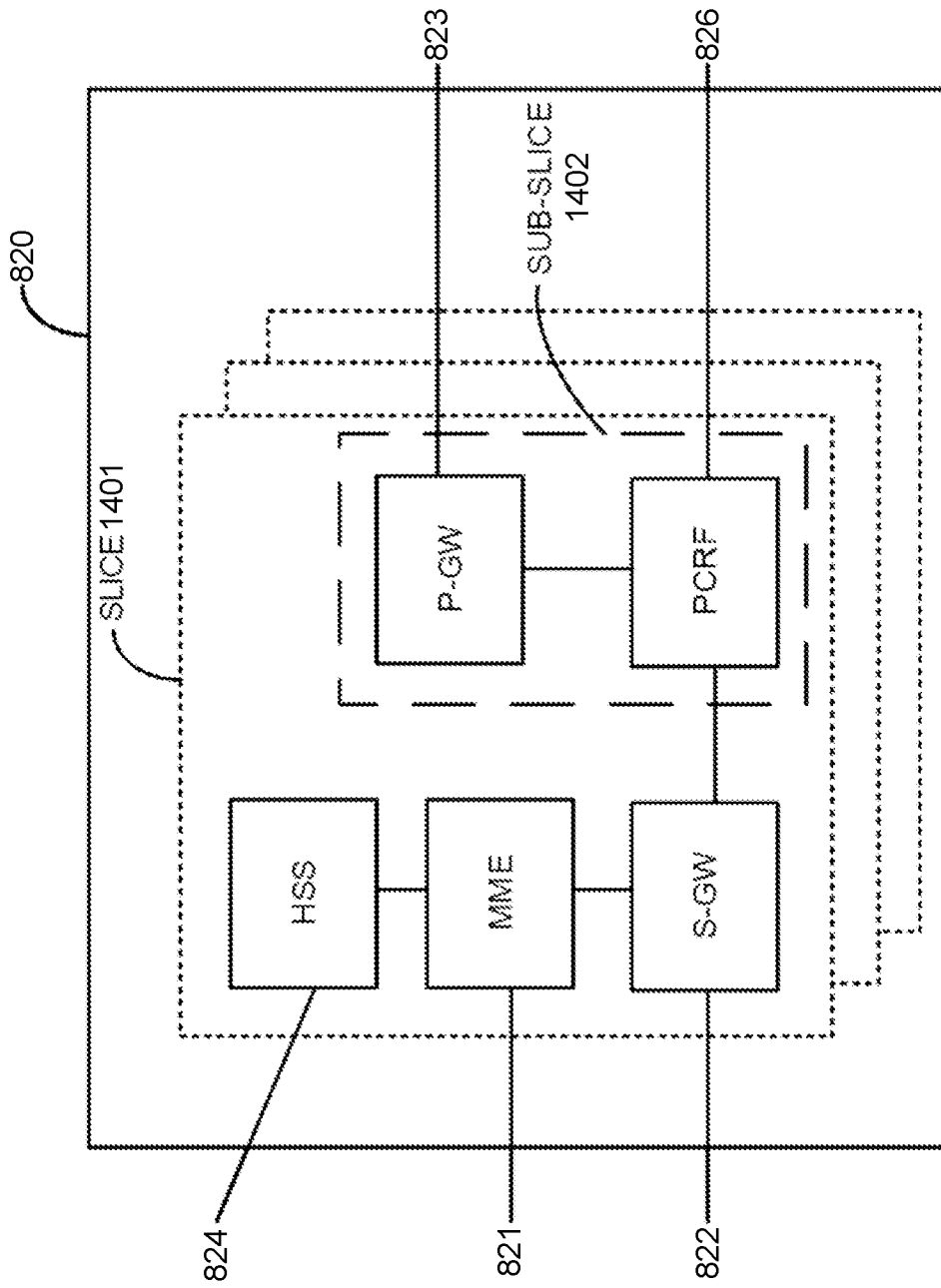


Figure 14

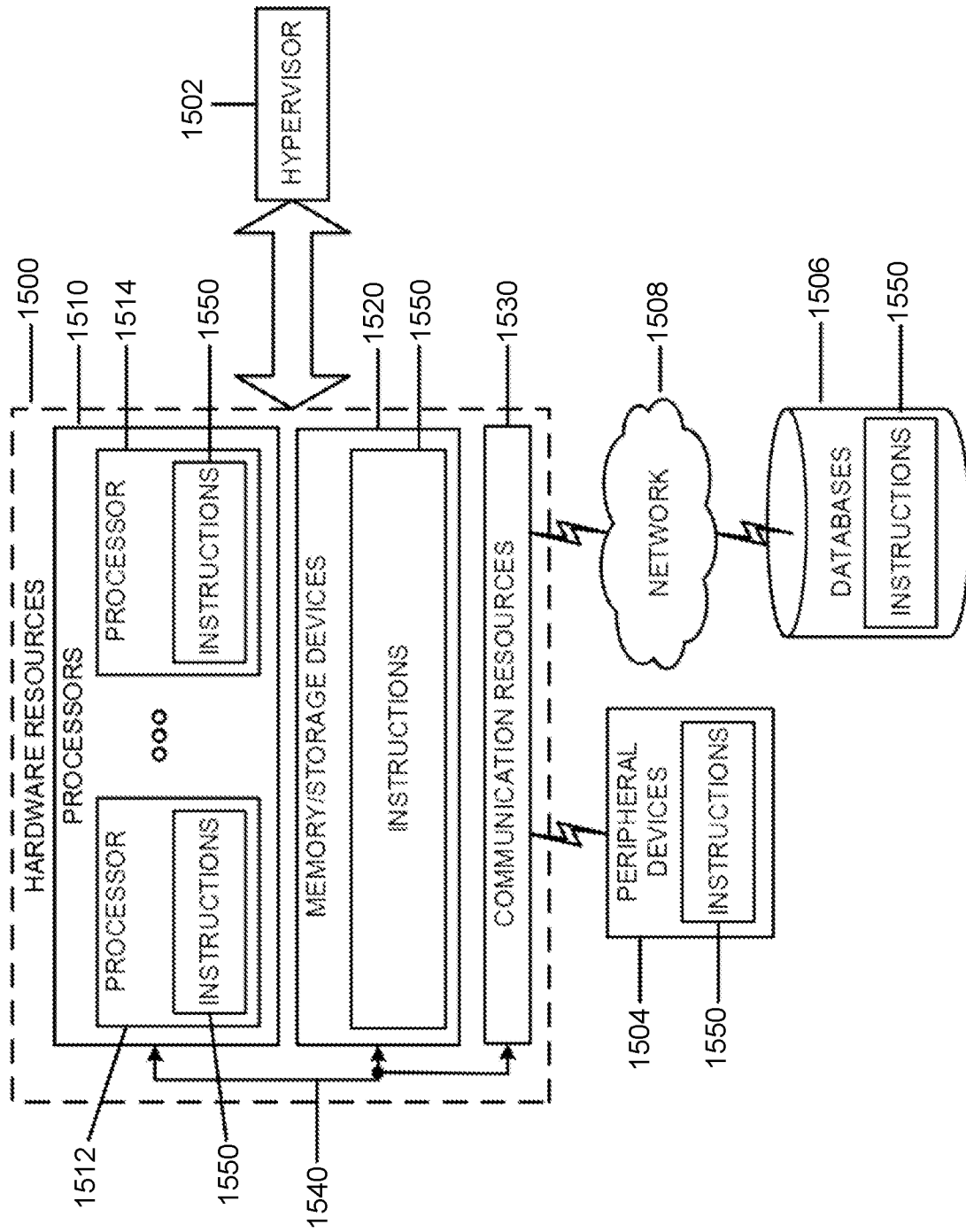


Figure 15

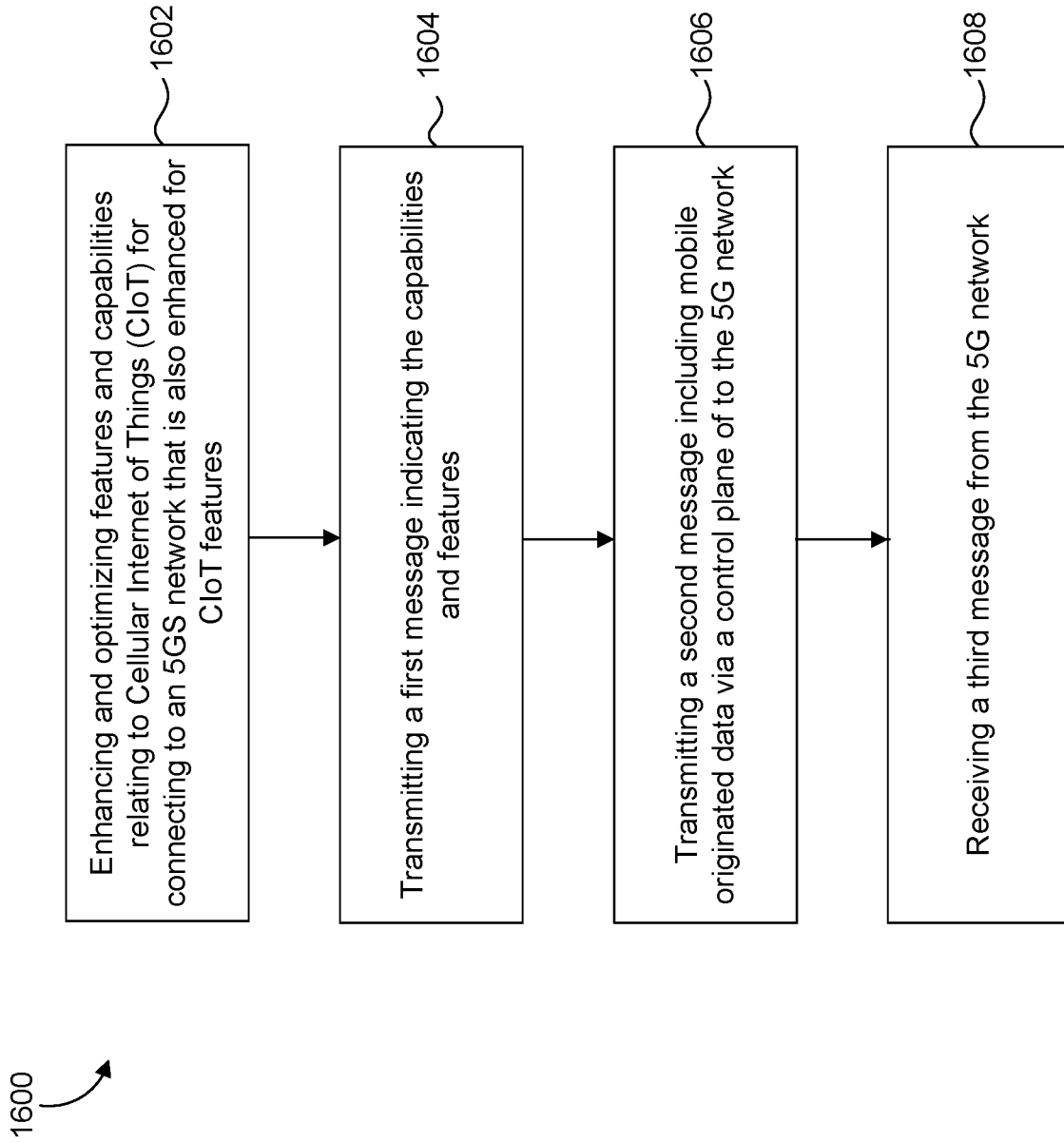


Figure 16

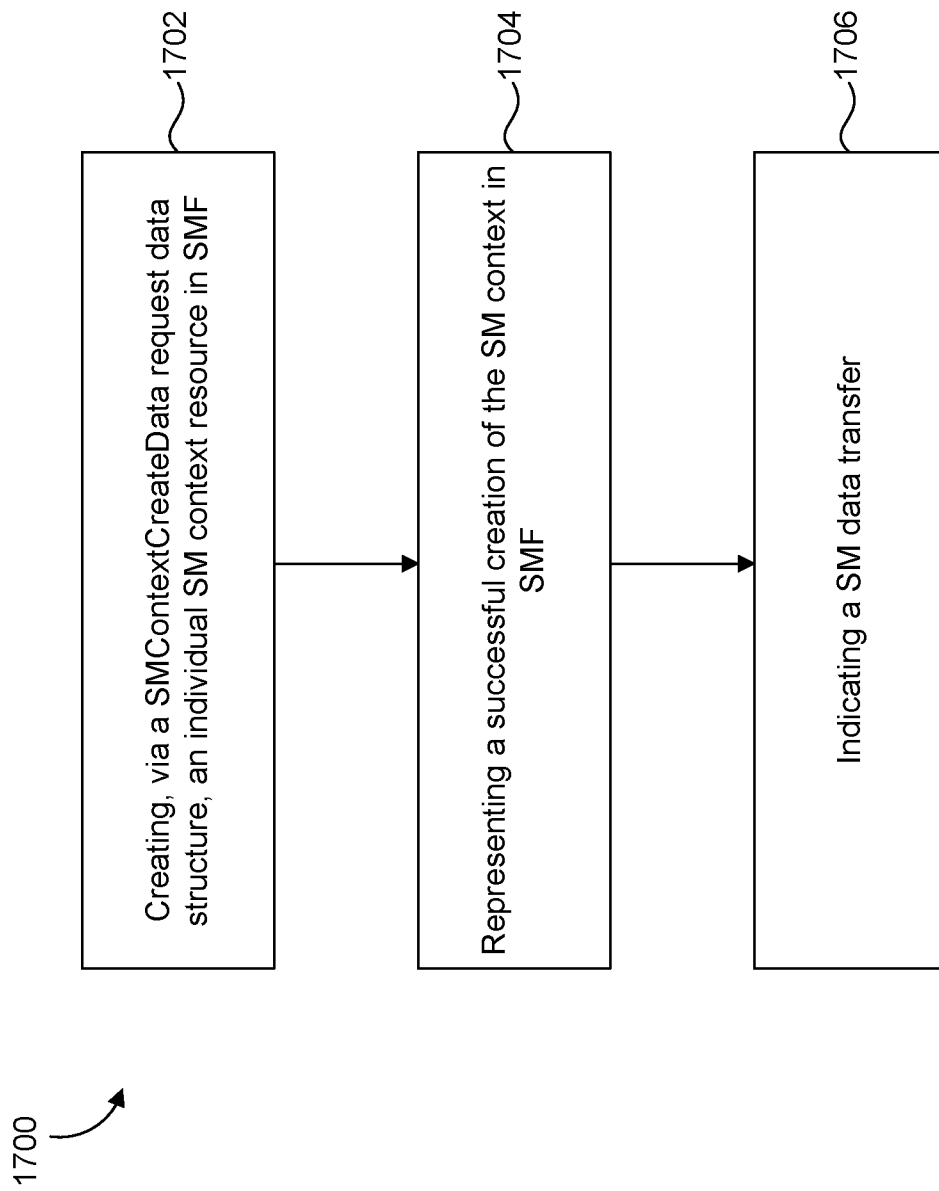


Figure 17

# INTERNATIONAL SEARCH REPORT

International application No <b>PCT/US2020/015233</b>
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<b>A. CLASSIFICATION OF SUBJECT MATTER</b> INV. H04W76/11 H04W4/70 ADD.		
According to International Patent Classification (IPC) or to both national classification and IPC		
<b>B. FIELDS SEARCHED</b>		
Minimum documentation searched (classification system followed by classification symbols) H04W		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPO-Internal, WPI Data		
<b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2017/151437 A1 (INTEL IP CORP [US]) 8 September 2017 (2017-09-08) paragraph [0061] - paragraph [0109] -----	1-20
X	WO 2018/138163 A1 (ERICSSON TELEFON AB L M [SE]) 2 August 2018 (2018-08-02) page 14, line 10 - page 24, line 3 ----- -/--	1-20
<input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C. <span style="margin-left: 100px;"><input checked="" type="checkbox"/> See patent family annex.</span>		
* Special categories of cited documents :		
"A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family	
Date of the actual completion of the international search	Date of mailing of the international search report	
27 April 2020	08/05/2020	
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer  Kalabic, Faris	

**INTERNATIONAL SEARCH REPORT**

International application No  
PCT/US2020/015233

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	<p>"3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; System Architecture for the 5G System; Stage 2 (Release 15)", 3GPP STANDARD; TECHNICAL SPECIFICATION; 3GPP TS 23.501, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE, vol. SA WG2, no. V15.2.0, 19 June 2018 (2018-06-19), pages 1-217, XP051472860, [retrieved on 2018-06-19] paragraph [5.17] - paragraph [5.17.4]</p> <p align="center">-----</p>	1-20
A	<p>"3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Study on Cellular Internet of Things (IoT) support and evolution for the 5G System (Release 16)", 3GPP STANDARD; TECHNICAL REPORT; 3GPP TR 23.724, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE, vol. SA WG2, no. V16.0.0, 19 December 2018 (2018-12-19), pages 1-276, XP051591216, [retrieved on 2018-12-19] paragraph [06.3] - paragraph [6.5.6]</p> <p align="center">-----</p>	1-20

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Information on patent family members

International application No PCT/US2020/015233
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WO 2018138163	A1	02-08-2018	CN	110192399 A	30-08-2019
			EP	3479613 A1	08-05-2019
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			JP	2019533917 A	21-11-2019
			WO	2018138163 A1	02-08-2018
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