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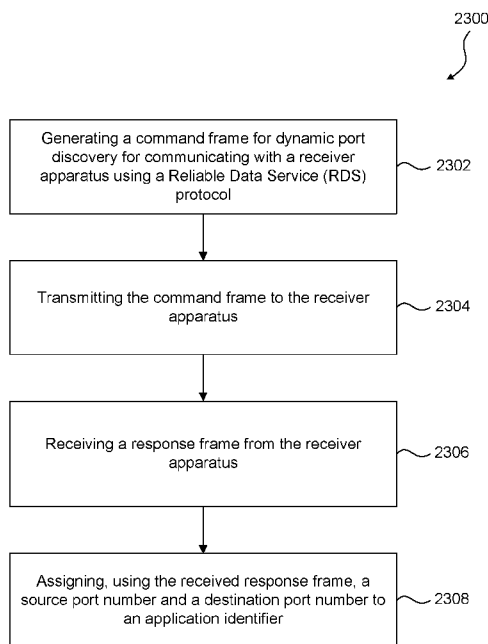**(54) Title: PORT MANAGEMENT FOR RELIABLE DATA SERVICE (RDS) PROTOCOL**

Figure 23

(57) Abstract: Systems, apparatuses, methods, and computer-readable media are provided for use in a wireless network for dynamic port discovery. Some embodiments are directed to an originator device that includes processor circuitry and radio front circuitry. The processor circuitry can be configured to generate a command frame for dynamic port discovery for communicating with a receiver device using a Reliable Data Service (RDS) protocol. The processor circuitry can be further configured to transmit, using the radio front end circuitry, the command frame to the receiver device and receive, using the radio front end circuitry, a response frame from the receiver device. The processor circuitry can be further configured to assign, using the received response frame, a source port number and a destination port number to an application identifier. The application identifier can be associated with an application on the originator device communicating with a corresponding application on the receiver device.

PORT MANAGEMENT FOR RELIABLE DATA SERVICE (RDS) PROTOCOL

CROSS REFERENCE TO RELATED APPLICATIONS

[0001]   This application claims the benefit under 35 U.S.C. § 119(e) of U.S. Provisional Application No. 62/792,089, filed January 14, 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 dynamic port discovery.

[0004]   Some embodiments are directed to an originator device. The originator device includes processor circuitry and radio front end circuitry. The processor circuitry can be configured to generate a command frame for dynamic port discovery for communicating with a receiver device using a Reliable Data Service (RDS) protocol. The processor circuitry can be further configured to transmit, using the radio front end circuitry, the command frame to the receiver device and receive, using the radio front end circuitry, a response frame from the receiver device. The processor circuitry can be further configured to assign, using the received response frame, a source port number and a destination port number to an application identifier. The application identifier can be associated with an application on the originator device communicating with a corresponding application on the receiver device.

[0005]   Some embodiments are directed to an originator device. The originator device includes a memory that stores instructions and a processor. The processor, upon executing the instructions, can be configured to generate a command frame for dynamic port discovery for communicating with a receiver device using a Reliable Data Service (RDS) protocol. The processor can be also configured to transmit the command frame to the

receiver device and receive a response frame from the receiver device. The processor can be further configured to assign, using the received response frame, a source port number and a destination port number to an application identifier. The application identifier can be associated with an application on the originator device communicating with a corresponding application on the receiver device.

[0006]   Some embodiments are directed to a method including generating, at an originator device, a command frame for dynamic port discovery for communicating with a receiver device using a Reliable Data Service (RDS) protocol. The method can also include transmitting the command frame to the receiver device and receiving a response frame from the receiver device. The method can also include assigning, using the received response frame, a source port number and a destination port number to an application identifier. The application identifier can be associated with an application on the originator device communicating with a corresponding application on the receiver device.

BRIEF DESCRIPTION OF THE DRAWINGS/FIGURES

[0007]   Figure 1 depicts an example of protocol layering for reliable data transfer between UE and SCEF via E-UTRAN, in accordance with some embodiments.

[0008]   Figure 2 depicts an example SET_PARAMETERS field format, in accordance with some embodiments.

[0009]   Figure 3 depicts an example bitmap of port numbers, in accordance with some embodiments.

[0010]   Figure 4 depicts an example RDS_Reserve_Port Command frame and an example RDS_Reserve_Port Response frame, in accordance with some embodiments.

[0011]   Figure 5 depicts an example RDS_Release_Port Command frame and an example RDS_Release_Port Response frame, in accordance with some embodiments.

[0012]   Figure 6 depicts an example RDS_PORT_MGMT field format, in accordance with some embodiments.

[0013]   Figure 7 depicts an example RDS frame format, in accordance with some embodiments.

[0014]   Figure 8 depicts an example Address and Control field format, in accordance with some embodiments.

[0015]   Figure 9 depicts an example establishment of acknowledged transfer procedure, in accordance with some embodiments.

[0016]   Figure 10 depicts an example acknowledged information transfer procedure, in accordance with some embodiments.

[0017]   Figure 11 depicts an example termination of acknowledged transfer procedure, in accordance with some embodiments.

[0018]   Figure 12 depicts an example unacknowledged information transfer procedure, in accordance with some embodiments.

[0019]   Figure 13 depicts an architecture of a system of a network, in accordance with some embodiments.

[0020]   Figure 14 depicts an architecture of a system including a first core network, in accordance with some embodiments.

[0021]   Figure 15 depicts an architecture of a system including a second core network in accordance with some embodiments.

[0022]   Figure 16 depicts an example of infrastructure equipment, in accordance with various embodiments.

[0023]   Figure 17 depicts example components of a computer platform, in accordance with various embodiments.

[0024]   Figure 18 depicts example components of baseband circuitry and radio frequency circuitry, in accordance with various embodiments.

[0025]   Figure 19 is an illustration of various protocol functions that may be used for various protocol stacks, in accordance with various embodiments.

[0026]   Figure 20 illustrates components of a core network in accordance with various embodiments.

[0027]   Figure 21 is a block diagram illustrating components, according to some example embodiments, of a system to support NFV.

[0028]   Figure 22 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.

[0029]   Figure 23 depicts an example flowchart for practicing the various embodiments discussed herein, for example, for dynamic port discovery.

[0030] 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

[0031] 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).

[0032] The Reliable Data Service (RDS) protocol is used to perform non-IP data transfer between a UE (e.g., UE 1301 of Figure 13) and Service Capability Exposure Function (SCEF)/PDN-GW. RDS supports peer-to-peer data transfers and provides reliable data delivery between the UE and the SCEF or P-GW. The data is transferred via a PDN connection between the UE and SCEF or P-GW. The UE can connect to multiple SCEFs or P-GWs. A UE can connect to multiple SCS/AS via the SCEF or P-GW. RDS supports multiple applications on the UE to simultaneously conduct data transfers with their peer entities on the SCEF or P-GW using a single PDN connection between the UE and SCEF or P-GW. RDS supports both acknowledged and unacknowledged data transfers. RDS supports variable-length frames and allows detection and elimination of duplicate frames at the receiving endpoint.

[0033] Figure 1 shows a reference model of the protocol layering for reliable data transfer between the UE and SCEF. The RDS operates above the NAS and Diameter layers in the

reference architecture. RDS establishes a peer-to-peer logical link between the UE and SCEF or P-GW. The logical link is identified by a pair of port numbers and EPS bearer ID. Each port number is used to identify an application on the UE side or at the network (SCEF or P-GW) side and is carried in the address field of each frame. The source port number identifies the application on the originator and the destination port number identifies the application on the receiver. When a single application on the originator conducts data transfer with a single application on the receiver, the source port number and destination port number need not be used. Each RDS frame consists of a header and an information field of variable length. The header contains information about port numbers and the frame number that is used to identify the frame and provide reliable transmission. The information field contains the payload to be transferred between the UE and SCEF or P-GW.

[0034]   The UE establishes a PDN connection with the SCEF or P-GW either during Attach or through UE requested PDN connectivity. The UE uses the EPS bearer ID to select the bearer to transfer RDS PDUs to the SCEF or P-GW. The EPS bearer ID identifies the destination (at the UE or at the SCEF or P-GW) and is not carried in the frame as it is already included in the NAS ESM message header. Once the UE and network successfully negotiate to use RDS for a particular PDN connection, the PDN connection transfers data only using RDS protocol.

[0035]   RDS supports both single and multiple applications within the UE. RDS also provides fuctionality for flow control and sequence control to maintain the sequential order of frames across the logical link.

[0036]   In acknowledged operation the information is transmitted in order in numbered Information (I) frames. The I frames are acknowledged at the RDS layer. Error recovery and reordering mechanisms based on retransmission of acknowledged I frames are specified. Several I frames can be acknowledged at the same time. Flow control is implemented via a sliding window mechanism. In unacknowledged operation the information is transmitted in numbered Unconfirmed Information (UI) frames. The UI frames are not acknowledged at the RDS layer. Error recovery and reordering mechanisms are not defined. Duplicate UI frames are discarded. Flow control procedures are not defined.

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[0037]   The RDS protocol is currently being used in 4G and is also likely to be used in 5G systems for CIoT type applications. Currently, port number assignment and management is not included in RDS protocol and is done outside it by proprietary mechanisms, some other OTT applications or through static configuration.

[0038]   Embodiments herein extend the RDS protocol so that dynamic port discovery can be added to it. The purpose of port discovery is to allow originators (UE or SCEF) to dynamically discover destination port numbers and other associated applications that use RDS transfer over the EPS bearer ID. For UEs with limited subscription to only non-IP APN(s), this RDS based discovery application may be the only way to dynamically discover these port numbers.

[0039]   RDS may be used for CIoT systems and applications, for example, data transfer for applications like smart metering, power grid management and other IoT type applications. Dynamic port discovery makes the protocol more flexible and usable.

RDS Port Discovery

Source port number (Source Port)

[0040]   When a UE application starts to use the PDN connection to transmit RDS frames, the UE and the SCEF or P-GW establish which source port number will be used for the application on the UE side for MO traffic and which destination port number will be used for the application intended to receive the frames on the SCEF or P-GW side. Similarly for MT traffic when an application in the network starts to use the PDN connection to transmit RDS frames, the UE and the SCEF or P-GW establish which source port number will be used for the application on the SCEF or P-GW side and which destination port number will be used for the application intended to receive the frames on the UE side. How the applications on the originator side and their peer entities on receiver side synchronize port numbers is outside the scope of this specification.

[0041]   One way around this is that port numbers are hard coded and assigned a priori. Having these small ranges of port numbers hard coded to specific IoT applications might not be suitable for flexible deployments as it requires firmware upgrade at the UE side each time a port number is added, deleted or updated. For UEs that support both IP and non-IP protocol stack and have subscription to both IP and non-IP APNs, there is a way to dynamically discover these port numbers outside the RDS protocol. For example, a

web discovery server running over http/https protocol might be used to dynamically discover/allocate these port numbers. For UEs that does not have subscription to IP based APN, there is not a way to dynamically discover these port numbers but to use RDS protocol.

[0042]   In various embodiments, the RDS protocol is extended so that dynamic port discovery can be added to it. The purpose of port discovery is to allow originators (UE or SCEF) to dynamically discover destination port numbers and other associated applications that use RDS transfer over the EPS bearer ID. For UEs with limited subscription to only non-IP APN(s), this RDS based discovery application may be the only way to dynamically discover these port numbers.

[0043]   In a first embodiment, the SET_PARAMETERs command/response is extended for port discovery. In a second embodiment, a new command RDS_PORT_MGMT is defined for port discovery.

[0044]   The highlighted yellow text is new text proposed to TS 24.250.

Embodiment 1

SET_PARAMETERS command / response

[0045]   The SET_PARAMETERS command and response is used to negotiate values of parameters between originator and receiver in both acknowledged and unacknowledged mode of transfer. These parameters include the version of the RDS.

[0046]   If the originator wants to negotiate the value of parameters, the originator sends a SET_PARAMETERS command including the set of parameters along with their values to the receiver. The receiver sends a SET_PARAMETERS response, either confirming these parameter values by returning the requested values, or proposing different ones in their place. Both, the originator and the receiver uses the negotiated values after the completion of the negotiation process.

[0047]   Table 1 lists the negotiable RDS layer parameters. Figure 2 shows the SET_PARAMETERS field format. A parameter item consists of Type and Length octets followed by the value of that parameter. The Length octet indicates the number of octets that the value actually occupies.

Table 1: RDS layer parameters

Parameter Name	Type	Length	Format (87654321)	Range
RDS_Version	0	1	bbbbbbbb	0 through 255
RDS_Query_Port_List	1	2	Bitmap	See below
RDS_Reserve_Port	2			See below
RDS_Release_Port	3			See below

RDS_Query Port List

[0048]   The RDS_Query_Port_List parameter allows the originator to query the receiver as to which port numbers are assigned and which are free on the receiver side. The originator passes a bitmap of Source port numbers (0-15) to receiver. If a port is assigned on originator side, the bit position is set to 1 and if a port is free then the corresponding bit position is set to 0. The receiver sends a corresponding bitmap of Destination ports on receiver side to originator. In some variants the Application ID associated with reserved port numbers may also be included after the bitmap of port numbers. An example bitmap of port numbers, in accordance with some embodiments, is illustrated in Figure 3.

RDS_Reserve_Port

[0049]   The RDS_Reserve_Port command allows the originator to assign a combination of Source port and Destination port numbers to a specific application. The originator sends the Source Port number, Destination Port number and Application Id to the receiver in the command frame. The receiver returns the Source Port number, Destination Port number, Application Id and Status to the originator in response frame. The Status field indicates if the receiver was able to successfully assign the Source and Destination port numbers for the specified application.

[0050]   The application identifier Application ID is specified as follows:

a)   "OS Id + OS App Id" where OS Id contains a Universally Unique IDentifier (UUID) as specified in IETF RFC 4122 ("A Universally Unique IDentifier (UUID) URN Namespace".) of 16 bytes and OS app id contains an OS specific application identifier of N bytes; or

b)   Only "OS App Id" (example: URN) of 4 bytes that is more universally recognized by IoT applications without subscription to IP-based APNs.

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[0051]   Figure 4 depicts an example RDS_Reserve_Port Command frame 401 and an

example RDS_Reserve_Port Response frame 411, in accordance with some

embodiments. According to some embodiments, RDS_Reserve_Port Command frame

401 can include Source Port number 403, Destination Port number 405, and Application

Identifier 407. According to some embodiments, RDS_Reserve_Port Response frame 411

can include Source Port number 413, Destination Port number 415, Application Identifier

417, and Status 419. Status 419 in the RDS_Reserve_Port Response frame 411 can be as

follows:

Status:

0   Successful

1   Destination Port already assigned

2   Application ID not valid

RDS_Release Port

[0052]   The RDS_Release_Port command allows the originator to release a combination

of Source port and Destination port numbers which have been previously assigned to a

specific application. The originator sends the Source Port number, Destination Port

number and Application Id to the receiver in the command frame. The receiver returns the

Source Port number, Destination Port number, Application Id and Status to the originator

in response frame. The Status field indicates if the receiver was able to successfully

release the Source and Destination port numbers from the specified application.

[0053]   Figure 5 depicts an example RDS_Release_Port Command frame 501 and an

example RDS_Release_Port Response frame 511, in accordance with some embodiments.

According to some embodiments, RDS_Release_Port Command frame 501 can include

Source Port number 503, Destination Port number 505, and Application Identifier 507.

According to some embodiments, RDS_Release_Port Response frame 511 can include

Source Port number 513, Destination Port number 515, Application Identifier 517, and

Status 519. Status 519 in the RDS_Release_Port Response frame 511 can be as follows:

Status:

0   Successful

1   Port Busy

2   Application ID not valid

Embodiment 2

Commands and responses

General

[0054]   The following commands and responses are used by the UE side and SCEF side as shown in table 2. Each link connection supports the appropriate set of commands and responses for the type of operation desired.

Table 2: Commands and responses

Frame	Commands	Responses	Encoding					
			S1	S2	M4	M3	M2	M1
S Frame or I Frame	SACK	SACK	1	1	-	-	-	-
U Frame	ERROR	ERROR	-	-	0	0	0	1
U Frame	DISCONNECT	-	-	-	0	1	0	0
U Frame	-	ACCEPT	-	-	0	1	1	0
U Frame	SET_ACK_MODE	-	-	-	0	1	1	1
U Frame	SET_PARAMETERS	SET_PARAMETERS	-	-	1	0	1	1
U Frame	RDS_PORT_MGMT	RDS_PORT_MGMT	-	-	1	0	1	0

RDS_PORT_MGMT command / response

[0055]   The RDS_PORT_MGMT command and response is used to discover which port numbers are free and which port numbers have associated applications with them. Applications can then use this command to reserve or release a port number at originator and receiver.

[0056]   If the originator wants to discover the list of all port numbers already reserved, or reserve a new port number or release an already assigned port number, the originator sends a RDS_PORT_MGMT command including the set of parameters along with their values to the receiver. The receiver sends a RDS_PORT_MGMT response, either returning all the information requested by the originator or reserving or releasing a port number as requested by the originator. The receiver also includes the status of operation in the response.

[0057]   Figure 6 shows the RDS_PORT_MGMT field format. A parameter item consists of Port Mgmt Command and Length octets followed by other parameters depending on

type of port management command. The Length octet indicates the number of octets that the frame actually occupies.

[0058]   The following Port Mgmt Commands are supported.

RDS_Query_Port_List	1
RDS_Reserve_Port	2
RDS_Release_Port	3

[0059]   The frame formats for command and response are similar to that described in Option 1.

RDS Aspects

Frame structure and format of fields

General

[0060]   The peer-to-peer transfers using RDS conforms to the frame format as shown in Figure 7. The frame header consists of the Address and Control field and is a minimum of 1 octet and a maximum of 3 octets long. The Information field is of variable length.

Address and Control field

Address and Control field format

[0061]   The Address and Control field identifies the type of frame and consists of minimum of 1 octet and maximum of 3 octets. The following types of control field frames are specified:

- confirmed information transfer (I frame);
- supervisory functions (S frame);
- unconfirmed information transfer (UI frame); and
- control functions (U frame).

[0062]   The address and control field format for RDS is shown in Figure 8.The description of address and control field bits is shown in Table 3.

Table 3: Address and Control field bits description

Control field bits	Description
A	Acknowledgement request bit
M_n	Unnumbered function bit
N(R)	Receive sequence number

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N(S)	Send sequence number
N(U)	Unconfirmed sequence number
S_n	Supervisory function bit
R_n	Selective acknowledgement bitmap bit
PD	Protocol Discriminator bit
C/R	Command / Response bit
ADS	Address bit
Source Port	Source port number
Destination Port	Destination port number
X	Spare bit

Protocol Discriminator bit (PD)

[0063]   The PD bit indicates whether a frame is an RDS frame or belongs to a different protocol. RDS frames have the PD bit set to 0. If a frame with the PD bit set to 1 is received, then it is treated as an invalid frame.

Address bit (ADS)

[0064]   The ADS bit controls if the Source Port and Destination Port are included in the frame format. When a single application on UE side conducts data transfer with a single application on SCEF or P-GW side, the source and destination port numbers need not be used. The source and destination port numbers enable multiple applications on the UE side to simultaneously communicate with their peer entities on the SCEF or P-GW side using the same PDN connection. Source Port and Destination Port are included in the frame format only if the ADS bit is set to 1.

Source port number (Source Port)

[0065]   When a UE application starts to use the PDN connection to transmit RDS frames, the UE and the SCEF or P-GW establish which source port number will be used for the application on the UE side for MO traffic and which destination port number will be used for the application intended to receive the frames on the SCEF or P-GW side. Similarly for MT traffic when an application in the network starts to use the PDN connection to transmit RDS frames, the UE and the SCEF or P-GW establish which source port number will be used for the application on the SCEF or P-GW side and which destination port number will be used for the application intended to receive the frames on the UE side. How the applications on the originator side and their peer entities on receiver side synchronize port numbers is outside the scope of this specification.

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[0066] Source Port is included only if the ADS bit is 1. Source Port has values from 0 to 15.

Destination port number (Destination Port)

[0067] The Destination Port is used to identify the destination application on the receiver that is receiving the frame.

[0068] Destination Port is included only if the ADS bit is 1. Destination Port has values from 0 to 15.

Information transfer frame - I

[0069] The I frame is used to perform an information transfer between peer entities with acknowledgement. Each I frame has a send sequence number $N(S)$, a receive sequence number $N(R)$ and an acknowledgement request bit A, that may be set to 0 or 1. The use of $N(S)$, $N(R)$, and A is defined below.

[0070] Each I frame also contains supervisory function bits $S(n)$ and the Selective Acknowledgement bitmap $R(n)$ which are defined below.

Supervisory frame - S

[0071] The S frame is used to perform supervisory control functions such as acknowledge I frames. The supervisory frame has supervisory function bits $S(n)$ that are used for encoding commands and responses which perform the supervisory control functions. Each supervisory frame has a receive sequence number $N(R)$ and an acknowledgement request bit A, that may be set to 0 or 1. In acknowledged operation, all I and S frames contain $R(n)$, the Selective Acknowledgement bitmap. The commands and responses are defined below and the use of $S(n)$, $N(R)$, A and $R(n)$ is defined below.

Unconfirmed Information frame - UI

[0072] The UI frame is used to perform an information transfer between peer entities without acknowledgement. The UI frames contain $N(U)$, the unconfirmed sequence number of transmitted UI frames. No verification of sequence numbers is performed for UI frames.

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Unnumbered frame - U

[0073]   The U frame is used to provide additional link control functions. Each U frame has Unnumbered function bits M(n) that are used to encode link control commands and response. The U frame has Command/Response bit (C/R) that identifies a U frame as either a command or a response. The U fame contains no sequence number. The commands and responses are defined below and the use of M(n) is defined below.

Command / Response bit (C/R)

[0074]   The C/R bit identifies a frame as either a command or a response. The UE side sends commands with the C/R bit set to 0, and responses with the C/R bit set to 1. The SCEF or P-GW side does the opposite; i.e., commands are sent with C/R set to 1, and responses are sent with C/R set to 0. The combinations for the SCEF or P-GW side and UE side are shown in table 4.

Table 4: C/R field bit usage

Type	Direction	C/R value
Command	SCEF or P-GW side to UE side	1
Command	UE side to SCEF or P-GW side	0
Response	SCEF or P-GW side to UE side	0
Response	UE side to SCEF or P-GW side	1

Control field parameters and associated state variables

[0075]   The various parameters associated with the control field frames are described below.

Acknowledgement request bit (A)

[0076]   All I and S frames contain the Acknowledgement Request (A) bit.

[0077]   The A bit set to 1 is used to solicit an acknowledgement (i.e., an I frame or S frame) from the receiver. The A bit set to 0 is used to indicate that the receiver is not requested to send an acknowledgement.

Acknowledged operation variables and parameters

Send state variable V(S)

[0078]   In acknowledged operation, each originator has an associated send state variable V(S) when using I frames. V(S) denotes the sequence number of the next in-sequence I frame to be transmitted. V(S) can take on the value 0 through (MAX SEQUENCE NUMBER -1). The value of V(S) is incremented by 1 with each successive I frame transmission, and will not exceed acknowledge state variable V(A) by more than the maximum number of outstanding I frames k. The value of k may be in the range $1 \le k \le$ (MAX SEQUENCE NUMBER/2 -1). V(S) will not be incremented when an I frame is retransmitted.

Acknowledge state variable V(A)

[0079]   In acknowledged operation, each peer originator has an associated acknowledge state variable V(A) when using I frame and supervisory frame commands and responses. V(A) identifies the first I frame in the transmit window, so that V(A) - 1 equals N(S) of the last in-sequence acknowledged I frame. V(A) can take on the value 0 through (MAX SEQUENCE NUMBER -1). The value of V(A) is updated by the valid N(R) values received from its peer. A valid N(R) value is in the range $V(A) \le N(R) \le V(S)$.

Send sequence number N(S)

[0080]   In acknowledged operation, only I frames contain N(S), the send sequence number of transmitted I frames. At the time that an in-sequence I frame is designated for transmission, the value of N(S) is set equal to the value of the send state variable V(S).

Receive state variable V(R)

[0081]   In acknowledged operation, each receiver has an associated receive state variable V(R) when using I frame and supervisory frame commands and responses. V(R) denotes the sequence number of the next in-sequence I frame expected to be received. V(R) can take on the value 0 through (MAX SEQUENCE NUMBER -1). The value of V(R) is incremented by one with the receipt of an error-free, in-sequence I frame whose send sequence number N(S) equals V(R).

Receive sequence number N(R)

[0082]   In acknowledged operation, all I frames and S frames contain N(R), the expected send sequence number of the next in-sequence received I frame. At the time that a frame of the above types is designated for transmission, the value of N(R) is set equal to the value of the receive state variable V(R). N(R) indicates that the receiver transmitting the N(R) has correctly received all I frames numbered up to and including N(R) - 1.

Selective Acknowledgement (SACK) bitmap R(n)

[0083]   In acknowledged operation, all I frames and S frames contain R(n), the SACK bitmap. At the time that a S frame is designated for transmission, the value of each bit R(n) in the bitmap is set to 0 or 1 depending on whether I frame number N(R) + n has been received or not. R(n) = 1 indicates that the receiver transmitting the S frame has correctly received I frame number N(R) + n. R(n) = 0 indicates that the receiver transmitting the S frame has not correctly received I frame number N(R) + n. The SACK bitmap contains (k) bits.

Unacknowledged operation variables and parameters

Unconfirmed send state variable V(U)

[0084]   Each peer entity has an associated unconfirmed send state variable V(U) when using UI frame commands. V(U) denotes the sequence number of the next UI frame to be transmitted. V(U) can take on the value 0 through 7. The value of V(U) is incremented by 1 with each successive UI frame transmission.

Unconfirmed sequence number N(U)

[0085]   Only UI frames contain N(U), the unconfirmed sequence number of transmitted UI frames. At the time that a UI frame is designated for transmission, the value of N(U) is set equal to the value of the unconfirmed send state variable V(U).

Unconfirmed receive state variable V(UR)

[0086]   Each peer entity has an associated unconfirmed receive state variable V(UR) when using UI frame commands. V(UR) denotes the sequence number of the next in-sequence UI frame expected to be received. V(UR) can take on the value 0 through 7.

Other parameters and variables

[0087]   The only other parameter defined for unacknowledged operation is the number of octets (N201) in the information field of the UI frame.

Procedures

Types of RDS procedures

[0088]   The following RDS protocol procedures are defined:
- Establishment of acknowledged transfer;
- Acknowledged information transfer;
- Termination of acknowledged transfer; and
- Unacknowledged information transfer.

Establishment of acknowledged transfer procedure

General

[0089]   The purpose of the establishment of acknowledged transfer procedure is for the originator to establish acknowledged transmission of information with the receiver. All frames other than U and UI frames received during the establishment of acknowledged transfer procedure is ignored.

Establishment of acknowledged transfer procedure initiation

[0090]   Figure 9 depicts an example establishment of acknowledged transfer procedure, in accordance with some embodiments. The originator initiates the establishment of acknowledged transfer procedure when upper layers indicate information is to be transmitted using acknowledged operation. The originator and the receiver identify the source and destination port numbers before initiating establishment of acknowledged transfer procedure.

[0091]   The originator initiates the establishment of acknowledged transfer procedure by transmitting a SET_ACK_MODE command to receiver. When a single application on the originator conducts data transfer with a single application on the receiver, the Source Port and Destination Port numbers need not be used; otherwise the originator sets the Source Port to the port number of the source application on the originator and the Destination Port to the port number of the destination application on the receiver. The originator

clears all exception conditions, discard all queued I frames, reset the retransmission counter and timer T200 is set.

[0092]   If a logical link between the UE and SCEF identified without port numbers exists and the originator needs to initiate establishment of an additional acknowledged transfer procedure, the additional logical link between the UE and SCEF is identified with port numbers while the first logical link can remain without port numbers.

Establishment of acknowledged transfer procedure accepted by receiver

[0093]   Upon receiving a SET_ACK_MODE command, the receiver checks if the Destination Port number contained in the SET_ACK_MODE command corresponds to an application on the receiver.

[0094]   If the check is successful and if the application accepts to enter acknowledged transfer mode, the receiver sends an ACCEPT response to the originator. When a single application on the originator conducts data transfer with a single application on the receiver, the Source Port and Destination Port numbers need not be used; otherwise the receiver sets the Source Port to the port number of the application on the receiver and the Destination Port to the port number of the application on the originator. The receiver resets timer T200 if active, clear all exception conditions and set V(S), V(R) and V(A) to 0.

Establishment of acknowledged transfer procedure completed by originator

[0095]   Upon receipt of the ACCEPT response and if the Destination Port number corresponds to the application which initiated the establishment of acknowledged transfer procedure, the originator enters acknowledged mode transfer. The originator resets timer T200 if active, clear all exception conditions and set V(S), V(R) and V(A) to 0 and the establishment of acknowledged transfer procedure is successfully completed.

Establishment of acknowledged transfer procedure not accepted by receiver

[0096]   Upon receiving a SET_ACK_MODE command if the Destination Port number contained in the SET_ACK_MODE command,

-     is not supported by the receiver; or
-     corresponds to an application that is not able to perform acknowledged transfer mode,

then the receiver sends an ERROR response to the originator.

Acknowledged information transfer procedure

General

[0097]   The purpose of the acknowledged information transfer procedure is for the originator to transfer I frames to receiver and receive acknowledgements for these frames from receiver.

[0098]   The originator stores the history of the transmitted I frames, and remembers the I-frame transmission sequence. The history is used to decide which I frames to retransmit. Due to retransmission, the history is not necessarily an in-order sequence.

[0099]   A frame within the receive window is either:

- received: the frame has been correctly received; or
- not received: the frame has not been correctly received.

[0100]   A frame within the transmit window is either:

- not yet transmitted: the frame has not yet been transmitted;
- transmitted: the frame has been (re-) transmitted, but the originator does not know if the frame has been received by the receiver;
- acknowledged: the frame has been acknowledged by the receiver; or
- marked for retransmission: the originator has decided to retransmit this I frame.

[0101]   I frames is transmitted in ascending N(S) order. When I frames are retransmitted, the frame with the lowest N(S) is retransmitted first. This is used by the receiver to detect lost frames.

Transmitting I frames and requesting acknowledgements

[0102]   Figure 10 depicts an example acknowledged information transfer procedure, in accordance with some embodiments. If the originator has received information to be transmitted from upper layers, the information is inserted in an I frame. The control field parameters N(S) and N(R) is assigned the values V(S) and V(R), respectively. V(S) is incremented by 1 at the end of the transmission of the I frame.

[0103]   The originator requests an acknowledgement from the receiver by transmitting an I or S frame with the A bit set to 1. The originator may request an acknowledgement at any time. An acknowledgement is requested when:

- the last I frame in a sequence of one or more I frames is transmitted; or

- V(S) = V(A) + k as a result of the transmission of the I frame.

[0104]   The originator transmits a frame in the following order of priority:

- If there are any I frames marked for retransmission then the originator increments by 1 the retransmission count variable for the I frame with the lowest send sequence number N(S). If the retransmission count variable exceeds the value of N200, then the originator initiates the Establishment of acknowledged operation procedure as described above. If the retransmission count variable does not exceed the value of N200, then the originator retransmits the I frame.

- If the originator has a new I frame to transmit, if V(S) < V(A) + k (where k is the maximum number of outstanding I frames) then the new I frame is transmitted.

- If the originator has an acknowledgement to transmit then the originator transmits an S frame.

[0105]   When requesting an acknowledgement, the originator sets timer T201 and associate the timer with the I frame currently being transmitted, or, if the A bit is transmitted in an S frame, with the I frame last transmitted.

Receiving I frames and sending acknowledgements

[0106]   When the receiver receives a valid I frame whose N(S) is equal to the current V(R), the receiver:

- passes the contents of the Information field to the appropriate upper layer entity;

- increments its V(R) by 1; and

- responds with a I or S frame containing the SACK bitmap, if the A bit of the received I frame was set to 1.

[0107]   When the receiver receives a valid I frame whose N(S) is not in the range V(R) ≤ N(S) < V(R) + k, the receiver discards the frame as a duplicate.

[0108]   When the receiver receives a valid I frame where V(R) < N(S) < V(R) + k, then the receiver stores the I frame until all frames from V(R) to N(S) - 1 inclusive are correctly received. Once all the frames are correctly received the receiver then:

- passes the contents of the Information field to the appropriate upper layer entity; and
- sets its $V(R) = N(S) + 1$.

[0109] Whenever the receiver detects an error in the sequence of received I frames, it transmits an I or S frame.

[0110] If the receiver receives an I frame with a higher $N(S)$ than the $N(S)$ of the previously received I frame, and if there are I frames missing between these two $N(S)$ values, then the receiver assumes that the missing I frames have been lost. If the receiver receives an I frame with a lower $N(S)$ than the $N(S)$ of the previously received I frame, it can assume that its peer originator has (re-) started retransmission due to the reception of an acknowledgement.

Receiving acknowledgements

[0111] On receipt of a valid I or S frame , the originator, if $N(R)$ is valid, treats the $N(R)$ contained in this frame as an acknowledgement for all the I frames it has transmitted with an $N(S)$ up to and including the received $N(R) - 1$. A valid $N(R)$ value is one that is in the range $V(A) \leq N(R) \leq V(S)$. If $N(R)$ is not valid, then the received SACK bitmap is disregarded.

[0112] $V(A)$ is then set to $N(R)$.

[0113] On receipt of a valid I or S frame containing the SACK bitmap, the originator considers all I frames with the corresponding bit set to 1 in the SACK bitmap as acknowledged.

[0114] If timer T201 is active and associated with an acknowledged I frame, then timer T201 is reset.

[0115] The originator determines which I frames to retransmit by analyzing it's I frame transmission sequence history and the acknowledgements received. An unacknowledged I frame that was transmitted prior to an acknowledged I frame is considered lost and is marked for retransmission. Acknowledged I frames is removed from the I frame transmission sequence history.

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Termination of acknowledged transfer procedure

General

[0116]   The purpose of the termination of acknowledged transfer procedure is to terminate the acknowledged transmission of information between the UE side and the SCEF or P-GW side. All frames other than U and UI frames received during the termination of acknowledged transfer procedure is ignored and all queued I frames is discarded.

Termination of acknowledged transfer procedure initiation

[0117]   Figure 11 depicts an example termination of acknowledged transfer procedure, in accordance with some embodiments. The originator or receiver initiates the termination of acknowledged transfer procedure when upper layers indicate termination of acknowledged operation.

[0118]   The originator initiates the termination of acknowledged transfer procedure by transmitting a DISCONNECT command. When a single application on the originator conducts data transfer with a single application on the receiver, the Source Port and Destination Port numbers need not be used; otherwise the originator sets the Source Port to the port number of the source application on the originator and the Destination Port to the port number of the destination application on the receiver. The originator resets the retransmission counter and timer T200 is set.

Termination of acknowledged transfer procedure accepted by receiver

[0119]   Upon receiving a DISCONNECT command, the receiver checks if the Destination Port number contained in the DISCONNECT command corresponds to an application on the receiver.

[0120]   If the check is successful the receiver sends an ACCEPT response to the originator. When a single application on the originator conducts data transfer with a single application on the receiver, the Source Port and Destination Port numbers need not be used; otherwise the receiver sets the Source Port to the port number of the application on the receiver and the Destination Port to the port number of the application on the originator.

Termination of acknowledged transfer procedure completed by originator

[0121]   Upon receipt of the ACCEPT response and if the Destination Port number corresponds to the application which initiated the termination of acknowledged transfer procedure, the originator terminates acknowledged transfer mode. The originator resets timer T200 if active, and the termination of acknowledged transfer procedure is successfully completed.

Termination of acknowledged transfer procedure not accepted by receiver

[0122]   Upon receiving a DISCONNECT command if the Destination Port number contained in the DISCONNECT command

- is not supported by the receiver; or

- corresponds to an application that is not in acknowledged transfer mode, then the receiver sends an ERROR response to the originator.

Unacknowledged information transfer procedure

General

[0123]   The purpose of the unacknowledged information transfer procedure is for the originator to perform unacknowledged transmission of information to the receiver. No error recovery mechanisms are defined for unacknowledged operation.

Unacknowledged information transfer procedure initiation

[0124]   Figure 12 depicts an example unacknowledged information transfer procedure, in accordance with some embodiments. The originator initiates the unacknowledged information transfer procedure when information from upper layers is to be transmitted using unacknowledged operation. The originator and the receiver negotiate the use of source and destination port numbers before initiating unacknowledged information transfer.

[0125]   The originator initiates the unacknowledged information transfer procedure by transmitting a UI frame to receiver. When a single application on the originator conducts data transfer with a single application on the receiver, the Source Port and Destination Port numbers need not be used; otherwise the originator sets the Source Port to the port number of the source application on the originator and the Destination Port to the port

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number of the destination application on the receiver. The originator sets the unconfirmed sequence number N(U) in UI frame to the value of unconfirmed send state variable V(U).

Unacknowledged information transfer procedure accepted by receiver

[0126]   Upon receiving a UI frame the receiver passes the contents of the Information field to the appropriate upper layer corresponding to the Destination Port. The receiver sets the unconfirmed receive state variable V(UR) to N(U) + 1.

Unacknowledged information transfer procedure completed by originator

[0127]   Upon transmission of the UI frame the unacknowledged information transfer procedure is completed by the originator.

Unacknowledged information transfer procedure not accepted by receiver

[0128]   Upon receiving a UI frame,

- if the Destination Port number is not in use by the receiver; or
- if N(U) of the received UI frame is in the range (V(UR) –

  k') $\leq$ N(U) < V(UR) and if a UI frame with the same N(U) has already been
  received,

then the UI frame is discarded by the receiver without any further action. The value of k' may be in the range 1 < k' < MAX SEQUENCE NUMBER/2.

Abnormal cases

Expiry of timer T200

[0129]   Timer T200 is set when a U frame with any of the following commands is transmitted.

- SET_ACK_MODE;
- DISCONNECT; and
- SET_PARAMETERS.

[0130]   If timer T200 expires before a response to the sent command is received then the originator retransmits the command, and resets and start timer T200 and increment the retransmission counter. After retransmission of the command N200 times, the originator aborts the operation and notify the upper layers.

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Expiry of timer T201

[0131]   On expiry of timer T201, the originator increments by 1 the retransmission count variable for the I frame associated with timer T201. If the value of the retransmission count variable does not exceed N200, the originator resets and start timer T201, and retransmit the I frame with the A bit set to 1. If the value of the retransmission count variable exceeds N200, the originator sends the ERROR command to the receiver and initiate the establishment of acknowledged transfer procedure to re-establish the acknowledged transfer mode with the receiver.

List of RDS Parameters

[0132]   The following parameters are applicable for Reliable Data Service (RDS).

[0133]   RDS version number (Version): The RDS version number (Version) is an RDS layer parameter. The default version number is 0.

[0134]   Retransmission timers (T200 and T201) : The default value of timers T200 and T201 is 250 seconds.

[0135]   Maximum number of retransmissions (N200): The default value of N200 is 3.

[0136]   Maximum number of outstanding I frames (k): k is the maximum number of sequentially-numbered I frames that may be outstanding (i.e. unacknowledged) at any given time. k is also denoted as window size. The default value of k is 3. The value of MAX SEQUENCE NUMBER is 8.

[0137]   Maximum length of Information Field (N201): The default value of N201 is 1520 octets.

Systems and Implementations

[0138]   Figure 13 illustrates an example architecture of a system 1300 of a network, in accordance with various embodiments. The following description is provided for an example system 1300 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.

[0139]   As shown by Figure 13, the system 1300 includes UE 1301a and UE 1301b
(collectively referred to as "UEs 1301" or "UE 1301"). In this example, UEs 1301 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.

[0140]   In some embodiments, any of the UEs 1301 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.

[0141]   The UEs 1301 may be configured to connect, for example, communicatively
couple, with an or RAN 1310. In embodiments, the RAN 1310 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 1310 that operates in an NR
or 5G system 1300, and the term "E-UTRAN" or the like may refer to a RAN 1310 that
operates in an LTE or 4G system 1300. The UEs 1301 utilize connections (or channels)
1303 and 1304, respectively, each of which comprises a physical communications
interface or layer (discussed in further detail below).

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[0142]   In this example, the connections 1303 and 1304 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 1301 may directly exchange communication data via a ProSe interface 1305. The ProSe interface 1305 may alternatively be referred to as a SL interface 1305 and may comprise one or more logical channels, including but not limited to a PSCCH, a PSSCH, a PSDCH, and a PSBCH.

[0143]   The UE 1301b is shown to be configured to access an AP 1306 (also referred to as "WLAN node 1306," "WLAN 1306," "WLAN Termination 1306," "WT 1306" or the like) via connection 1307. The connection 1307 can comprise a local wireless connection, such as a connection consistent with any IEEE 802.11 protocol, wherein the AP 1306 would comprise a wireless fidelity (Wi-Fi®) router. In this example, the AP 1306 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 1301b, RAN 1310, and AP 1306 may be configured to utilize LWA operation and/or LWIP operation. The LWA operation may involve the UE 1301b in RRC_CONNECTED being configured by a RAN node 1311a-b to utilize radio resources of LTE and WLAN. LWIP operation may involve the UE 1301b using WLAN radio resources (e.g., connection 1307) via IPsec protocol tunneling to authenticate and encrypt packets (e.g., IP packets) sent over the connection 1307. 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.

[0144]   The RAN 1310 can include one or more AN nodes or RAN nodes 1311a and 1311b (collectively referred to as "RAN nodes 1311" or "RAN node 1311") that enable the connections 1303 and 1304. 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

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term "NG RAN node" or the like may refer to a RAN node 1311 that operates in an NR or 5G system 1300 (for example, a gNB), and the term "E-UTRAN node" or the like may refer to a RAN node 1311 that operates in an LTE or 4G system 1300 (e.g., an eNB). According to various embodiments, the RAN nodes 1311 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.

[0145]   In some embodiments, all or parts of the RAN nodes 1311 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 1311; 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 1311; 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 1311. This virtualized framework allows the freed-up processor cores of the RAN nodes 1311 to perform other virtualized applications. In some implementations, an individual RAN node 1311 may represent individual gNB-DUs that are connected to a gNB-CU via individual F1 interfaces (not shown by Figure 13). In these implementations, the gNB-DUs may include one or more remote radio heads or RFEMs (see, e.g., Figure 16), and the gNB-CU may be operated by a server that is located in the RAN 1310 (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 1311 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 1301, and are connected to a 5GC (e.g., CN 1520 of Figure 15) via an NG interface (discussed infra).

[0146]   In V2X scenarios one or more of the RAN nodes 1311 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 1301 (vUEs 1301). 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.

[0147]   Any of the RAN nodes 1311 can terminate the air interface protocol and can be the first point of contact for the UEs 1301. In some embodiments, any of the RAN nodes 1311 can fulfill various logical functions for the RAN 1310 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.

[0148]   In embodiments, the UEs 1301 can be configured to communicate using OFDM communication signals with each other or with any of the RAN nodes 1311 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.

[0149]   In some embodiments, a downlink resource grid can be used for downlink transmissions from any of the RAN nodes 1311 to the UEs 1301, 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.

[0150]   According to various embodiments, the UEs 1301 and the RAN nodes 1311 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.

[0151]   To operate in the unlicensed spectrum, the UEs 1301 and the RAN nodes 1311 may operate using LAA, eLAA, and/or feLAA mechanisms. In these implementations, the UEs 1301 and the RAN nodes 1311 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.

[0152]   LBT is a mechanism whereby equipment (for example, UEs 1301, RAN nodes
1311, 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.

[0153]   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
1301, AP 1306, or the like) intends to transmit, the WLAN node may first perform CCA
before transmission. Additionally, a backoff mechanism is used to avoid collisions in
situations where more than one WLAN node senses the channel as idle and transmits at
the same time. The backoff mechanism may be a counter that is drawn randomly within
the CWS, which is increased exponentially upon the occurrence of collision and reset to a
minimum value when the transmission succeeds. The LBT mechanism designed for LAA
is somewhat similar to the CSMA/CA of WLAN. In some implementations, the LBT
procedure for DL or UL transmission bursts including PDSCH or PUSCH transmissions,
respectively, may have an LAA contention window that is variable in length between X
and Y ECCA slots, where X and Y are minimum and maximum values for the CWSs for
LAA. In one example, the minimum CWS for an LAA transmission may be 9
microseconds (μs); however, the size of the CWS and a MCOT (for example, a
transmission burst) may be based on governmental regulatory requirements.

[0154]   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.

[0155]   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 1301 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.

[0156]   The PDSCH carries user data and higher-layer signaling to the UEs 1301. 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 1301 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 1301b within a cell) may be performed at any of the RAN nodes 1311 based on channel quality information fed back from any of the UEs 1301. The downlink resource assignment information may be sent on the PDCCH used for (e.g., assigned to) each of the UEs 1301.

[0157]   The PDCCH uses CCEs to convey the control information. Before being mapped to resource elements, the PDCCH complex-valued symbols may first be organized into quadruplets, which may then be permuted using a sub-block interleaver for rate matching. Each PDCCH may be transmitted using one or more of these CCEs, where each CCE may correspond to nine sets of four physical resource elements known as REGs. Four Quadrature Phase Shift Keying (QPSK) symbols may be mapped to each REG. The PDCCH can be transmitted using one or more CCEs, depending on the size of the DCI and the channel condition. There can be four or more different PDCCH formats defined in LTE with different numbers of CCEs (e.g., aggregation level, L=1, 2, 4, or 8).

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[0158]   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.

[0159]   The RAN nodes 1311 may be configured to communicate with one another via interface 1312. In embodiments where the system 1300 is an LTE system (e.g., when CN 1320 is an EPC 1420 as in Figure 14), the interface 1312 may be an X2 interface 1312. The X2 interface may be defined between two or more RAN nodes 1311 (e.g., two or more eNBs and the like) that connect to EPC 1320, and/or between two eNBs connecting to EPC 1320. 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 1301 from an SeNB for user data; information of PDCP PDUs that were not delivered to a UE 1301; 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.

[0160]   In embodiments where the system 1300 is a 5G or NR system (e.g., when CN 1320 is an 5GC 1520 as in Figure 15), the interface 1312 may be an Xn interface 1312. The Xn interface is defined between two or more RAN nodes 1311 (e.g., two or more gNBs and the like) that connect to 5GC 1320, between a RAN node 1311 (e.g., a gNB) connecting to 5GC 1320 and an eNB, and/or between two eNBs connecting to 5GC 1320. 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

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control functionality. The Xn-C may provide management and error handling functionality, functionality to manage the Xn-C interface; mobility support for UE 1301 in a connected mode (e.g., CM-CONNECTED) including functionality to manage the UE mobility for connected mode between one or more RAN nodes 1311. The mobility support may include context transfer from an old (source) serving RAN node 1311 to new (target) serving RAN node 1311; and control of user plane tunnels between old (source) serving RAN node 1311 to new (target) serving RAN node 1311. 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.

[0161]   The RAN 1310 is shown to be communicatively coupled to a core network—in this embodiment, core network (CN) 1320. The CN 1320 may comprise a plurality of network elements 1322, which are configured to offer various data and telecommunications services to customers/subscribers (e.g., users of UEs 1301) who are connected to the CN 1320 via the RAN 1310. The components of the CN 1320 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 1320 may be referred to as a network slice, and a logical instantiation of a portion of the CN 1320 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.

[0162]   Generally, the application server 1330 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 1330 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 1301 via the EPC 1320.

[0163]   In embodiments, the CN 1320 may be a 5GC (referred to as "5GC 1320" or the like), and the RAN 1310 may be connected with the CN 1320 via an NG interface 1313. In embodiments, the NG interface 1313 may be split into two parts, an NG user plane (NG-U) interface 1314, which carries traffic data between the RAN nodes 1311 and a UPF, and the S1 control plane (NG-C) interface 1315, which is a signaling interface between the RAN nodes 1311 and AMFs. Embodiments where the CN 1320 is a 5GC 1320 are discussed in more detail with regard to Figure 15.

[0164]   In embodiments, the CN 1320 may be a 5G CN (referred to as "5GC 1320" or the like), while in other embodiments, the CN 1320 may be an EPC). Where CN 1320 is an EPC (referred to as "EPC 1320" or the like), the RAN 1310 may be connected with the CN 1320 via an S1 interface 1313. In embodiments, the S1 interface 1313 may be split into two parts, an S1 user plane (S1-U) interface 1314, which carries traffic data between the RAN nodes 1311 and the S-GW, and the S1-MME interface 1315, which is a signaling interface between the RAN nodes 1311 and MMEs. An example architecture wherein the CN 1320 is an EPC 1320 is shown by Figure 14.

[0165]   Figure 14 illustrates an example architecture of a system 1400 including a first CN 1420, in accordance with various embodiments. In this example, system 1400 may implement the LTE standard wherein the CN 1420 is an EPC 1420 that corresponds with CN 1320 of Figure 13. Additionally, the UE 1401 may be the same or similar as the UEs 1301 of Figure 13, and the E-UTRAN 1410 may be a RAN that is the same or similar to the RAN 1310 of Figure 13, and which may include RAN nodes 1311 discussed previously. The CN 1420 may comprise MMEs 1421, an S-GW 1422, a P-GW 1423, a HSS 1424, and a SGSN 1425.

[0166]   The MMEs 1421 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 1401.

The MMEs 1421 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 1401, provide user identity confidentiality, and/or perform other like services to users/subscribers. Each UE 1401 and the MME 1421 may include an MM or EMM sublayer, and an MM context may be established in the UE 1401 and the MME 1421 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 1401. The MMEs 1421 may be coupled with the HSS 1424 via an S6a reference point, coupled with the SGSN 1425 via an S3 reference point, and coupled with the S-GW 1422 via an S11 reference point.

[0167]   The SGSN 1425 may be a node that serves the UE 1401 by tracking the location of an individual UE 1401 and performing security functions. In addition, the SGSN 1425 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 1421; handling of UE 1401 time zone functions as specified by the MMEs 1421; and MME selection for handovers to E-UTRAN 3GPP access network. The S3 reference point between the MMEs 1421 and the SGSN 1425 may enable user and bearer information exchange for inter-3GPP access network mobility in idle and/or active states.

[0168]   The HSS 1424 may comprise a database for network users, including subscription-related information to support the network entities' handling of communication sessions. The EPC 1420 may comprise one or several HSSs 1424, depending on the number of mobile subscribers, on the capacity of the equipment, on the organization of the network, etc. For example, the HSS 1424 can provide support for routing/roaming, authentication, authorization, naming/addressing resolution, location dependencies, etc. An S6a reference point between the HSS 1424 and the MMEs 1421 may enable transfer of subscription and authentication data for authenticating/authorizing user access to the EPC 1420 between HSS 1424 and the MMEs 1421.

[0169]   The S-GW 1422 may terminate the S1 interface 1313 ("S1-U" in Figure 14) toward the RAN 1410, and routes data packets between the RAN 1410 and the EPC 1420. In addition, the S-GW 1422 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 1422 and the MMEs 1421 may provide a control plane between the MMEs 1421 and the S-GW 1422. The S-GW 1422 may be coupled with the P-GW 1423 via an S5 reference point.

[0170]   The P-GW 1423 may terminate an SGi interface toward a PDN 1430. The P-GW 1423 may route data packets between the EPC 1420 and external networks such as a network including the application server 1330 (alternatively referred to as an "AF") via an IP interface 1325 (see e.g., Figure 13). In embodiments, the P-GW 1423 may be communicatively coupled to an application server (application server 1330 of Figure 13 or PDN 1430 in Figure 14) via an IP communications interface 1325 (see, e.g., Figure 13). The S5 reference point between the P-GW 1423 and the S-GW 1422 may provide user plane tunneling and tunnel management between the P-GW 1423 and the S-GW 1422. The S5 reference point may also be used for S-GW 1422 relocation due to UE 1401 mobility and if the S-GW 1422 needs to connect to a non-collocated P-GW 1423 for the required PDN connectivity. The P-GW 1423 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 1423 and the packet data network (PDN) 1430 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 1423 may be coupled with a PCRF 1426 via a Gx reference point.

[0171]   PCRF 1426 is the policy and charging control element of the EPC 1420. In a non-roaming scenario, there may be a single PCRF 1426 in the Home Public Land Mobile Network (HPLMN) associated with a UE 1401'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 1401'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 1426 may be communicatively coupled to the application server 1430 via the P-GW 1423. The application server 1430 may signal the PCRF 1426 to indicate a new service flow and select the appropriate QoS and charging parameters. The PCRF 1426 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 1430. The Gx reference point between the PCRF 1426 and the P-GW
1423 may allow for the transfer of QoS policy and charging rules from the PCRF 1426 to
PCEF in the P-GW 1423. An Rx reference point may reside between the PDN 1430 (or
"AF 1430") and the PCRF 1426.

[0172]   Figure 15 illustrates an architecture of a system 1500 including a second CN 1520
in accordance with various embodiments. The system 1500 is shown to include a UE
1501, which may be the same or similar to the UEs 1301 and UE 1401 discussed
previously; a (R)AN 1510, which may be the same or similar to the RAN 1310 and RAN
1410 discussed previously, and which may include RAN nodes 1311 discussed
previously; and a DN 1503, which may be, for example, operator services, Internet access
or 3rd party services; and a 5GC 1520. The 5GC 1520 may include an AUSF 1522; an
AMF 1521; a SMF 1524; a NEF 1523; a PCF 1526; a NRF 1525; a UDM 1527; an AF
1528; a UPF 1502; and a NSSF 1529.

[0173]   The UPF 1502 may act as an anchor point for intra-RAT and inter-RAT mobility,
an external PDU session point of interconnect to DN 1503, and a branching point to
support multi-homed PDU session. The UPF 1502 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 1502 may include an uplink classifier to
support routing traffic flows to a data network. The DN 1503 may represent various
network operator services, Internet access, or third party services. DN 1503 may include,
or be similar to, application server 1330 discussed previously. The UPF 1502 may
interact with the SMF 1524 via an N4 reference point between the SMF 1524 and the
UPF 1502.

[0174]   The AUSF 1522 may store data for authentication of UE 1501 and handle
authentication-related functionality. The AUSF 1522 may facilitate a common
authentication framework for various access types. The AUSF 1522 may communicate
with the AMF 1521 via an N12 reference point between the AMF 1521 and the AUSF
1522; and may communicate with the UDM 1527 via an N13 reference point between the

UDM 1527 and the AUSF 1522. Additionally, the AUSF 1522 may exhibit an Nausf service-based interface.

[0175]   The AMF 1521 may be responsible for registration management (e.g., for registering UE 1501, etc.), connection management, reachability management, mobility management, and lawful interception of AMF-related events, and access authentication and authorization. The AMF 1521 may be a termination point for the an N11 reference point between the AMF 1521 and the SMF 1524. The AMF 1521 may provide transport for SM messages between the UE 1501 and the SMF 1524, and act as a transparent pro21 for routing SM messages. AMF 1521 may also provide transport for SMS messages between UE 1501 and an SMSF (not shown by Figure 15). AMF 1521 may act as SEAF, which may include interaction with the AUSF 1522 and the UE 1501, receipt of an intermediate key that was established as a result of the UE 1501 authentication process. Where USIM based authentication is used, the AMF 1521 may retrieve the security material from the AUSF 1522. AMF 1521 may also include a SCM function, which receives a key from the SEA that it uses to derive access-network specific keys. Furthermore, AMF 1521 may be a termination point of a RAN CP interface, which may include or be an N2 reference point between the (R)AN 1510 and the AMF 1521; and the AMF 1521 may be a termination point of NAS (N1) signalling, and perform NAS ciphering and integrity protection.

[0176]   AMF 1521 may also support NAS signalling with a UE 1501 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 1510 and the AMF 1521 for the control plane, and may be a termination point for the N3 reference point between the (R)AN 1510 and the UPF 1502 for the user plane. As such, the AMF 1521 may handle N2 signalling from the SMF 1524 and the AMF 1521 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 1501 and AMF 1521 via an N1 reference point between the UE 1501 and the AMF 1521, and relay uplink and downlink user-plane packets between the UE 1501 and UPF 1502. The N3IWF also provides mechanisms for IPsec tunnel establishment with the UE 1501. The

AMF 1521 may exhibit an Namf service-based interface, and may be a termination point for an N14 reference point between two AMFs 1521 and an N17 reference point between the AMF 1521 and a 5G-EIR (not shown by Figure 15).

[0177]   The UE 1501 may need to register with the AMF 1521 in order to receive network services. RM is used to register or deregister the UE 1501 with the network (e.g., AMF 1521), and establish a UE context in the network (e.g., AMF 1521). The UE 1501 may operate in an RM-REGISTERED state or an RM-DEREGISTERED state. In the RM-DEREGISTERED state, the UE 1501 is not registered with the network, and the UE context in AMF 1521 holds no valid location or routing information for the UE 1501 so the UE 1501 is not reachable by the AMF 1521. In the RM-REGISTERED state, the UE 1501 is registered with the network, and the UE context in AMF 1521 may hold a valid location or routing information for the UE 1501 so the UE 1501 is reachable by the AMF 1521. In the RM-REGISTERED state, the UE 1501 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 1501 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.

[0178]   The AMF 1521 may store one or more RM contexts for the UE 1501, 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 1521 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 1521 may store a CE mode B Restriction parameter of the UE 1501 in an associated MM context or RM context. The AMF 1521 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).

[0179]   CM may be used to establish and release a signaling connection between the UE 1501 and the AMF 1521 over the N1 interface. The signaling connection is used to enable NAS signaling exchange between the UE 1501 and the CN 1520, 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 1501 between the AN (e.g., RAN 1510) and the AMF 1521. The UE 1501 may operate in one of two CM states,

CM-IDLE mode or CM-CONNECTED mode. When the UE 1501 is operating in the
CM-IDLE state/mode, the UE 1501 may have no NAS signaling connection established
with the AMF 1521 over the N1 interface, and there may be (R)AN 1510 signaling
connection (e.g., N2 and/or N3 connections) for the UE 1501. When the UE 1501 is
operating in the CM-CONNECTED state/mode, the UE 1501 may have an established
NAS signaling connection with the AMF 1521 over the N1 interface, and there may be a
(R)AN 1510 signaling connection (e.g., N2 and/or N3 connections) for the UE 1501.
Establishment of an N2 connection between the (R)AN 1510 and the AMF 1521 may
cause the UE 1501 to transition from CM-IDLE mode to CM-CONNECTED mode, and
the UE 1501 may transition from the CM-CONNECTED mode to the CM-IDLE mode
when N2 signaling between the (R)AN 1510 and the AMF 1521 is released.

[0180]   The SMF 1524 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 1501 and a data network (DN) 1503 identified by a Data Network Name
(DNN). PDU sessions may be established upon UE 1501 request, modified upon UE
1501 and 5GC 1520 request, and released upon UE 1501 and 5GC 1520 request using
NAS SM signaling exchanged over the N1 reference point between the UE 1501 and the
SMF 1524. Upon request from an application server, the 5GC 1520 may trigger a specific
application in the UE 1501. In response to receipt of the trigger message, the UE 1501
may pass the trigger message (or relevant parts/information of the trigger message) to one
or more identified applications in the UE 1501. The identified application(s) in the UE
1501 may establish a PDU session to a specific DNN. The SMF 1524 may check whether
the UE 1501 requests are compliant with user subscription information associated with

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the UE 1501. In this regard, the SMF 1524 may retrieve and/or request to receive update notifications on SMF 1524 level subscription data from the UDM 1527.

[0181]   The SMF 1524 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 1524 may be included in the system 1500, which may be between another SMF 1524 in a visited network and the SMF 1524 in the home network in roaming scenarios. Additionally, the SMF 1524 may exhibit the Nsmf service-based interface.

[0182]   The NEF 1523 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 1528), edge computing or fog computing systems, etc. In such embodiments, the NEF 1523 may authenticate, authorize, and/or throttle the AFs. NEF 1523 may also translate information exchanged with the AF 1528 and information exchanged with internal network functions. For example, the NEF 1523 may translate between an AF-Service-Identifier and an internal 5GC information. NEF 1523 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 1523 as structured data, or at a data storage NF using standardized interfaces. The stored information can then be re-exposed by the NEF 1523 to other NFs and AFs, and/or used for other purposes such as analytics. Additionally, the NEF 1523 may exhibit an Nnef service-based interface.

[0183]   The NRF 1525 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 1525 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 1525 may exhibit the Nnrf service-based interface.

[0184]   The PCF 1526 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 1526 may also implement an FE to access subscription information relevant for policy decisions in a UDR of the UDM 1527. The PCF 1526 may communicate with the AMF 1521 via an N15 reference point between the PCF 1526 and the AMF 1521, which may include a PCF 1526 in a visited network and the AMF 1521 in case of roaming scenarios. The PCF 1526 may communicate with the AF 1528 via an N5 reference point between the PCF 1526 and the AF 1528; and with the SMF 1524 via an N7 reference point between the PCF 1526 and the SMF 1524. The system 1500 and/or CN 1520 may also include an N24 reference point between the PCF 1526 (in the home network) and a PCF 1526 in a visited network. Additionally, the PCF 1526 may exhibit an Npcf service-based interface.

[0185]   The UDM 1527 may handle subscription-related information to support the network entities' handling of communication sessions, and may store subscription data of UE 1501. For example, subscription data may be communicated between the UDM 1527 and the AMF 1521 via an N8 reference point between the UDM 1527 and the AMF. The UDM 1527 may include two parts, an application FE and a UDR (the FE and UDR are not shown by Figure 15). The UDR may store subscription data and policy data for the UDM 1527 and the PCF 1526, and/or structured data for exposure and application data (including PFDs for application detection, application request information for multiple UEs 1501) for the NEF 1523. The Nudr service-based interface may be exhibited by the UDR 221 to allow the UDM 1527, PCF 1526, and NEF 1523 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 1524 via an N10 reference point between the UDM 1527 and the SMF 1524. UDM 1527 may also support SMS management, wherein an SMS-FE implements the similar application logic as discussed previously. Additionally, the UDM 1527 may exhibit the Nudm service-based interface.

[0186]   The AF 1528 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 1520 and AF 1528 to provide information to each other via NEF 1523, 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 1501 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 1502 close to the UE 1501 and execute traffic steering from the UPF 1502 to DN 1503 via the N6 interface. This may be based on the UE subscription data, UE location, and information provided by the AF 1528. In this way, the AF 1528 may influence UPF (re)selection and traffic routing. Based on operator deployment, when AF 1528 is considered to be a trusted entity, the network operator may permit AF 1528 to interact directly with relevant NFs. Additionally, the AF 1528 may exhibit an Naf service-based interface.

[0187]   The NSSF 1529 may select a set of network slice instances serving the UE 1501. The NSSF 1529 may also determine allowed NSSAI and the mapping to the subscribed S-NSSAIs, if needed. The NSSF 1529 may also determine the AMF set to be used to serve the UE 1501, or a list of candidate AMF(s) 1521 based on a suitable configuration and possibly by querying the NRF 1525. The selection of a set of network slice instances for the UE 1501 may be triggered by the AMF 1521 with which the UE 1501 is registered by interacting with the NSSF 1529, which may lead to a change of AMF 1521. The NSSF 1529 may interact with the AMF 1521 via an N22 reference point between AMF 1521 and NSSF 1529; and may communicate with another NSSF 1529 in a visited network via an N31 reference point (not shown by Figure 15). Additionally, the NSSF 1529 may exhibit an Nnssf service-based interface.

[0188]   As discussed previously, the CN 1520 may include an SMSF, which may be responsible for SMS subscription checking and verification, and relaying SM messages to/from the UE 1501 to/from other entities, such as an SMS-GMSC/IWMSC/SMS-router. The SMS may also interact with AMF 1521 and UDM 1527 for a notification procedure that the UE 1501 is available for SMS transfer (e.g., set a UE not reachable flag, and notifying UDM 1527 when UE 1501 is available for SMS).

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[0189]   The CN 120 may also include other elements that are not shown by Figure 15, 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 15). 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 15). 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 pro21 that performs topology hiding, message filtering, and policing on inter-PLMN control plane interfaces.

[0190]   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 15 for clarity. In one example, the CN 1520 may include an Nx interface, which is an inter-CN interface between the MME (e.g., MME 1421) and the AMF 1521 in order to enable interworking between CN 1520 and CN 1420. 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.

[0191]   Figure 16 illustrates an example of infrastructure equipment 1600 in accordance with various embodiments. The infrastructure equipment 1600 (or "system 1600") may be implemented as a base station, radio head, RAN node such as the RAN nodes 1311 and/or AP 1306 shown and described previously, application server(s) 1330, and/or any other element/device discussed herein. In other examples, the system 1600 could be implemented in or by a UE.

[0192]   The system 1600 includes application circuitry 1605, baseband circuitry 1610, one or more radio front end modules (RFEMs) 1615, memory circuitry 1620, power management integrated circuitry (PMIC) 1625, power tee circuitry 1630, network controller circuitry 1635, network interface connector 1640, satellite positioning circuitry 1645, and user interface 1650. In some embodiments, the device 1600 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.

[0193]   Application circuitry 1605 includes circuitry such as, but not limited to one or more processors (or processor cores), cache memory, and one or more of low drop-out voltage regulators (LDOs), interrupt controllers, serial interfaces such as SPI, I^2C or universal programmable serial interface module, real time clock (RTC), timer-counters including interval and watchdog timers, general purpose input/output (I/O or IO), memory card controllers such as Secure Digital (SD) MultiMediaCard (MMC) or similar, Universal Serial Bus (USB) interfaces, Mobile Industry Processor Interface (MIPI) interfaces and Joint Test Access Group (JTAG) test access ports. The processors (or cores) of the application circuitry 1605 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 1600. 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.

[0194]   The processor(s) of application circuitry 1605 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 1605 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 1605 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

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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 1600 may not utilize application circuitry 1605, and instead may include a special-purpose processor/controller to process IP data received from an EPC or 5GC, for example.

[0195]   In some implementations, the application circuitry 1605 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 1605 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 1605 may include memory cells (e.g., erasable programmable read-only memory (EPROM), electrically erasable programmable read-only memory (EEPROM), flash memory, static memory (e.g., static random access memory (SRAM), anti-fuses, etc.)) used to store logic blocks, logic fabric, data, etc. in look-up-tables (LUTs) and the like.

[0196]   The baseband circuitry 1610 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 1610 are discussed infra with regard to Figure 18.

[0197]   User interface circuitry 1650 may include one or more user interfaces designed to enable user interaction with the system 1600 or peripheral component interfaces designed to enable peripheral component interaction with the system 1600. 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

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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.

[0198]   The radio front end modules (RFEMs) 1615 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 1811 of Figure 18 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 1615, which incorporates both mmWave antennas and sub-mmWave.

[0199]   The memory circuitry 1620 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 1620 may be implemented as one or more of solder down packaged integrated circuits, socketed memory modules and plug-in memory cards.

[0200]   The PMIC 1625 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 1630 may provide for electrical power drawn from a network cable to provide both power supply and data connectivity to the infrastructure equipment 1600 using a single cable.

[0201]   The network controller circuitry 1635 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 1600 via network interface connector 1640 using a physical connection, which may be electrical

(commonly referred to as a "copper interconnect"), optical, or wireless. The network controller circuitry 1635 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 1635 may include multiple controllers to provide connectivity to other networks using the same or different protocols.

[0202]   The positioning circuitry 1645 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 1645 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 1645 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 1645 may also be part of, or interact with, the baseband circuitry 1610 and/or RFEMs 1615 to communicate with the nodes and components of the positioning network. The positioning circuitry 1645 may also provide position data and/or time data to the application circuitry 1605, which may use the data to synchronize operations with various infrastructure (e.g., RAN nodes 1311, etc.), or the like.

[0203]   The components shown by Figure 16 may communicate with one another using interface circuitry, which may include any number of bus and/or interconnect (IX) technologies such as industry standard architecture (ISA), extended ISA (EISA), peripheral component interconnect (PCI), peripheral component interconnect extended (PCIx), PCI express (PCIe), or any number of other technologies. The bus/IX may be a proprietary bus, for example, used in a SoC based system. Other bus/IX systems may be

included, such as an I²C interface, an SPI interface, point to point interfaces, and a power bus, among others.

[0204]   Figure 17 illustrates an example of a platform 1700 (or "device 1700") in accordance with various embodiments. In embodiments, the computer platform 1700 may be suitable for use as UEs 1301, 1401, 1502, application servers 1330, and/or any other element/device discussed herein. The platform 1700 may include any combinations of the components shown in the example. The components of platform 1700 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 1700, or as components otherwise incorporated within a chassis of a larger system. The block diagram of Figure 17 is intended to show a high level view of components of the computer platform 1700. 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.

[0205]   Application circuitry 1705 includes circuitry such as, but not limited to one or more processors (or processor cores), cache memory, and one or more of LDOs, interrupt controllers, serial interfaces such as SPI, I²C or universal programmable serial interface module, RTC, timer-counters including interval and watchdog timers, general purpose I/O, memory card controllers such as SD MMC or similar, USB interfaces, MIPI interfaces, and JTAG test access ports. The processors (or cores) of the application circuitry 1705 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 1700. 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.

[0206]   The processor(s) of application circuitry 1605 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 1605 may comprise, or may be, a special-purpose processor/controller to operate according to the various embodiments herein.

[0207]   As examples, the processor(s) of application circuitry 1705 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 1705 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 1705 may be a part of a system on a chip (SoC) in which the application circuitry 1705 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.

[0208]   Additionally or alternatively, application circuitry 1705 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 1705 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 1705 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.

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[0209]   The baseband circuitry 1710 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 1710 are discussed infra with regard to Figure 18.

[0210]   The RFEMs 1715 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 1811 of Figure 18 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 1715, which incorporates both mmWave antennas and sub-mmWave.

[0211]   The memory circuitry 1720 may include any number and type of memory devices used to provide for a given amount of system memory. As examples, the memory circuitry 1720 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 1720 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 1720 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 1720 may be on-die memory or registers associated with the application circuitry 1705. To provide for persistent storage of information such as data, applications, operating systems and so forth, memory circuitry 1720 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,

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holographic memories, or chemical memories, among others. For example, the computer platform 1700 may incorporate the three-dimensional (3D) cross-point (XPOINT) memories from Intel® and Micron®.

[0212]   Removable memory circuitry 1723 may include devices, circuitry, enclosures/housings, ports or receptacles, etc. used to couple portable data storage devices with the platform 1700. 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.

[0213]   The platform 1700 may also include interface circuitry (not shown) that is used to connect external devices with the platform 1700. The external devices connected to the platform 1700 via the interface circuitry include sensor circuitry 1721 and electro-mechanical components (EMCs) 1722, as well as removable memory devices coupled to removable memory circuitry 1723.

[0214]   The sensor circuitry 1721 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.

[0215]   EMCs 1722 include devices, modules, or subsystems whose purpose is to enable platform 1700 to change its state, position, and/or orientation, or move or control a mechanism or (sub)system. Additionally, EMCs 1722 may be configured to generate and send messages/signalling to other components of the platform 1700 to indicate a current state of the EMCs 1722. Examples of the EMCs 1722 include one or more power switches, relays including electromechanical relays (EMRs) and/or solid state relays

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(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 1700 is configured to operate one or more EMCs 1722 based on one or more captured events and/or instructions or control signals received from a service provider and/or various clients.

[0216]   In some implementations, the interface circuitry may connect the platform 1700 with positioning circuitry 1745. The positioning circuitry 1745 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 1745 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 1745 may include a Micro-PNT IC that uses a master timing clock to perform position tracking/estimation without GNSS assistance. The positioning circuitry 1745 may also be part of, or interact with, the baseband circuitry 1610 and/or RFEMs 1715 to communicate with the nodes and components of the positioning network. The positioning circuitry 1745 may also provide position data and/or time data to the application circuitry 1705, 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

[0217]   In some implementations, the interface circuitry may connect the platform 1700 with Near-Field Communication (NFC) circuitry 1740. NFC circuitry 1740 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 1740 and NFC-enabled devices external to the platform 1700 (e.g., an "NFC touchpoint"). NFC circuitry 1740 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

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NFC circuitry 1740 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 1740, or initiate data transfer between the NFC circuitry 1740 and another active NFC device (e.g., a smartphone or an NFC-enabled POS terminal) that is proximate to the platform 1700.

[0218]   The driver circuitry 1746 may include software and hardware elements that operate to control particular devices that are embedded in the platform 1700, attached to the platform 1700, or otherwise communicatively coupled with the platform 1700. The driver circuitry 1746 may include individual drivers allowing other components of the platform 1700 to interact with or control various input/output (I/O) devices that may be present within, or connected to, the platform 1700. For example, driver circuitry 1746 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 1700, sensor drivers to obtain sensor readings of sensor circuitry 1721 and control and allow access to sensor circuitry 1721, EMC drivers to obtain actuator positions of the EMCs 1722 and/or control and allow access to the EMCs 1722, 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.

[0219]   The power management integrated circuitry (PMIC) 1725 (also referred to as "power management circuitry 1725") may manage power provided to various components of the platform 1700. In particular, with respect to the baseband circuitry 1710, the PMIC 1725 may control power-source selection, voltage scaling, battery charging, or DC-to-DC conversion. The PMIC 1725 may often be included when the platform 1700 is capable of being powered by a battery 1730, for example, when the device is included in a UE 1301, 1401, 1502.

[0220]   In some embodiments, the PMIC 1725 may control, or otherwise be part of, various power saving mechanisms of the platform 1700. For example, if the platform 1700 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

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Reception Mode (DRX) after a period of inactivity. During this state, the platform 1700 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 1700 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 1700 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 1700 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.

[0221]   A battery 1730 may power the platform 1700, although in some examples the platform 1700 may be mounted deployed in a fixed location, and may have a power supply coupled to an electrical grid. The battery 1730 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 1730 may be a typical lead-acid automotive battery.

[0222]   In some implementations, the battery 1730 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 1700 to track the state of charge (SoCh) of the battery 1730. The BMS may be used to monitor other parameters of the battery 1730 to provide failure predictions, such as the state of health (SoH) and the state of function (SoF) of the battery 1730. The BMS may communicate the information of the battery 1730 to the application circuitry 1705 or other components of the platform 1700. The BMS may also include an analog-to-digital (ADC) convertor that allows the application circuitry 1705 to directly monitor the voltage of the battery 1730 or the current flow from the battery 1730. The battery parameters may be used to determine actions that the platform 1700 may perform, such as transmission frequency, network operation, sensing frequency, and the like.

[0223]   A power block, or other power supply coupled to an electrical grid may be coupled with the BMS to charge the battery 1730. In some examples, the power block 1730 may be replaced with a wireless power receiver to obtain the power wirelessly, for example, through a loop antenna in the computer platform 1700. 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 1730, 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.

[0224]   User interface circuitry 1750 includes various input/output (I/O) devices present within, or connected to, the platform 1700, and includes one or more user interfaces designed to enable user interaction with the platform 1700 and/or peripheral component interfaces designed to enable peripheral component interaction with the platform 1700. The user interface circuitry 1750 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 1700. 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 1721 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,

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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.

[0225]   Although not shown, the components of platform 1700 may communicate with one another using a suitable bus or interconnect (IX) technology, which may include any number of technologies, including ISA, EISA, PCI, PCIx, PCIe, a Time-Trigger Protocol (TTP) system, a FlexRay system, or any number of other technologies. The bus/IX may be a proprietary bus/IX, for example, used in a SoC based system. Other bus/IX systems may be included, such as an I^2C interface, an SPI interface, point-to-point interfaces, and a power bus, among others.

[0226]   Figure 18 illustrates example components of baseband circuitry 1810 and radio front end modules (RFEM) 1815 in accordance with various embodiments. The baseband circuitry 1810 corresponds to the baseband circuitry 1610 and 1710 of Figures 16 and 17, respectively. The RFEM 1815 corresponds to the RFEM 1615 and 1715 of Figures 16 and 17, respectively. As shown, the RFEMs 1815 may include Radio Frequency (RF) circuitry 1806, front-end module (FEM) circuitry 1808, antenna array 1811 coupled together at least as shown.

[0227]   The baseband circuitry 1810 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 1806. 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 1810 may include Fast-Fourier Transform (FFT), precoding, or constellation mapping/demapping functionality. In some embodiments, encoding/decoding circuitry of the baseband circuitry 1810 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 1810 is configured to process baseband signals received from a receive signal path of the RF circuitry 1806 and to generate baseband signals for a transmit signal

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path of the RF circuitry 1806. The baseband circuitry 1810 is configured to interface with application circuitry 1605/1705 (see Figures 16 and 17) for generation and processing of the baseband signals and for controlling operations of the RF circuitry 1806. The baseband circuitry 1810 may handle various radio control functions.

[0228]   The aforementioned circuitry and/or control logic of the baseband circuitry 1810 may include one or more single or multi-core processors. For example, the one or more processors may include a 3G baseband processor 1804A, a 4G/LTE baseband processor 1804B, a 5G/NR baseband processor 1804C, or some other baseband processor(s) 1804D 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 1804A-D may be included in modules stored in the memory 1804G and executed via a Central Processing Unit (CPU) 1804E. In other embodiments, some or all of the functionality of baseband processors 1804A-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 1804G may store program code of a real-time OS (RTOS), which when executed by the CPU 1804E (or other baseband processor), is to cause the CPU 1804E (or other baseband processor) to manage resources of the baseband circuitry 1810, schedule tasks, etc. Examples of the RTOS may include Operating System Embedded (OSE)™ provided by Enea®, Nucleus RTOS™ provided by Mentor Graphics®, Versatile Real-Time Executive (VRTX) provided by Mentor Graphics®, ThreadX™ provided by Express Logic®, FreeRTOS, REX OS provided by Qualcomm®, OKL4 provided by Open Kernel (OK) Labs®, or any other suitable RTOS, such as those discussed herein. In addition, the baseband circuitry 1810 includes one or more audio digital signal processor(s) (DSP) 1804F. The audio DSP(s) 1804F include elements for compression/decompression and echo cancellation and may include other suitable processing elements in other embodiments.

[0229]   In some embodiments, each of the processors 1804A-1804E include respective memory interfaces to send/receive data to/from the memory 1804G. The baseband circuitry 1810 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 1810; an application circuitry interface to send/receive

data to/from the application circuitry 1605/1705 of Figures. 16-18); an RF circuitry interface to send/receive data to/from RF circuitry 1806 of Figure 18; 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 1725.

[0230]   In alternate embodiments (which may be combined with the above described embodiments), baseband circuitry 1810 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 1810 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 1815).

[0231]   Although not shown by Figure 18, in some embodiments, the baseband circuitry 1810 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 1810 and/or RF circuitry 1806 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 1810 and/or RF circuitry 1806 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., 1804G) 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 1810 may also support radio communications for more than one wireless protocol.

[0232]   The various hardware elements of the baseband circuitry 1810 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 1810 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 1810 and RF circuitry 1806 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 1810 may be implemented as a separate SoC that is communicatively coupled with and RF circuitry 1806 (or multiple instances of RF circuitry 1806). In yet another example, some or all of the constituent components of the baseband circuitry 1810 and the application circuitry 1605/1705 may be implemented together as individual SoCs mounted to a same circuit board (e.g., a "multi-chip package").

[0233]   In some embodiments, the baseband circuitry 1810 may provide for communication compatible with one or more radio technologies. For example, in some embodiments, the baseband circuitry 1810 may support communication with an E-UTRAN or other WMAN, a WLAN, a WPAN. Embodiments in which the baseband circuitry 1810 is configured to support radio communications of more than one wireless protocol may be referred to as multi-mode baseband circuitry.

[0234]   RF circuitry 1806 may enable communication with wireless networks using modulated electromagnetic radiation through a non-solid medium. In various embodiments, the RF circuitry 1806 may include switches, filters, amplifiers, etc. to facilitate the communication with the wireless network. RF circuitry 1806 may include a receive signal path, which may include circuitry to down-convert RF signals received from the FEM circuitry 1808 and provide baseband signals to the baseband circuitry 1810. RF circuitry 1806 may also include a transmit signal path, which may include circuitry to up-convert baseband signals provided by the baseband circuitry 1810 and provide RF output signals to the FEM circuitry 1808 for transmission.

[0235]   In some embodiments, the receive signal path of the RF circuitry 1806 may include mixer circuitry 1806a, amplifier circuitry 1806b and filter circuitry 1806c. In some embodiments, the transmit signal path of the RF circuitry 1806 may include filter circuitry 1806c and mixer circuitry 1806a. RF circuitry 1806 may also include synthesizer circuitry 1806d for synthesizing a frequency for use by the mixer circuitry 1806a of the receive signal path and the transmit signal path. In some embodiments, the mixer circuitry 1806a of the receive signal path may be configured to down-convert RF signals received from the FEM circuitry 1808 based on the synthesized frequency provided by synthesizer circuitry 1806d. The amplifier circuitry 1806b may be configured to amplify the down-converted signals and the filter circuitry 1806c 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 1810 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 1806a of the receive signal path may comprise passive mixers, although the scope of the embodiments is not limited in this respect.

[0236]   In some embodiments, the mixer circuitry 1806a of the transmit signal path may be configured to up-convert input baseband signals based on the synthesized frequency provided by the synthesizer circuitry 1806d to generate RF output signals for the FEM circuitry 1808. The baseband signals may be provided by the baseband circuitry 1810 and may be filtered by filter circuitry 1806c.

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[0237]   In some embodiments, the mixer circuitry 1806a of the receive signal path and the
mixer circuitry 1806a 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 1806a of the receive signal path and the mixer circuitry
1806a 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 1806a of the receive signal path and the mixer circuitry 1806a of the transmit
signal path may be arranged for direct downconversion and direct upconversion,
respectively. In some embodiments, the mixer circuitry 1806a of the receive signal path
and the mixer circuitry 1806a of the transmit signal path may be configured for super-
heterodyne operation.

[0238]   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 1806 may include analog-to-digital converter (ADC) and digital-to-analog
converter (DAC) circuitry and the baseband circuitry 1810 may include a digital baseband
interface to communicate with the RF circuitry 1806.

[0239]   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.

[0240]   In some embodiments, the synthesizer circuitry 1806d 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 1806d may be a delta-sigma synthesizer, a frequency
multiplier, or a synthesizer comprising a phase-locked loop with a frequency divider.

[0241]   The synthesizer circuitry 1806d may be configured to synthesize an output
frequency for use by the mixer circuitry 1806a of the RF circuitry 1806 based on a
frequency input and a divider control input. In some embodiments, the synthesizer
circuitry 1806d may be a fractional N/N+1 synthesizer.

[0242]   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 1810 or the application circuitry 1605/1705 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 1605/1705.

[0243]   Synthesizer circuitry 1806d of the RF circuitry 1806 may include a divider, a delay-locked loop (DLL), a multiplexer and a phase accumulator. In some embodiments, the divider may be a dual modulus divider (DMD) and the phase accumulator may be a digital phase accumulator (DPA). In some embodiments, the DMD may be configured to divide the input signal by either N or N+1 (e.g., based on a carry out) to provide a fractional division ratio. In some example embodiments, the DLL may include a set of cascaded, tunable, delay elements, a phase detector, a charge pump and a D-type flip-flop. In these embodiments, the delay elements may be configured to break a VCO period up into Nd equal packets of phase, where Nd is the number of delay elements in the delay line. In this way, the DLL provides negative feedback to help ensure that the total delay through the delay line is one VCO cycle.

[0244]   In some embodiments, synthesizer circuitry 1806d 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 1806 may include an IQ/polar converter.

[0245]   FEM circuitry 1808 may include a receive signal path, which may include circuitry configured to operate on RF signals received from antenna array 1811, amplify the received signals and provide the amplified versions of the received signals to the RF circuitry 1806 for further processing. FEM circuitry 1808 may also include a transmit signal path, which may include circuitry configured to amplify signals for transmission provided by the RF circuitry 1806 for transmission by one or more of antenna elements of antenna array 1811. In various embodiments, the amplification through the transmit or receive signal paths may be done solely in the RF circuitry 1806, solely in the FEM circuitry 1808, or in both the RF circuitry 1806 and the FEM circuitry 1808.

[0246]   In some embodiments, the FEM circuitry 1808 may include a TX/RX switch to switch between transmit mode and receive mode operation. The FEM circuitry 1808 may include a receive signal path and a transmit signal path. The receive signal path of the FEM circuitry 1808 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 1806). The transmit signal path of the FEM circuitry 1808 may include a power amplifier (PA) to amplify input RF signals (e.g., provided by RF circuitry 1806), and one or more filters to generate RF signals for subsequent transmission by one or more antenna elements of the antenna array 1811.

[0247]   The antenna array 1811 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 1810 is converted into analog RF signals (e.g., modulated waveform) that will be amplified and transmitted via the antenna elements of the antenna array 1811 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 1811 may comprise microstrip antennas or printed antennas that are fabricated on the surface of one or more printed circuit boards. The antenna array 1811 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 1806 and/or FEM circuitry 1808 using metal transmission lines or the like.

[0248]   Processors of the application circuitry 1605/1705 and processors of the baseband circuitry 1810 may be used to execute elements of one or more instances of a protocol stack. For example, processors of the baseband circuitry 1810, alone or in combination, may be used execute Layer 3, Layer 2, or Layer 1 functionality, while processors of the application circuitry 1605/1705 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.

[0249]   Figure 19 illustrates various protocol functions that may be implemented in a
wireless communication device according to various embodiments. In particular, Figure
19 includes an arrangement 1900 showing interconnections between various protocol
layers/entities. The following description of Figure 19 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 19 may be applicable to other
wireless communication network systems as well.

[0250]   The protocol layers of arrangement 1900 may include one or more of PHY 1910,
MAC 1920, RLC 1930, PDCP 1940, SDAP 1947, RRC 1955, and NAS layer 1957, in
addition to other higher layer functions not illustrated. The protocol layers may include
one or more service access points (e.g., items 1959, 1956, 1950, 1949, 1945, 1935, 1925,
and 1915 in Figure 19) that may provide communication between two or more protocol
layers.

[0251]   The PHY 1910 may transmit and receive physical layer signals 1905 that may be
received from or transmitted to one or more other communication devices. The physical
layer signals 1905 may comprise one or more physical channels, such as those discussed
herein. The PHY 1910 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 1955. The
PHY 1910 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
1910 may process requests from and provide indications to an instance of MAC 1920 via
one or more PHY-SAP 1915. According to some embodiments, requests and indications
communicated via PHY-SAP 1915 may comprise one or more transport channels.

[0252]   Instance(s) of MAC 1920 may process requests from, and provide indications to,
an instance of RLC 1930 via one or more MAC-SAPs 1925. These requests and
indications communicated via the MAC-SAP 1925 may comprise one or more logical
channels. The MAC 1920 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 1910 via the transport channels, de-multiplexing MAC SDUs

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to one or more logical channels from TBs delivered from the PHY 1910 via transport channels, multiplexing MAC SDUs onto TBs, scheduling information reporting, error correction through HARQ, and logical channel prioritization.

[0253]   Instance(s) of RLC 1930 may process requests from and provide indications to an instance of PDCP 1940 via one or more radio link control service access points (RLC-SAP) 1935. These requests and indications communicated via RLC-SAP 1935 may comprise one or more RLC channels. The RLC 1930 may operate in a plurality of modes of operation, including: Transparent Mode (TM), Unacknowledged Mode (UM), and Acknowledged Mode (AM). The RLC 1930 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 1930 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.

[0254]   Instance(s) of PDCP 1940 may process requests from and provide indications to instance(s) of RRC 1955 and/or instance(s) of SDAP 1947 via one or more packet data convergence protocol service access points (PDCP-SAP) 1945. These requests and indications communicated via PDCP-SAP 1945 may comprise one or more radio bearers. The PDCP 1940 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.).

[0255]   Instance(s) of SDAP 1947 may process requests from and provide indications to one or more higher layer protocol entities via one or more SDAP-SAP 1949. These requests and indications communicated via SDAP-SAP 1949 may comprise one or more QoS flows. The SDAP 1947 may map QoS flows to DRBs, and vice versa, and may also mark QFIs in DL and UL packets. A single SDAP entity 1947 may be configured for an individual PDU session. In the UL direction, the NG-RAN 1310 may control the mapping

of QoS Flows to DRB(s) in two different ways, reflective mapping or explicit mapping.

For reflective mapping, the SDAP 1947 of a UE 1301 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 1947 of the UE 1301 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 1510 may

mark DL packets over the Uu interface with a QoS flow ID. The explicit mapping may

involve the RRC 1955 configuring the SDAP 1947 with an explicit QoS flow to DRB

mapping rule, which may be stored and followed by the SDAP 1947. In embodiments, the

SDAP 1947 may only be used in NR implementations and may not be used in LTE

implementations.

[0256]   The RRC 1955 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 1910, MAC 1920, RLC 1930, PDCP 1940 and SDAP 1947. In

embodiments, an instance of RRC 1955 may process requests from and provide

indications to one or more NAS entities 1957 via one or more RRC-SAPs 1956. The main

services and functions of the RRC 1955 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 1301 and RAN 1310 (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.

[0257]   The NAS 1957 may form the highest stratum of the control plane between the UE

1301 and the AMF 1521. The NAS 1957 may support the mobility of the UEs 1301 and

the session management procedures to establish and maintain IP connectivity between the

UE 1301 and a P-GW in LTE systems.

[0258]   According to various embodiments, one or more protocol entities of arrangement

1900 may be implemented in UEs 1301, RAN nodes 1311, AMF 1521 in NR

implementations or MME 1421 in LTE implementations, UPF 1502 in NR

implementations or S-GW 1422 and P-GW 1423 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 1301, gNB 1311, AMF 1521, 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 1311 may host the RRC

1955, SDAP 1947, and PDCP 1940 of the gNB that controls the operation of one or more

gNB-DUs, and the gNB-DUs of the gNB 1311 may each host the RLC 1930, MAC 1920,

and PHY 1910 of the gNB 1311.

[0259]   In a first example, a control plane protocol stack may comprise, in order from

highest layer to lowest layer, NAS 1957, RRC 1955, PDCP 1940, RLC 1930, MAC 1920,

and PHY 1910. In this example, upper layers 1960 may be built on top of the NAS 1957,

which includes an IP layer 1961, an SCTP 1962, and an application layer signaling

protocol (AP) 1963.

[0260]   In NR implementations, the AP 1963 may be an NG application protocol layer

(NGAP or NG-AP) 1963 for the NG interface 1313 defined between the NG-RAN node

1311 and the AMF 1521, or the AP 1963 may be an Xn application protocol layer (XnAP

or Xn-AP) 1963 for the Xn interface 1312 that is defined between two or more RAN

nodes 1311.

[0261]   The NG-AP 1963 may support the functions of the NG interface 1313 and may

comprise Elementary Procedures (EPs). An NG-AP EP may be a unit of interaction

between the NG-RAN node 1311 and the AMF 1521. The NG-AP 1963 services may

comprise two groups: UE-associated services (e.g., services related to a UE 1301) and

non-UE-associated services (e.g., services related to the whole NG interface instance

between the NG-RAN node 1311 and AMF 1521). These services may include functions

including, but not limited to: a paging function for the sending of paging requests to NG-

RAN nodes 1311 involved in a particular paging area; a UE context management function

for allowing the AMF 1521 to establish, modify, and/or release a UE context in the AMF

1521 and the NG-RAN node 1311; a mobility function for UEs 1301 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 1301 and AMF 1521; a NAS node selection function for determining an association between the AMF 1521 and the UE 1301; 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 1311 via CN 1320; and/or other like functions.

[0262]   The XnAP 1963 may support the functions of the Xn interface 1312 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 1311 (or E-UTRAN 1410), 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 1301, such as Xn interface setup and reset procedures, NG-RAN update procedures, cell activation procedures, and the like.

[0263]   In LTE implementations, the AP 1963 may be an S1 Application Protocol layer (S1-AP) 1963 for the S1 interface 1313 defined between an E-UTRAN node 1311 and an MME, or the AP 1963 may be an X2 application protocol layer (X2AP or X2-AP) 1963 for the X2 interface 1312 that is defined between two or more E-UTRAN nodes 1311.

[0264]   The S1 Application Protocol layer (S1-AP) 1963 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 1311 and an MME 1421within an LTE CN 1320. The S1-AP 1963 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.

[0265]   The X2AP 1963 may support the functions of the X2 interface 1312 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 1320, 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 1301, such as X2 interface setup and reset procedures, load indication procedures, error indication procedures, cell activation procedures, and the like.

[0266]   The SCTP layer (alternatively referred to as the SCTP/IP layer) 1962 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 1962 may ensure reliable delivery of signaling messages between the RAN node 1311 and the AMF 1521/MME 1421 based, in part, on the IP protocol, supported by the IP 1961. The Internet Protocol layer (IP) 1961 may be used to perform packet addressing and routing functionality. In some implementations the IP layer 1961 may use point-to-point transmission to deliver and convey PDUs. In this regard, the RAN node 1311 may comprise L2 and L1 layer communication links (e.g., wired or wireless) with the MME/AMF to exchange information.

[0267]   In a second example, a user plane protocol stack may comprise, in order from highest layer to lowest layer, SDAP 1947, PDCP 1940, RLC 1930, MAC 1920, and PHY 1910. The user plane protocol stack may be used for communication between the UE 1301, the RAN node 1311, and UPF 1502 in NR implementations or an S-GW 1422 and P-GW 1423 in LTE implementations. In this example, upper layers 1951 may be built on top of the SDAP 1947, and may include a user datagram protocol (UDP) and IP security layer (UDP/IP) 1952, a General Packet Radio Service (GPRS) Tunneling Protocol for the user plane layer (GTP-U) 1953, and a User Plane PDU layer (UP PDU) 1963.

[0268]   The transport network layer 1954 (also referred to as a "transport layer") may be built on IP transport, and the GTP-U 1953 may be used on top of the UDP/IP layer 1952 (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.

[0269]   The GTP-U 1953 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 1952 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 1311 and the S-GW 1422 may utilize an S1-U interface to exchange user plane data via a protocol stack comprising an L1 layer (e.g., PHY 1910), an L2 layer (e.g., MAC 1920, RLC 1930, PDCP 1940, and/or SDAP 1947), the UDP/IP layer 1952, and the GTP-U 1953. The S-GW 1422 and the P-GW 1423 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 1952, and the GTP-U 1953. As discussed previously, NAS protocols may support the mobility of the UE 1301 and the session management procedures to establish and maintain IP connectivity between the UE 1301 and the P-GW 1423.

[0270]   Moreover, although not shown by Figure 19, an application layer may be present above the AP 1963 and/or the transport network layer 1954. The application layer may be a layer in which a user of the UE 1301, RAN node 1311, or other network element interacts with software applications being executed, for example, by application circuitry 1605 or application circuitry 1705, respectively. The application layer may also provide one or more interfaces for software applications to interact with communications systems of the UE 1301 or RAN node 1311, such as the baseband circuitry 1810. 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).

[0271]   Figure 20 illustrates components of a core network in accordance with various embodiments. The components of the CN 1420 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 1520 may be implemented in a

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same or similar manner as discussed herein with regard to the components of CN 1420. 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 1420 may be referred to as a network slice 2001, and individual logical instantiations of the CN 1420 may provide specific network capabilities and network characteristics. A logical instantiation of a portion of the CN 1420 may be referred to as a network sub-slice 2002 (e.g., the network sub-slice 2002 is shown to include the P-GW 1423 and the PCRF 1426).

[0272]   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.

[0273]   With respect to 5G systems (see, e.g., Figure 15), 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 1501 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.

[0274]   A network slice may include the CN 1520 control plane and user plane NFs, NG-RANs 1510 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 1501 (e.g., enterprise users). For example,

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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 1521 instance serving an individual UE 1501 may belong to each of the network slice instances serving that UE.

[0275]   Network Slicing in the NG-RAN 1510 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 1510 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 1510 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 1510 selects the RAN part of the network slice using assistance information provided by the UE 1501 or the 5GC 1520, which unambiguously identifies one or more of the pre-configured network slices in the PLMN. The NG-RAN 1510 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 1510 may also apply an appropriate RRM policy for the SLA in place to each supported slice. The NG-RAN 1510 may also support QoS differentiation within a slice.

[0276]   The NG-RAN 1510 may also use the UE assistance information for the selection of an AMF 1521 during an initial attach, if available. The NG-RAN 1510 uses the assistance information for routing the initial NAS to an AMF 1521. If the NG-RAN 1510 is unable to select an AMF 1521 using the assistance information, or the UE 1501 does not provide any such information, the NG-RAN 1510 sends the NAS signaling to a default AMF 1521, which may be among a pool of AMFs 1521. For subsequent accesses, the UE 1501 provides a temp ID, which is assigned to the UE 1501 by the 5GC 1520, to enable the NG-RAN 1510 to route the NAS message to the appropriate AMF 1521 as long as the temp ID is valid. The NG-RAN 1510 is aware of, and can reach, the AMF 1521 that is associated with the temp ID. Otherwise, the method for initial attach applies.

[0277]   The NG-RAN 1510 supports resource isolation between slices. NG-RAN 1510

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 1510 resources to a certain slice. How NG-RAN 1510 supports

resource isolation is implementation dependent.

[0278]   Some slices may be available only in part of the network. Awareness in the NG-

RAN 1510 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 1510 and the 5GC 1520 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 1510.

[0279]   The UE 1501 may be associated with multiple network slices simultaneously. In

case the UE 1501 is associated with multiple slices simultaneously, only one signaling

connection is maintained, and for intra-frequency cell reselection, the UE 1501 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 1501 camps. The 5GC 1520 is to validate

that the UE 1501 has the rights to access a network slice. Prior to receiving an Initial

Context Setup Request message, the NG-RAN 1510 may be allowed to apply some

provisional/local policies, based on awareness of a particular slice that the UE 1501 is

requesting to access. During the initial context setup, the NG-RAN 1510 is informed of

the slice for which resources are being requested.

[0280]   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.

[0281]   Figure 21 is a block diagram illustrating components, according to some example

embodiments, of a system 2100 to support NFV. The system 2100 is illustrated as

including a VIM 2102, an NFVI 2104, an VNFM 2106, VNFs 2108, an EM 2110, an

NFVO 2112, and a NM 2114.

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[0282]   The VIM 2102 manages the resources of the NFVI 2104. The NFVI 2104 can include physical or virtual resources and applications (including hypervisors) used to execute the system 2100. The VIM 2102 may manage the life cycle of virtual resources with the NFVI 2104 (e.g., creation, maintenance, and tear down of VMs associated with one or more physical resources), track VM instances, track performance, fault and security of VM instances and associated physical resources, and expose VM instances and associated physical resources to other management systems.

[0283]   The VNFM 2106 may manage the VNFs 2108. The VNFs 2108 may be used to execute EPC components/functions. The VNFM 2106 may manage the life cycle of the VNFs 2108 and track performance, fault and security of the virtual aspects of VNFs 2108. The EM 2110 may track the performance, fault and security of the functional aspects of VNFs 2108. The tracking data from the VNFM 2106 and the EM 2110 may comprise, for example, PM data used by the VIM 2102 or the NFVI 2104. Both the VNFM 2106 and the EM 2110 can scale up/down the quantity of VNFs of the system 2100.

[0284]   The NFVO 2112 may coordinate, authorize, release and engage resources of the NFVI 2104 in order to provide the requested service (e.g., to execute an EPC function, component, or slice). The NM 2114 may provide a package of end-user functions with the responsibility for the management of a network, which may include network elements with VNFs, non-virtualized network functions, or both (management of the VNFs may occur via the EM 2110).

[0285]   Figure 22 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 22 shows a diagrammatic representation of hardware resources 2200 including one or more processors (or processor cores) 2210, one or more memory/storage devices 2220, and one or more communication resources 2230, each of which may be communicatively coupled via a bus 2240. For embodiments where node virtualization (e.g., NFV) is utilized, a hypervisor 2202 may be executed to provide an execution environment for one or more network slices/sub-slices to utilize the hardware resources 2200.

[0286]   The processors 2210 may include, for example, a processor 2212 and a processor 2214. The processor(s) 2210 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.

[0287]   The memory/storage devices 2220 may include main memory, disk storage, or any suitable combination thereof. The memory/storage devices 2220 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.

[0288]   The communication resources 2230 may include interconnection or network interface components or other suitable devices to communicate with one or more peripheral devices 2204 or one or more databases 2206 via a network 2208. For example, the communication resources 2230 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..

[0289]   Instructions 2250 may comprise software, a program, an application, an applet, an app, or other executable code for causing at least any of the processors 2210 to perform any one or more of the methodologies discussed herein. The instructions 2250 may reside, completely or partially, within at least one of the processors 2210 (e.g., within the processor's cache memory), the memory/storage devices 2220, or any suitable combination thereof. Furthermore, any portion of the instructions 2250 may be transferred to the hardware resources 2200 from any combination of the peripheral devices 2204 or the databases 2206. Accordingly, the memory of processors 2210, the memory/storage devices 2220, the peripheral devices 2204, and the databases 2206 are examples of computer-readable and machine-readable media.

[0290]   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

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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.

[0291]   Figure 23 illustrates a flowchart 2300 that describes an apparatus, such as an originator apparatus, performing dynamic port discovery. The apparatus can be a UE, such as UE 1301, 1401, 1700, according to some embodiments of the disclosure. Additionally, or alternatively, the apparatus can be a base station, radio head, RAN node such as infrastructure equipment 1600, the RAN nodes 1311 and/or AP 1306, according to embodiments of the disclosure. In embodiments, the flowchart 2300 can be performed or controlled by a processor or processor circuitry described in the various embodiments herein, including the processor shown in Figure 22, the baseband circuitry 1610 shown in Figure 16, and/or the baseband circuitry 1710 shown in Figure 17.

[0292]   At 2302, a command frame is generated. For example, an originator device generates the command frame for dynamic port discovery for communicating with a receiver device using a Reliable Data Service (RDS) protocol. According to some examples, the command frame can include a source port field, a destination port field, and an application identifier field. At 2304, the command frame is transmitted to the receiver device. For example, the originator device transmits the command frame to the receiver apparatus.

[0293]   At 2306, a response frame is received from the receiver device. For example, the originator device receives the response frame from the receiver device. The response frame can include a source port field, a destination port field, an application identifier field, and a status field, according to some examples. The originator device and the receiver device can use the command frame and the response frame to negotiate the parameters for their communications. These parameters can include a source port number and a destination port number for an application.

[0294]   At 2308, the source port number and the destination port number are assigned to an application identifier associated with an application on the originator device communicating with a corresponding application on the receiver device.

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EXAMPLES

[0295]   Example 1 includes a 5G system comprising: gNB, AMF, SMF, UPF, NEF, UDM, NSSF, AUSF, AF, AS and other elements as described in 3GPP TS 23.501 and 3GPP TS 24.501.

[0296]   Example 2 includes the 5G system of example 1 and/or some other examples herein, further comprising a UE, wherein the UE performs Reliable Data Transfer between UE and NEF using the RDS protocol as described in TS 24.250, wherein the communication between UE and NEF is bidirectional and supports both MO/MT data delivery in roaming and non-roaming scenarios.

[0297]   Example 3 includes the 5G system of example 2 and/or some other examples herein, wherein the communication between UE and NEF can be performed over both 3GPP and non-3GPP accesses.

[0298]   Example 4 includes the 5G system of example 2 and/or some other examples herein, wherein the UE discovers support for RDS with NEF during the Registration procedure. The UE specifies "RDS Supported" indication over non-3GPP and 3GPP accesses in REGISTRATION_REQUEST message. The network responds with "RDS Supported" or no support indication in REGISTRATION_ACCEPT/REGISTRATION_REJECT message.

[0299]   Example 5 includes the 5G system of example 4 and/or some other examples herein, wherein RDS packets are transmitted over NAS without the need to establish data radio bearers, for example, via NAS transport message, which can carry RDS payload. UE and Network supports RDS protocol as specified in TS 24.250.

[0300]   Example 6 includes the 5G system of example 5 and/or some other examples herein, wherein originator uses SET_PARAMETERS command to discover the list of all port numbers and associated application on the receiver by setting the Type parameter to RDS_Query_Port_List. The originator sends a command frame as specified in this disclosure to the receiver. The receiver in turn sends a response frame as specified in this disclosure.

[0301]   Example 7 includes the 5G system of example 5 and/or some other examples herein, wherein originator uses SET_PARAMETERS command to reserve a Source port number on the receiver by setting the Type parameter to RDS_Reserve_Port_List. The

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originator sends a command frame as specified in this disclosure to the receiver. The receiver in turn sends a response frame as specified in this disclosure.

[0302]   Example 8 includes the 5G system of example 5 and/or some other examples herein, wherein originator uses SET_PARAMETERS command to release a port number on the receiver by setting the Type parameter to RDS_Release_Port_List. The originator sends a command frame as specified in this disclosure to the receiver. The receiver in turn sends a response frame as specified in this disclosure.

[0303]   Example 9 includes the 5G system of example 5 and/or some other examples herein, wherein originator uses a new command RDS_PORT_MGMT for RDS port management operations. This command is used to discover the list of all port numbers and associated application on the receiver, to reserve a port on receiver and release a port on the receiver by setting the Port Mgmt Command parameter appropriately as specified in this disclosure. The originator sends a command frame as specified in this disclosure to the receiver. The receiver in turn sends a response frame as specified in this disclosure.

[0304]   Example 10 includes the 5G system of examples 6, 7, 8, 9, and/or some other examples herein, wherein the Application ID is set as combination of OS id and OS App id wherein the OS Id contains a Universally Unique IDentifier (UUID) as specified in IETF RFC 4122 of 16 bytes and OS app id contains an OS specific application identifier of N bytes.

[0305]   Example 11 includes the 5G system of examples 6, 7, 8, 9, and/or some other examples herein, wherein the Application ID is set as only "OS App Id" (example: URN) of 4 bytes that is more universally recognized by IoT applications without subscription to IP-based APNs.

[0306]   Example Z01 may include an apparatus comprising means to perform one or more elements of a method described in or related to any of examples 1-11, or any other method or process described herein.

[0307]   Example Z02 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 1-11, or any other method or process described herein.

[0308]   Example Z03 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 1-11, or any other method or process described herein.

[0309]   Example Z04 may include a method, technique, or process as described in or related to any of examples 1-11, or portions or parts thereof.

[0310]   Example Z05 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 1-11, or portions thereof.

[0311]   Example Z06 may include a signal as described in or related to any of examples 1-11, or portions or parts thereof.

[0312]   Example Z07 may include a frame, packet, and/or protocol data unit (PDU) as described in or related to any of examples 1-11, or portions or parts thereof.

[0313]   Example Z08 may include a method of communicating in a wireless network as shown and described herein.

[0314]   Example Z09 may include a system for providing wireless communication as shown and described herein.

[0315]   Example Z10 may include a device for providing wireless communication as shown and described herein.

[0316]   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

[0317]   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.

[0318]   3GPP   Third Generation Partnership Project

[0319]   4G   Fourth Generation

[0320]   5G   Fifth Generation

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[0321]	5GC	5G Core network
[0322]	ACK	Acknowledgement
[0323]	AF	Application Function
[0324]	AM	Acknowledged Mode
[0325]	AMBR	Aggregate Maximum Bit Rate
[0326]	AMF	Access and Mobility Management Function
[0327]	AN	Access Network
[0328]	ANR	Automatic Neighbour Relation
[0329]	AP	Application Protocol, Antenna Port, Access Point
[0330]	API	Application Programming Interface
[0331]	APN	Access Point Name
[0332]	ARP	Allocation and Retention Priority
[0333]	ARQ	Automatic Repeat Request
[0334]	AS	Access Stratum
[0335]	ASN.1	Abstract Syntax Notation One
[0336]	AUSF	Authentication Server Function
[0337]	AWGN	Additive White Gaussian Noise
[0338]	BCH	Broadcast Channel
[0339]	BER	Bit Error Ratio
[0340]	BLER	Block Error Rate
[0341]	BPSK	Binary Phase Shift Keying
[0342]	BRAS	Broadband Remote Access Server
[0343]	BSS	Business Support System
[0344]	BS	Base Station
[0345]	BSR	Buffer Status Report
[0346]	BW	Bandwidth
[0347]	BWP	Bandwidth Part
[0348]	C-RNTI	Cell Radio Network Temporary Identity
[0349]	CA	Carrier Aggregation, Certification Authority
[0350]	CAPEX	CAPital EXpenditure
[0351]	CBRA	Contention Based Random Access
[0352]	CC	Component Carrier, Country Code, Cryptographic Checksum

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[0353]	CCA	Clear Channel Assessment
[0354]	CCE	Control Channel Element
[0355]	CCCH	Common Control Channel
[0356]	CE	Coverage Enhancement
[0357]	CDM	Content Delivery Network
[0358]	CDMA	Code-Division Multiple Access
[0359]	CFRA	Contention Free Random Access
[0360]	CG	Cell Group
[0361]	CI	Cell Identity
[0362]	CID	Cell-ID (e.g., positioning method)
[0363]	CIM	Common Information Model
[0364]	CIR	Carrier to Interference Ratio
[0365]	CK	Cipher Key
[0366]	CM	Connection Management, Conditional Mandatory
[0367]	CMAS	Commercial Mobile Alert Service
[0368]	CMD	Command
[0369]	CMS	Cloud Management System
[0370]	CO	Conditional Optional
[0371]	CoMP	Coordinated Multi-Point
[0372]	CORESET	Control Resource Set
[0373]	COTS	Commercial Off-The-Shelf
[0374]	CP	Control Plane, Cyclic Prefix, Connection Point
[0375]	CPD	Connection Point Descriptor
[0376]	CPE	Customer Premise Equipment
[0377]	CPICH	Common Pilot Channel
[0378]	CQI	Channel Quality Indicator
[0379]	CPU	CSI processing unit, Central Processing Unit
[0380]	C/R	Command/Response field bit
[0381]	CRAN	Cloud Radio Access Network, Cloud RAN
[0382]	CRB	Common Resource Block
[0383]	CRC	Cyclic Redundancy Check

[0384]	CRI	Channel-State Information Resource Indicator, CSI-RS Resource Indicator
[0385]	C-RNTI	Cell RNTI
[0386]	CS	Circuit Switched
[0387]	CSAR	Cloud Service Archive
[0388]	CSI	Channel-State Information
[0389]	CSI-IM	CSI Interference Measurement
[0390]	CSI-RS	CSI Reference Signal
[0391]	CSI-RSRP	CSI reference signal received power
[0392]	CSI-RSRQ	CSI reference signal received quality
[0393]	CSI-SINR	CSI signal-to-noise and interference ratio
[0394]	CSMA	Carrier Sense Multiple Access
[0395]	CSMA/CA	CSMA with collision avoidance
[0396]	CSS	Common Search Space, Cell-specific Search Space
[0397]	CTS	Clear-to-Send
[0398]	CW	Codeword
[0399]	CWS	Contention Window Size
[0400]	D2D	Device-to-Device
[0401]	DC	Dual Connectivity, Direct Current
[0402]	DCI	Downlink Control Information
[0403]	DF	Deployment Flavour
[0404]	DL	Downlink
[0405]	DMTF	Distributed Management Task Force
[0406]	DPDK	Data Plane Development Kit
[0407]	DM-RS, DMRS	Demodulation Reference Signal
[0408]	DN	Data network
[0409]	DRB	Data Radio Bearer
[0410]	DRS	Discovery Reference Signal
[0411]	DRX	Discontinuous Reception
[0412]	DSL	Domain Specific Language. Digital Subscriber Line
[0413]	DSLAM	DSL Access Multiplexer
[0414]	DwPTS	Downlink Pilot Time Slot

[0415]	E-LAN	Ethernet Local Area Network
[0416]	E2E	End-to-End
[0417]	ECCA	extended clear channel assessment, extended CCA
[0418]	ECCE	Enhanced Control Channel Element, Enhanced CCE
[0419]	ED	Energy Detection
[0420]	EDGE	Enhanced Datarates for GSM Evolution (GSM Evolution)
[0421]	EGMF	Exposure Governance Management Function
[0422]	EGPRS	Enhanced GPRS
[0423]	EIR	Equipment Identity Register
[0424]	eLAA	enhanced Licensed Assisted Access, enhanced LAA
[0425]	EM	Element Manager
[0426]	eMBB	enhanced Mobile Broadband
[0427]	eMBMS	Evolved MBMS
[0428]	EMS	Element Management System
[0429]	eNB	evolved NodeB, E-UTRAN Node B
[0430]	EN-DC	E-UTRA-NR Dual Connectivity
[0431]	EPC	Evolved Packet Core
[0432]	EPDCCH	enhanced PDCCH, enhanced Physical Downlink Control Cannel
[0433]	EPRE	Energy per resource element
[0434]	EPS	Evolved Packet System
[0435]	EREG	enhanced REG, enhanced resource element groups
[0436]	ETSI	European Telecommunications Standards Institute
[0437]	ETWS	Earthquake and Tsunami Warning System
[0438]	eUICC	embedded UICC, embedded Universal Integrated Circuit Card
[0439]	E-UTRA	Evolved UTRA
[0440]	E-UTRAN	Evolved UTRAN
[0441]	F1AP	F1 Application Protocol
[0442]	F1-C	F1 Control plane interface
[0443]	F1-U	F1 User plane interface
[0444]	FACCH	Fast Associated Control CHannel
[0445]	FACCH/F	Fast Associated Control Channel/Full rate
[0446]	FACCH/H	Fast Associated Control Channel/Half rate

[0447]	FACH	Forward Access Channel
[0448]	FAUSCH	Fast Uplink Signalling Channel
[0449]	FB	Functional Block
[0450]	FBI	Feedback Information
[0451]	FCC	Federal Communications Commission
[0452]	FCCH	Frequency Correction CHannel
[0453]	FDD	Frequency Division Duplex
[0454]	FDM	Frequency Division Multiplex
[0455]	FDMA	Frequency Division Multiple Access
[0456]	FE	Front End
[0457]	FEC	Forward Error Correction
[0458]	FFS	For Further Study
[0459]	FFT	Fast Fourier Transformation
[0460]	feLAA	further enhanced Licensed Assisted Access, further enhanced LAA
[0461]	FN	Frame Number
[0462]	FPGA	Field-Programmable Gate Array
[0463]	FR	Frequency Range
[0464]	G-RNTI	GERAN Radio Network Temporary Identity
[0465]	GERAN	GSM EDGE RAN, GSM EDGE Radio Access Network
[0466]	GGSN	Gateway GPRS Support Node
[0467]	GLONASS	GLObal'naya NAvigatsionnaya Sputnikovaya Sistema (Engl.: Global Navigation Satellite System)
[0468]	gNB	Next Generation NodeB
[0469]	gNB-CU	gNB-centralized unit, Next Generation NodeB centralized unit
[0470]	gNB-DU	gNB-distributed unit, Next Generation NodeB distributed unit
[0471]	GNSS	Global Navigation Satellite System
[0472]	GPRS	General Packet Radio Service
[0473]	GSM	Global System for Mobile Communications, Groupe Spécial Mobile
[0474]	GTP	GPRS Tunneling Protocol
[0475]	GTP-U	GPRS Tunnelling Protocol for User Plane

[0476]	GUMMEI	Globally Unique MME Identifier
[0477]	GUTI	Globally Unique Temporary UE Identity
[0478]	HARQ	Hybrid ARQ, Hybrid Automatic Repeat Request
[0479]	HANDO, HO	Handover
[0480]	HFN	HyperFrame Number
[0481]	HHO	Hard Handover
[0482]	HLR	Home Location Register
[0483]	HN	Home Network
[0484]	HPLMN	Home Public Land Mobile Network
[0485]	HSDPA	High Speed Downlink Packet Access
[0486]	HSN	Hopping Sequence Number
[0487]	HSPA	High Speed Packet Access
[0488]	HSS	Home Subscriber Server
[0489]	HSUPA	High Speed Uplink Packet Access
[0490]	HTTP	Hyper Text Transfer Protocol
[0491]	HTTPS	Hyper Text Transfer Protocol Secure (https is http/1.1 over SSL, i.e. port 443)
[0492]	I-Block	Information Block
[0493]	ICCID	Integrated Circuit Card Identification
[0494]	ICIC	Inter-Cell Interference Coordination
[0495]	ID	Identity, identifier
[0496]	IDFT	Inverse Discrete Fourier Transform
[0497]	IE	Information element
[0498]	IEEE	Institute of Electrical and Electronics Engineers
[0499]	IEI	Information Element Identifier
[0500]	IEIDL	Information Element Identifier Data Length
[0501]	IETF	Internet Engineering Task Force
[0502]	IF	Infrastructure
[0503]	IM	Interference Measurement, Intermodulation, IP Multimedia
[0504]	IMC	IMS Credentials
[0505]	IMEI	International Mobile Equipment Identity
[0506]	IMGI	International mobile group identity

[0507]	IMPI	IP Multimedia Private Identity
[0508]	IMPU	IP Multimedia PUblic identity
[0509]	IMS	IP Multimedia Subsystem
[0510]	IMSI	International Mobile Subscriber Identity
[0511]	IoT	Internet of Things
[0512]	IP	Internet Protocol
[0513]	Ipsec	IP Security, Internet Protocol Security
[0514]	IP-CAN	IP-Connectivity Access Network
[0515]	IP-M	IP Multicast
[0516]	IPv4	Internet Protocol Version 4
[0517]	IPv6	Internet Protocol Version 6
[0518]	IR	Infrared
[0519]	IRP	Integration Reference Point
[0520]	ISDN	Integrated Services Digital Network
[0521]	ISIM	IM Services Identity Module
[0522]	ISO	International Organisation for Standardisation
[0523]	ISP	Internet Service Provider
[0524]	IWF	Interworking-Function
[0525]	I-WLAN	Interworking WLAN
[0526]	K	Constraint length of the convolutional code, USIM Individual key
[0527]	kB	Kilobyte (1000 bytes)
[0528]	kbps	kilo-bits per second
[0529]	Kc	Ciphering key
[0530]	Ki	Individual subscriber authentication key
[0531]	KPI	Key Performance Indicator
[0532]	KQI	Key Quality Indicator
[0533]	KSI	Key Set Identifier
[0534]	ksps	kilo-symbols per second
[0535]	KVM	Kernel Virtual Machine
[0536]	L1	Layer 1 (physical layer)
[0537]	L1-RSRP	Layer 1 reference signal received power

[0538]	L2	Layer 2 (data link layer)
[0539]	L3	Layer 3 (network layer)
[0540]	LAA	Licensed Assisted Access
[0541]	LAN	Local Area Network
[0542]	LBT	Listen Before Talk
[0543]	LCM	LifeCycle Management
[0544]	LCR	Low Chip Rate
[0545]	LCS	Location Services
[0546]	LI	Layer Indicator
[0547]	LLC	Logical Link Control, Low Layer Compatibility
[0548]	LPLMN	Local PLMN
[0549]	LPP	LTE Positioning Protocol
[0550]	LSB	Least Significant Bit
[0551]	LTE	Long Term Evolution
[0552]	LWA	LTE-WLAN aggregation
[0553]	LWIP	LTE/WLAN Radio Level Integration with IPsec Tunnel
[0554]	LTE	Long Term Evolution
[0555]	M2M	Machine-to-Machine
[0556]	MAC	Medium Access Control (protocol layering context)
[0557]	MAC	Message authentication code (security/encryption context)
[0558]	MAC-A	MAC used for authentication and key agreement (TSG T WG3 context)
[0559]	MAC-I	MAC used for data integrity of signalling messages (TSG T WG3 context)
[0560]	MANO	Management and Orchestration
[0561]	MBMS	Multimedia Broadcast and Multicast Service
[0562]	MBSFN	Multimedia Broadcast multicast service Single Frequency Network
[0563]	MCC	Mobile Country Code
[0564]	MCG	Master Cell Group
[0565]	MCOT	Maximum Channel Occupancy Time
[0566]	MCS	Modulation and coding scheme

[0567]	MDAF	Management Data Analytics Function
[0568]	MDAS	Management Data Analytics Service
[0569]	MDT	Minimization of Drive Tests
[0570]	ME	Mobile Equipment
[0571]	MeNB	master eNB
[0572]	MER	Message Error Ratio
[0573]	MGL	Measurement Gap Length
[0574]	MGRP	Measurement Gap Repetition Period
[0575]	MIB	Master Information Block, Management Information Base
[0576]	MIMO	Multiple Input Multiple Output
[0577]	MLC	Mobile Location Centre
[0578]	MM	Mobility Management
[0579]	MME	Mobility Management Entity
[0580]	MN	Master Node
[0581]	MO	Measurement Object, Mobile Originated
[0582]	MPBCH	MTC Physical Broadcast CHannel
[0583]	MPDCCH	MTC Physical Downlink Control CHannel
[0584]	MPDSCH	MTC Physical Downlink Shared CHannel
[0585]	MPRACH	MTC Physical Random Access CHannel
[0586]	MPUSCH	MTC Physical Uplink Shared Channel
[0587]	MPLS	MultiProtocol Label Switching
[0588]	MS	Mobile Station
[0589]	MSB	Most Significant Bit
[0590]	MSC	Mobile Switching Centre
[0591]	MSI	Minimum System Information, MCH Scheduling Information
[0592]	MSID	Mobile Station Identifier
[0593]	MSIN	Mobile Station Identification Number
[0594]	MSISDN	Mobile Subscriber ISDN Number
[0595]	MT	Mobile Terminated, Mobile Termination
[0596]	MTC	Machine-Type Communications
[0597]	mMTC	massive MTC, massive Machine-Type Communications
[0598]	MU-MIMO	Multi User MIMO

[0599]	MWUS	MTC wake-up signal, MTC WUS
[0600]	NACK	Negative Acknowledgement
[0601]	NAI	Network Access Identifier
[0602]	NAS	Non-Access Stratum, Non-Access Stratum layer
[0603]	NCT	Network Connectivity Topology
[0604]	NEC	Network Capability Exposure
[0605]	NE-DC	NR-E-UTRA Dual Connectivity
[0606]	NEF	Network Exposure Function
[0607]	NF	Network Function
[0608]	NFP	Network Forwarding Path
[0609]	NFPD	Network Forwarding Path Descriptor
[0610]	NFV	Network Functions Virtualization
[0611]	NFVI	NFV Infrastructure
[0612]	NFVO	NFV Orchestrator
[0613]	NG	Next Generation, Next Gen
[0614]	NGEN-DC	NG-RAN E-UTRA-NR Dual Connectivity
[0615]	NM	Network Manager
[0616]	NMS	Network Management System
[0617]	N-PoP	Network Point of Presence
[0618]	NMIB, N-MIB	Narrowband MIB
[0619]	NPBCH	Narrowband Physical Broadcast CHannel
[0620]	NPDCCH	Narrowband Physical Downlink Control CHannel
[0621]	NPDSCH	Narrowband Physical Downlink Shared CHannel
[0622]	NPRACH	Narrowband Physical Random Access CHannel
[0623]	NPUSCH	Narrowband Physical Uplink Shared CHannel
[0624]	NPSS	Narrowband Primary Synchronization Signal
[0625]	NSSS	Narrowband Secondary Synchronization Signal
[0626]	NR	New Radio, Neighbour Relation
[0627]	NRF	NF Repository Function
[0628]	NRS	Narrowband Reference Signal
[0629]	NS	Network Service
[0630]	NSA	Non-Standalone operation mode

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[0631]	NSD	Network Service Descriptor
[0632]	NSR	Network Service Record
[0633]	NSSAI	`Network Slice Selection Assistance Information
[0634]	S-NNSAI	Single-NSSAI
[0635]	NSSF	Network Slice Selection Function
[0636]	NW	Network
[0637]	NWUS	Narrowband wake-up signal, Narrowband WUS
[0638]	NZP	Non-Zero Power
[0639]	O&M	Operation and Maintenance
[0640]	ODU2	Optical channel Data Unit - type 2
[0641]	OFDM	Orthogonal Frequency Division Multiplexing
[0642]	OFDMA	Orthogonal Frequency Division Multiple Access
[0643]	OOB	Out-of-band
[0644]	OPEX	OPerating EXpense
[0645]	OSI	Other System Information
[0646]	OSS	Operations Support System
[0647]	OTA	over-the-air
[0648]	PAPR	Peak-to-Average Power Ratio
[0649]	PAR	Peak to Average Ratio
[0650]	PBCH	Physical Broadcast Channel
[0651]	PC	Power Control, Personal Computer
[0652]	PCC	Primary Component Carrier, Primary CC
[0653]	PCell	Primary Cell
[0654]	PCI	Physical Cell ID, Physical Cell Identity
[0655]	PCEF	Policy and Charging Enforcement Function
[0656]	PCF	Policy Control Function
[0657]	PCRF	Policy Control and Charging Rules Function
[0658]	PDCP	Packet Data Convergence Protocol, Packet Data Convergence Protocol layer
[0659]	PDCCH	Physical Downlink Control Channel
[0660]	PDCP	Packet Data Convergence Protocol
[0661]	PDN	Packet Data Network, Public Data Network

[0662]	PDSCH	Physical Downlink Shared Channel
[0663]	PDU	Protocol Data Unit
[0664]	PEI	Permanent Equipment Identifiers
[0665]	PFD	Packet Flow Description
[0666]	P-GW	PDN Gateway
[0667]	PHICH	Physical hybrid-ARQ indicator channel
[0668]	PHY	Physical layer
[0669]	PLMN	Public Land Mobile Network
[0670]	PIN	Personal Identification Number
[0671]	PM	Performance Measurement
[0672]	PMI	Precoding Matrix Indicator
[0673]	PNF	Physical Network Function
[0674]	PNFD	Physical Network Function Descriptor
[0675]	PNFR	Physical Network Function Record
[0676]	POC	PTT over Cellular
[0677]	PP, PTP	Point-to-Point
[0678]	PPP	Point-to-Point Protocol
[0679]	PRACH	Physical RACH
[0680]	PRB	Physical resource block
[0681]	PRG	Physical resource block group
[0682]	ProSe	Proximity Services, Proximity-Based Service
[0683]	PRS	Positioning Reference Signal
[0684]	PS	Packet Services
[0685]	PSBCH	Physical Sidelink Broadcast Channel
[0686]	PSDCH	Physical Sidelink Downlink Channel
[0687]	PSCCH	Physical Sidelink Control Channel
[0688]	PSSCH	Physical Sidelink Shared Channel
[0689]	PSCell	Primary SCell
[0690]	PSS	Primary Synchronization Signal
[0691]	PSTN	Public Switched Telephone Network
[0692]	PT-RS	Phase-tracking reference signal
[0693]	PTT	Push-to-Talk

[0694]	PUCCH	Physical Uplink Control Channel
[0695]	PUSCH	Physical Uplink Shared Channel
[0696]	QAM	Quadrature Amplitude Modulation
[0697]	QCI	QoS class of identifier
[0698]	QCL	Quasi co-location
[0699]	QFI	QoS Flow ID, QoS Flow Identifier
[0700]	QoS	Quality of Service
[0701]	QPSK	Quadrature (Quaternary) Phase Shift Keying
[0702]	QZSS	Quasi-Zenith Satellite System
[0703]	RA-RNTI	Random Access RNTI
[0704]	RAB	Radio Access Bearer, Random Access Burst
[0705]	RACH	Random Access Channel
[0706]	RADIUS	Remote Authentication Dial In User Service
[0707]	RAN	Radio Access Network
[0708]	RAND	RANDom number (used for authentication)
[0709]	RAR	Random Access Response
[0710]	RAT	Radio Access Technology
[0711]	RAU	Routing Area Update
[0712]	RB	Resource block, Radio Bearer
[0713]	RBG	Resource block group
[0714]	REG	Resource Element Group
[0715]	Rel	Release
[0716]	REQ	REQuest
[0717]	RF	Radio Frequency
[0718]	RI	Rank Indicator
[0719]	RIV	Resource indicator value
[0720]	RL	Radio Link
[0721]	RLC	Radio Link Control, Radio Link Control layer
[0722]	RLF	Radio Link Failure
[0723]	RLM	Radio Link Monitoring
[0724]	RLM-RS	Reference Signal for RLM
[0725]	RM	Registration Management

[0726]	RMC	Reference Measurement Channel
[0727]	RMSI	Remaining MSI, Remaining Minimum System Information
[0728]	RN	Relay Node
[0729]	RNC	Radio Network Controller
[0730]	RNL	Radio Network Layer
[0731]	RNTI	Radio Network Temporary Identifier
[0732]	ROHC	RObust Header Compression
[0733]	RRC	Radio Resource Control, Radio Resource Control layer
[0734]	RRM	Radio Resource Management
[0735]	RS	Reference Signal
[0736]	RSRP	Reference Signal Received Power
[0737]	RSRQ	Reference Signal Received Quality
[0738]	RSSI	Received Signal Strength Indicator
[0739]	RSU	Road Side Unit
[0740]	RSTD	Reference Signal Time difference
[0741]	RTP	Real Time Protocol
[0742]	RTS	Ready-To-Send
[0743]	RTT	Round Trip Time
[0744]	Rx	Reception, Receiving, Receiver
[0745]	S1AP	S1 Application Protocol
[0746]	S1-MME	S1 for the control plane
[0747]	S1-U	S1 for the user plane
[0748]	S-GW	Serving Gateway
[0749]	S-RNTI	SRNC Radio Network Temporary Identity
[0750]	S-TMSI	SAE Temporary Mobile Station Identifier
[0751]	SA	Standalone operation mode
[0752]	SAE	System Architecture Evolution
[0753]	SAP	Service Access Point
[0754]	SAPD	Service Access Point Descriptor
[0755]	SAPI	Service Access Point Identifier
[0756]	SCC	Secondary Component Carrier, Secondary CC
[0757]	SCEF	Service Capability Exposure Function

[0758]	SCell	Secondary Cell
[0759]	SC-FDMA	Single Carrier Frequency Division Multiple Access
[0760]	SCG	Secondary Cell Group
[0761]	SCM	Security Context Management
[0762]	SCS	Subcarrier Spacing
[0763]	SCTP	Stream Control Transmission Protocol
[0764]	SDAP	Service Data Adaptation Protocol, Service Data Adaptation Protocol layer
[0765]	SDL	Supplementary Downlink
[0766]	SDNF	Structured Data Storage Network Function
[0767]	SDP	Service Discovery Protocol (Bluetooth related)
[0768]	SDSF	Structured Data Storage Function
[0769]	SDU	Service Data Unit
[0770]	SEAF	Security Anchor Function
[0771]	SeNB	secondary eNB
[0772]	SEPP	Security Edge Protection Proxy
[0773]	SFI	Slot format indication
[0774]	SFTD	Space-Frequency Time Diversity, SFN and frame timing difference
[0775]	SFN	System Frame Number
[0776]	SgNB	Secondary gNB
[0777]	SGSN	Serving GPRS Support Node
[0778]	S-GW	Serving Gateway
[0779]	SI	System Information
[0780]	SI-RNTI	System Information RNTI
[0781]	SIB	System Information Block
[0782]	SIM	Subscriber Identity Module
[0783]	SIP	Session Initiated Protocol
[0784]	SiP	System in Package
[0785]	SL	Sidelink
[0786]	SLA	Service Level Agreement
[0787]	SM	Session Management

[0788]	SMF	Session Management Function
[0789]	SMS	Short Message Service
[0790]	SMSF	SMS Function
[0791]	SMTC	SSB-based Measurement Timing Configuration
[0792]	SN	Secondary Node, Sequence Number
[0793]	SoC	System on Chip
[0794]	SON	Self-Organizing Network
[0795]	SpCell	Special Cell
[0796]	SP-CSI-RNTI	Semi-Persistent CSI RNTI
[0797]	SPS	Semi-Persistent Scheduling
[0798]	SQN	Sequence number
[0799]	SR	Scheduling Request
[0800]	SRB	Signalling Radio Bearer
[0801]	SRS	Sounding Reference Signal
[0802]	SS	Synchronization Signal
[0803]	SSB	Synchronization Signal Block, SS/PBCH Block
[0804]	SSBRI	SS/PBCH Block Resource Indicator, Synchronization Signal Block Resource Indicator
[0805]	SSC	Session and Service Continuity
[0806]	SS-RSRP	Synchronization Signal based Reference Signal Received Power
[0807]	SS-RSRQ	Synchronization Signal based Reference Signal Received Quality
[0808]	SS-SINR	Synchronization Signal based Signal to Noise and Interference Ratio
[0809]	SSS	Secondary Synchronization Signal
[0810]	SST	Slice/Service Types
[0811]	SU-MIMO	Single User MIMO
[0812]	SUL	Supplementary Uplink
[0813]	TA	Timing Advance, Tracking Area
[0814]	TAC	Tracking Area Code
[0815]	TAG	Timing Advance Group
[0816]	TAU	Tracking Area Update
[0817]	TB	Transport Block

[0818]	TBS	Transport Block Size
[0819]	TBD	To Be Defined
[0820]	TCI	Transmission Configuration Indicator
[0821]	TCP	Transmission Communication Protocol
[0822]	TDD	Time Division Duplex
[0823]	TDM	Time Division Multiplexing
[0824]	TDMA	Time Division Multiple Access
[0825]	TE	Terminal Equipment
[0826]	TEID	Tunnel End Point Identifier
[0827]	TFT	Traffic Flow Template
[0828]	TMSI	Temporary Mobile Subscriber Identity
[0829]	TNL	Transport Network Layer
[0830]	TPC	Transmit Power Control
[0831]	TPMI	Transmitted Precoding Matrix Indicator
[0832]	TR	Technical Report
[0833]	TRP, TRxP	Transmission Reception Point
[0834]	TRS	Tracking Reference Signal
[0835]	TRx	Transceiver
[0836]	TS	Technical Specifications, Technical Standard
[0837]	TTI	Transmission Time Interval
[0838]	Tx	Transmission, Transmitting, Transmitter
[0839]	U-RNTI	UTRAN Radio Network Temporary Identity
[0840]	UART	Universal Asynchronous Receiver and Transmitter
[0841]	UCI	Uplink Control Information
[0842]	UE	User Equipment
[0843]	UDM	Unified Data Management
[0844]	UDP	User Datagram Protocol
[0845]	UDSF	Unstructured Data Storage Network Function
[0846]	UICC	Universal Integrated Circuit Card
[0847]	UL	Uplink
[0848]	UM	Unacknowledged Mode
[0849]	UML	Unified Modelling Language

[0850]	UMTS	Universal Mobile Telecommunications System
[0851]	UP	User Plane
[0852]	UPF	User Plane Function
[0853]	URI	Uniform Resource Identifier
[0854]	URL	Uniform Resource Locator
[0855]	URLLC	Ultra-Reliable and Low Latency
[0856]	USB	Universal Serial Bus
[0857]	USIM	Universal Subscriber Identity Module
[0858]	USS	UE-specific search space
[0859]	UTRA	UMTS Terrestrial Radio Access
[0860]	UTRAN	Universal Terrestrial Radio Access Network
[0861]	UwPTS	Uplink Pilot Time Slot
[0862]	V2I	Vehicle-to-Infrastruction
[0863]	V2P	Vehicle-to-Pedestrian
[0864]	V2V	Vehicle-to-Vehicle
[0865]	V2X	Vehicle-to-everything
[0866]	VIM	Virtualized Infrastructure Manager
[0867]	VL	Virtual Link,
[0868]	VLAN	Virtual LAN, Virtual Local Area Network
[0869]	VM	Virtual Machine
[0870]	VNF	Virtualized Network Function
[0871]	VNFFG	VNF Forwarding Graph
[0872]	VNFFGD	VNF Forwarding Graph Descriptor
[0873]	VNFM	VNF Manager
[0874]	VoIP	Voice-over-IP, Voice-over-Internet Protocol
[0875]	VPLMN	Visited Public Land Mobile Network
[0876]	VPN	Virtual Private Network
[0877]	VRB	Virtual Resource Block
[0878]	WiMAX	Worldwide Interoperability for Microwave Access
[0879]	WLAN	Wireless Local Area Network
[0880]	WMAN	Wireless Metropolitan Area Network
[0881]	WPAN	Wireless Personal Area Network

[0882]	X2-C	X2-Control plane
[0883]	X2-U	X2-User plane
[0884]	XML	eXtensible Markup Language
[0885]	XRES	EXpected user RESponse
[0886]	XOR	eXclusive OR
[0887]	ZC	Zadoff-Chu
[0888]	ZP	Zero Power

Terminology

[0889]   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.

[0890]   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.

[0891]   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."

[0892]   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.

[0893]   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.

[0894]   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.

[0895]   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.

[0896]   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

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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.

[0897]   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.

[0898]   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.

[0899]   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.

[0900] The terms "coupled," "communicatively coupled," along with derivatives thereof are used herein. The term "coupled" may mean two or more elements are in direct physical or electrical contact with one another, may mean that two or more elements indirectly contact each other but still cooperate or interact with each other, and/or may mean that one or more other elements are coupled or connected between the elements that are said to be coupled with each other. The term "directly coupled" may mean that two or more elements are in direct contact with one another. The term "communicatively coupled" may mean that two or more elements may be in contact with one another by a means of communication including through a wire or other interconnect connection, through a wireless communication channel or ink, and/or the like.

[0901] 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.

[0902] The term "SMTC" refers to an SSB-based measurement timing configuration configured by *SSB-MeasurementTimingConfiguration*.

[0903] The term "SSB" refers to an SS/PBCH block.

[0904] 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.

[0905] 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.

[0906] The term "Secondary Cell" refers to a cell providing additional radio resources on top of a Special Cell for a UE configured with CA.

[0907] 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.

[0908] 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.

[0909] 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/.

[0910]   The term "Special Cell" refers to the PCell of the MCG or the PSCell of the SCG for DC operation; otherwise, the term "Special Cell" refers to the Pcell.

WHAT IS CLAIMED IS:

1.   An originator device, comprising:

        radio front end circuitry; and

        processor circuitry configured to:

            generate a command frame for dynamic port discovery for communicating with a receiver device using a Reliable Data Service (RDS) protocol;

            transmit, using the radio front end circuitry, the command frame to the receiver device;

            receive, using the radio front end circuitry, a response frame from the receiver device; and

            assign, using the received response frame, a source port number and a destination port number to an application identifier, wherein the application identifier is associated with an application on the originator device communicating with a corresponding application on the receiver device.

2.   The originator device of claim 1, wherein the command frame comprises a source port field, a destination port field, and an application identifier field.

3.   The originator device of claim 1, wherein the response frame comprises a source port field, a destination port field, an application identifier field, and a status field.

4.   The originator device of claim 1, wherein the processor circuitry is further configured to query the receiver device to determine which destination ports on the receiver device are assigned and which destination ports on the receiver device are available.

5.   The originator device of claim 1, wherein the processor circuitry is further configured to transmit, using the radio front end circuitry and to the receiver device, a source bitmap associated with source ports on the originator device, wherein the source bitmap indicates which of the source ports are assigned and which of the source ports are available.

6.   The originator device of claim 1, wherein the processor circuitry is further configured to transmit, using the radio front end circuitry and to the receiver device, the source port number, the destination port number, and the application identifier to release the source port number and the destination port number from the application associated with the application identifier.

7.   The originator device of claim 1, wherein the command frame comprises a port management command comprising a port list query, a reserve port command, or a release port command.

8.   The originator device of claim 1, wherein the originator device comprises a user equipment (UE) and the receive device comprises a public data network (PDN) gateway (P-GW).

9.   The originator device of claim 1, wherein the originator device comprises a public data network (PDN) gateway (P-GW) and the receive device comprises a user equipment (UE).

10.   A method comprising:
           generating, at an originator device, a command frame for dynamic port discovery for communicating with a receiver device using a Reliable Data Service (RDS) protocol;
           transmitting the command frame to the receiver device;
           receiving a response frame from the receiver device; and
           assigning, using the received response frame, a source port number and a destination port number to an application identifier, wherein the application identifier is associated with an application on the originator device communicating with a corresponding application on the receiver device.

11.   The method of claim 10, further comprising:
           querying the receiver device to determine which destination ports on the receiver device are assigned and which destination ports on the receiver device are available.

12. The method of claim 10, further comprising:

transmitting, to the receiver device, a source bitmap associated with source ports on the originator device, wherein the source bitmap indicates which of the source ports are assigned and which of the source ports are available.

13. The method of claim 10, further comprising:

transmitting, to the receiver device, the source port number, the destination port number, and the application identifier to release the source port number and the destination port number from the application associated with the application identifier.

14. The method of claim 10, wherein the command frame comprises a port management command comprising a port list query, a reserve port command, or a release port command.
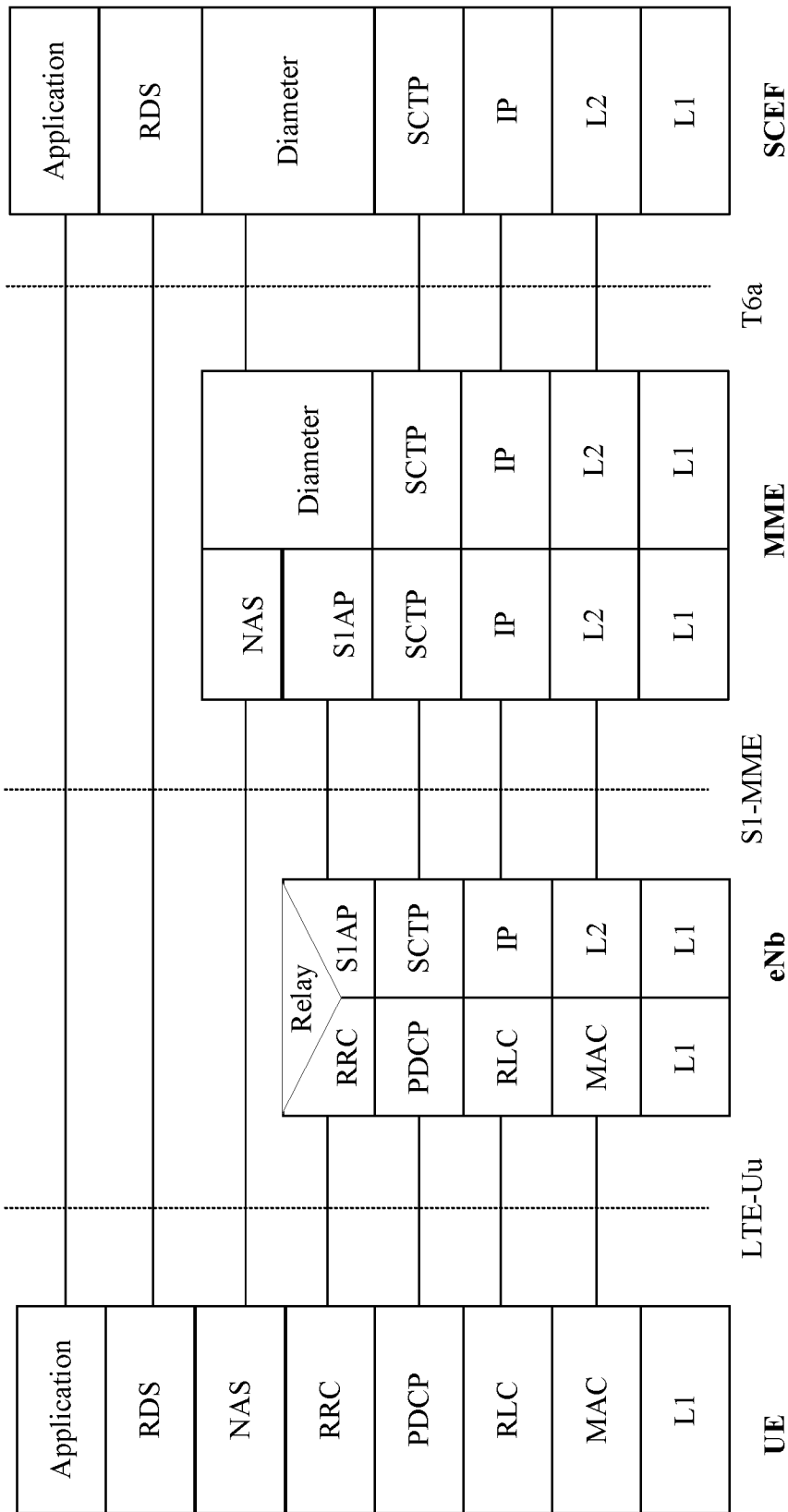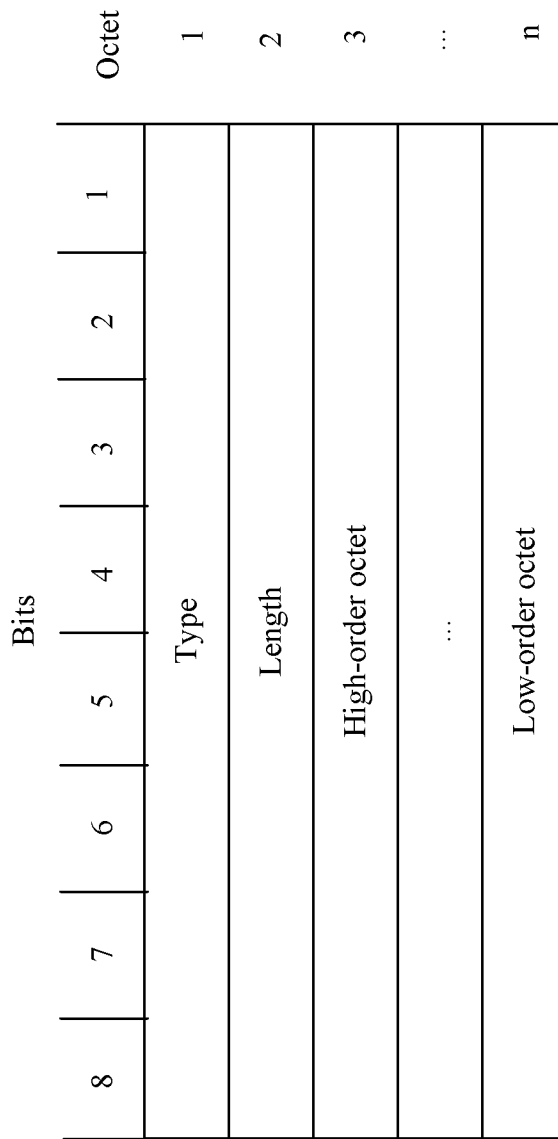
15. The method of claim 10, wherein

the command frame comprises a first source port field, a first destination port field, and a first application identifier field, and

the response frame comprises a second source port field, a second destination port field, a second application identifier field, and a status field.

16. An originator device, comprising:

a memory that stores instructions; and

a processor, upon executing the instructions, configured to:

generate a command frame for dynamic port discovery for communicating with a receiver device using a Reliable Data Service (RDS) protocol;

transmit the command frame to the receiver device;

receive a response frame from the receiver device; and

assign, using the received response frame, a source port number and a destination port number to an application identifier, wherein the application identifier is associated with an application on the originator device communicating with a corresponding application on the receiver device.

17. The originator device of claim 16, wherein the processor is further configured to query the receiver device to determine which destination ports on the receiver device are assigned and which destination ports on the receiver device are available.

18. The originator device of claim 16, wherein the processor is further configured to transmit, to the receiver device, a source bitmap associated with source ports on the originator device, wherein the source bitmap indicates which of the source ports are assigned and which of the source ports are available.

19. The originator device of claim 16, wherein the processor is further configured to transmit, to the receiver device, the source port number, the destination port number, and the application identifier to release the source port number and the destination port number from the application associated with the application identifier.

20. The originator device of claim 16, wherein the command frame comprises a port management command comprising a port list query, a reserve port command, or a release port command.

Figure 1

Octet	Bits							
	1	2	3	4	5	6	7	8
1	Type
2	Length
3	High-order octet
...	...
n	Low-order octet

Figure 2

	1	2	3	4	5	6	7	8
octet 1	Port 0	Port 1	Port 2	Port 3	Port 4	Port 5	Port 6	Port 7
octet 2	Port 8	Port 9	Port 10	Port 11	Port 12	Port 13	Port 14	Port 15

Figure 3

Figure 4

Figure 5

Bits								Octet
1	2	3	4	5	6	7	8	
Port Mgmt Comand								1
Length								2
High-order octet								3
...								4
								...
Low-order octet								n

Figure 6

8	7	6	5	4	3	2	1
Address and Control field (variable length, max. 3 octets)							
Information field (variable length, max. N201 octets)							
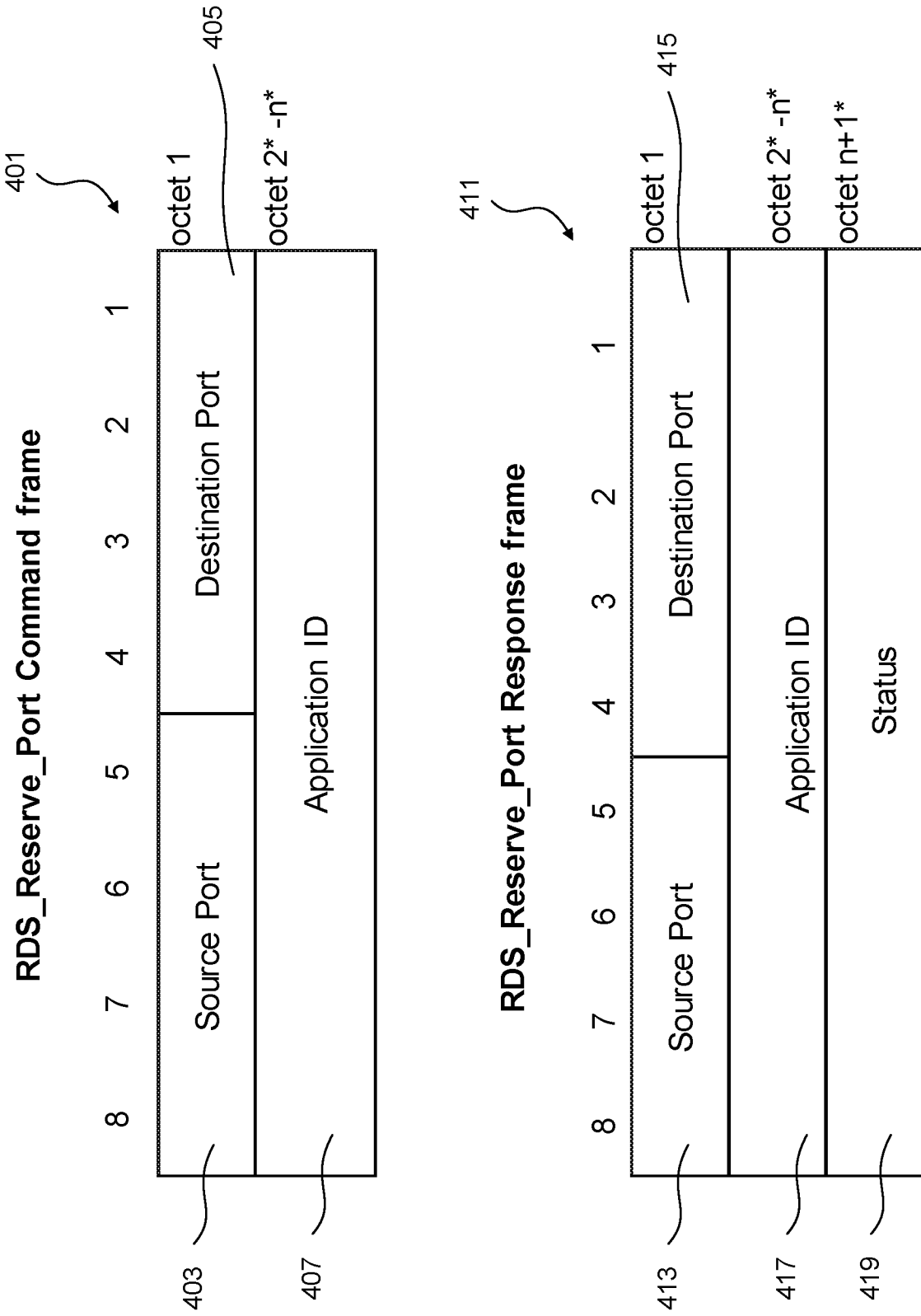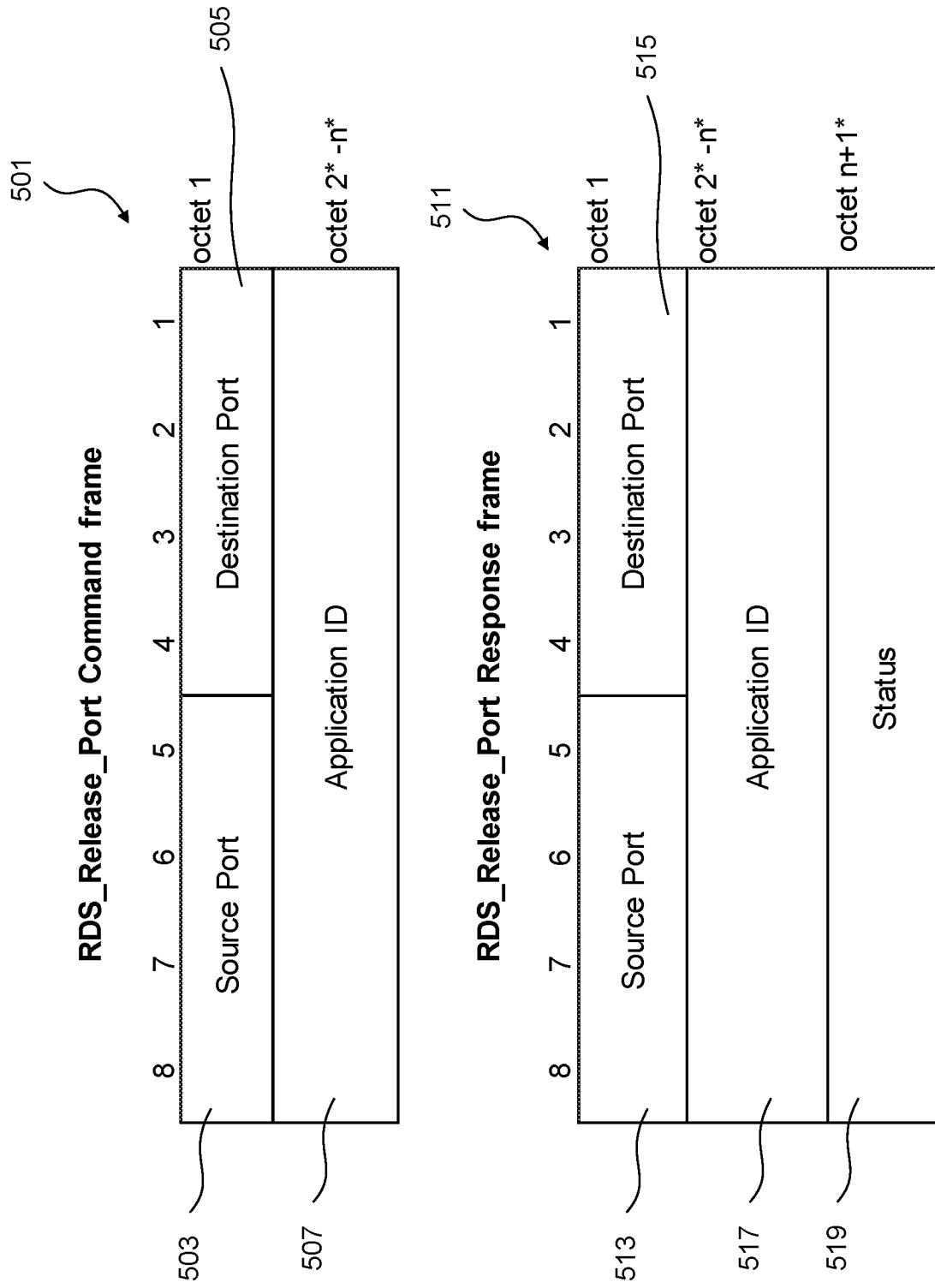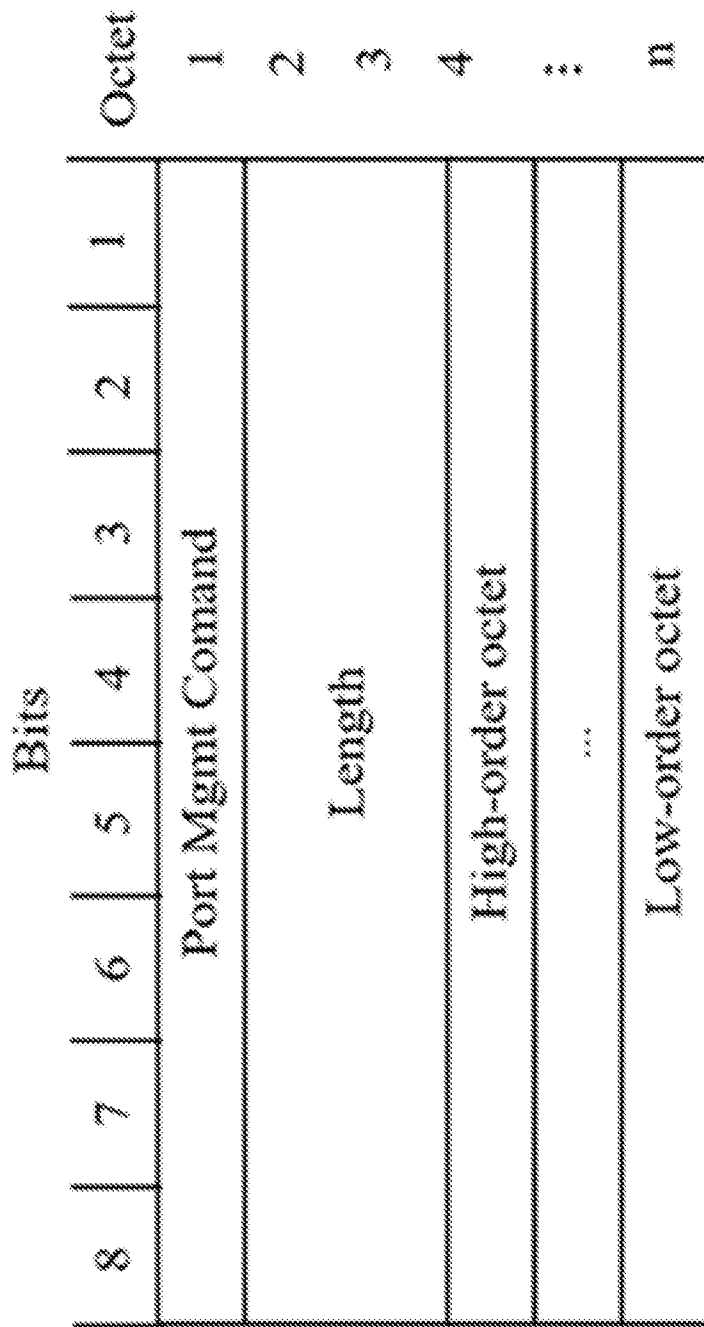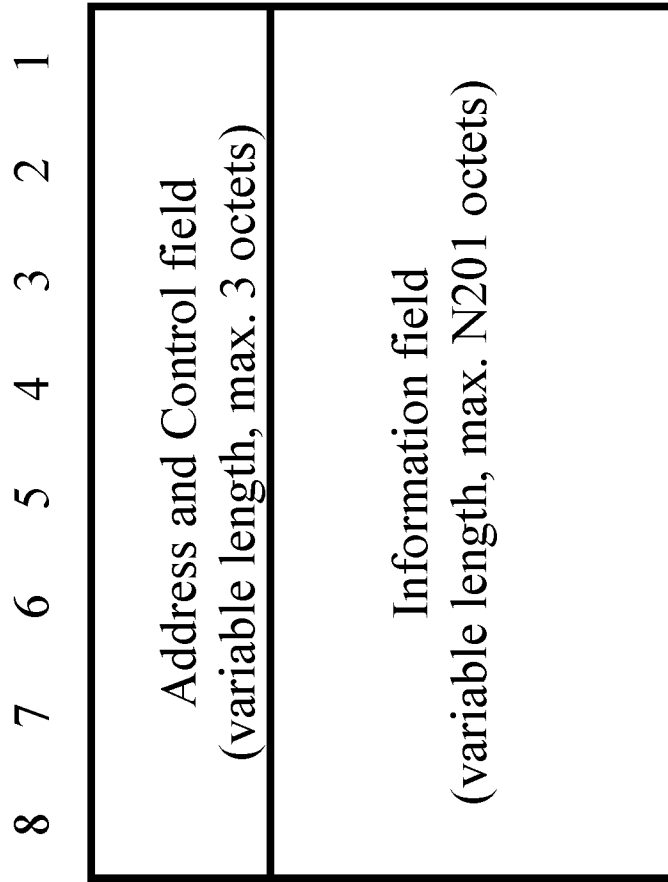
Figure 7

Address and Control Field Bits

Format	8	7	6	5	4	3	2	1	Octet
I Format	PD	0	A	X	ADS	N(S)			1
	N(R)			R1	R2	R3	S1	S2	2
	Source Port				Destination Port				3
S Format	PD	1	1	0	ADS	A	X	X	1
	N(R)			R1	R2	R3	S1	S2	2
	Source Port				Destination Port				3
UI Format	PD	1	0	X	ADS	N(U)			1
	Source Port				Destination Port				2
U Format	PD	1	1	1	ADS	CR	X	X	1
	X	X	X	X	M4	M3	M2	M1	2
	Source Port				Destination Port				3

Figure 8

Receiver

Originator

SET_ACK_MODE

ACCEPT

OR

SET_ACK_MODE

ERROR

Figure 9

Receiver

I Frame

S Frame or I Frame

Originator

Figure 10

Receiver

Originator

DISCONNECT

ACCEPT

OR

DISCONNECT

ERROR

Figure 11

Receiver

UI

Originator
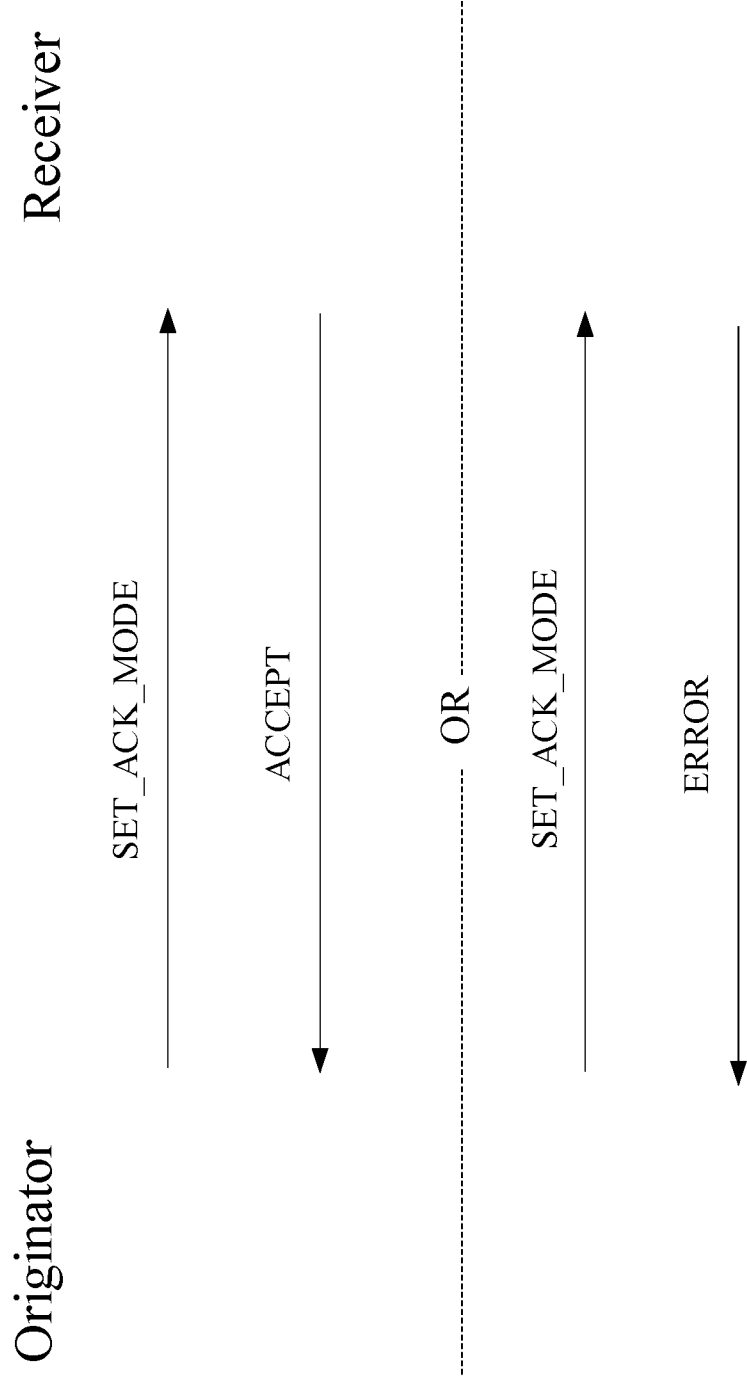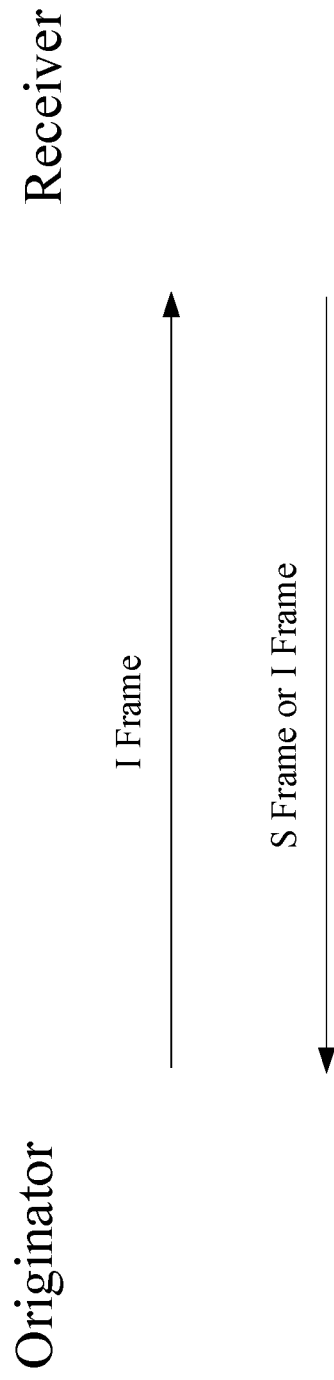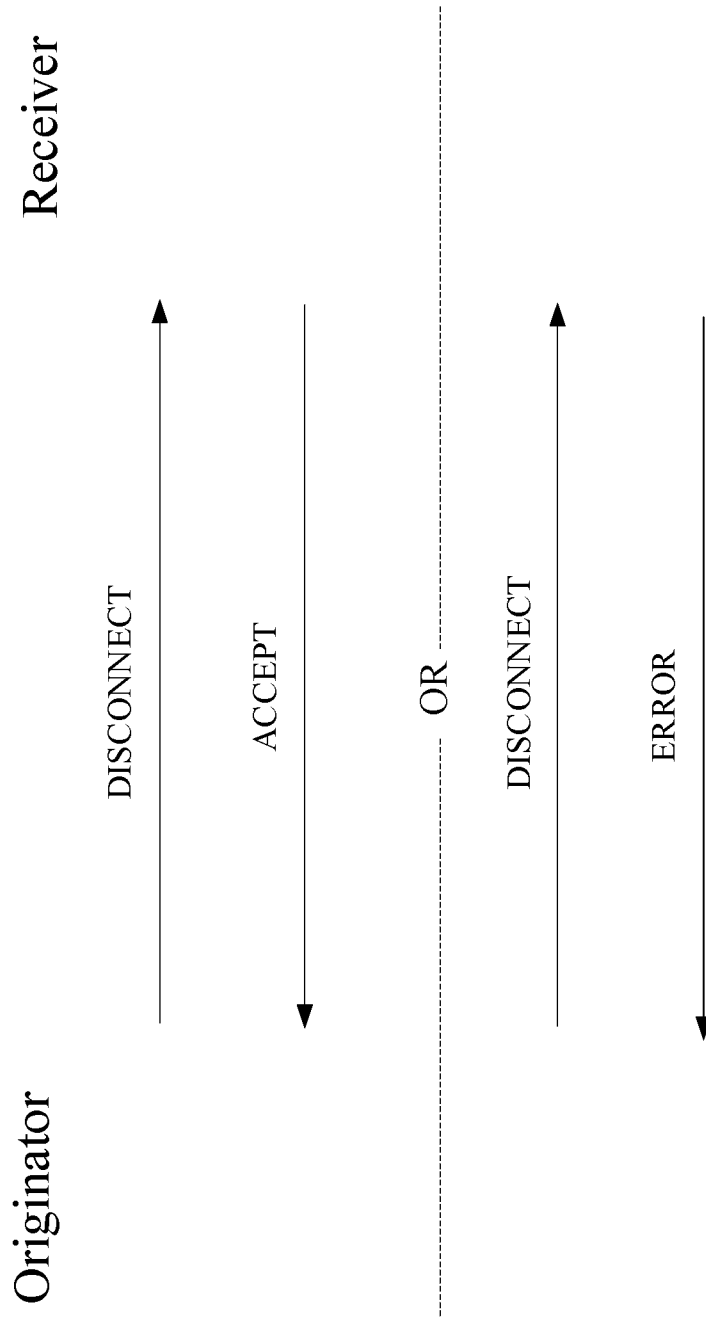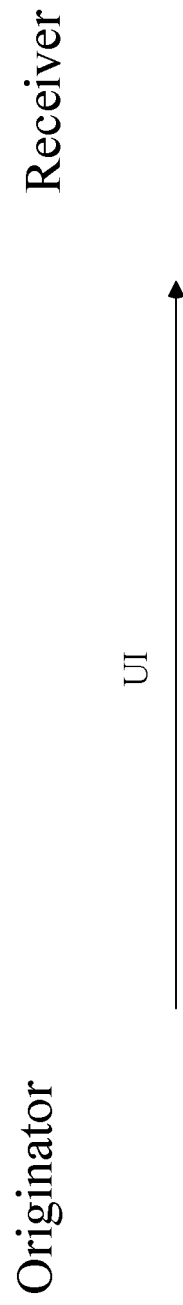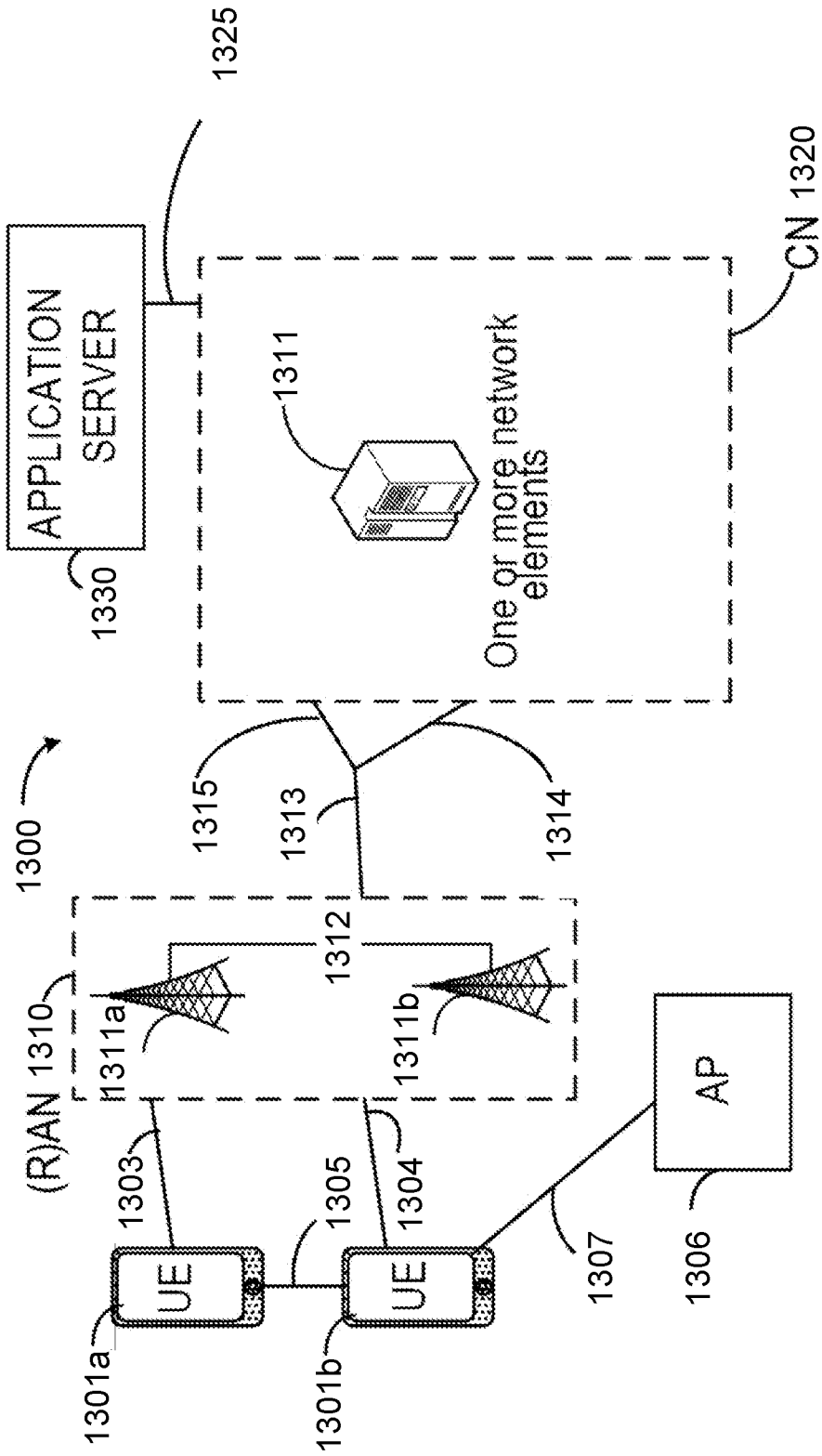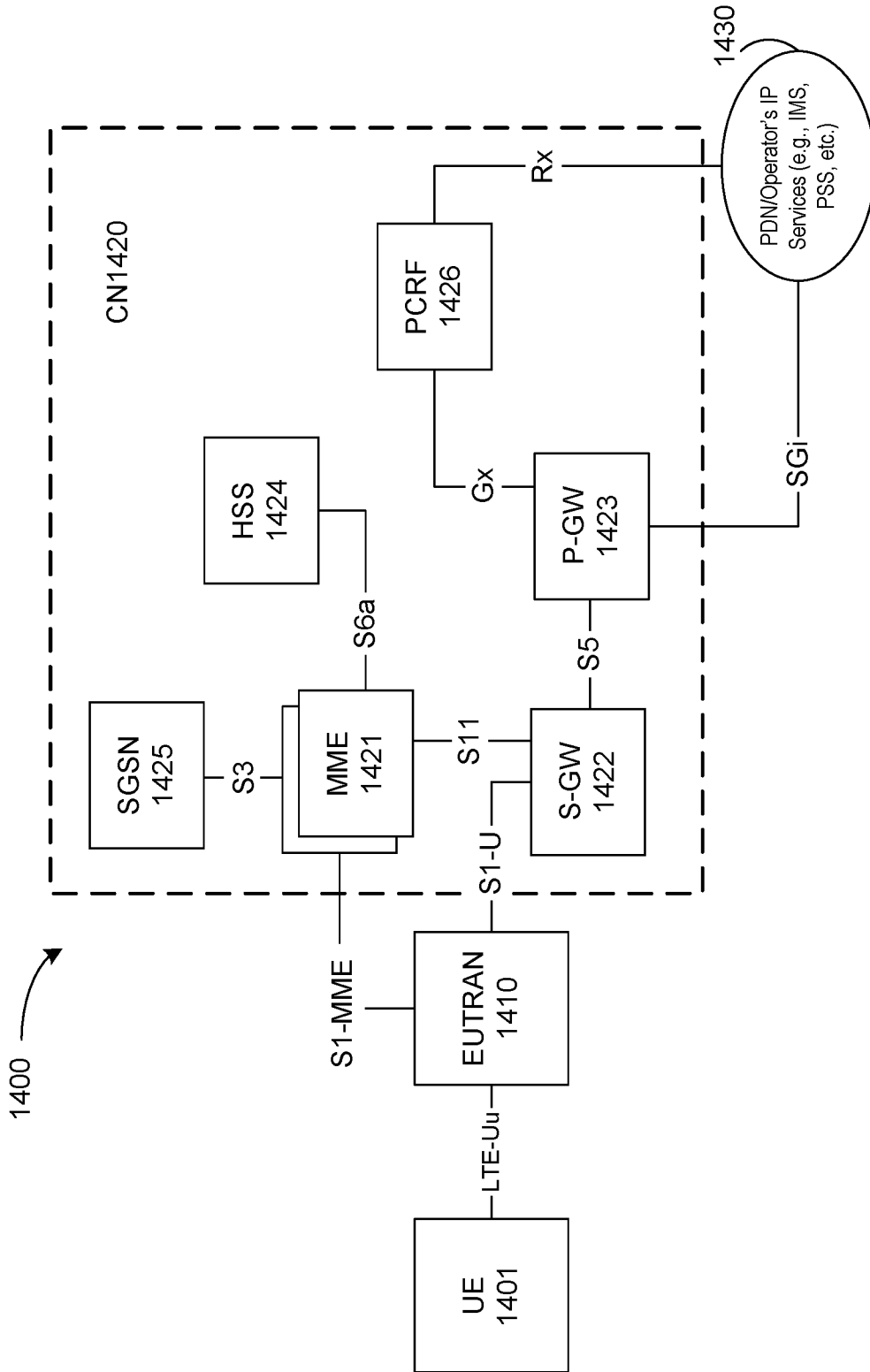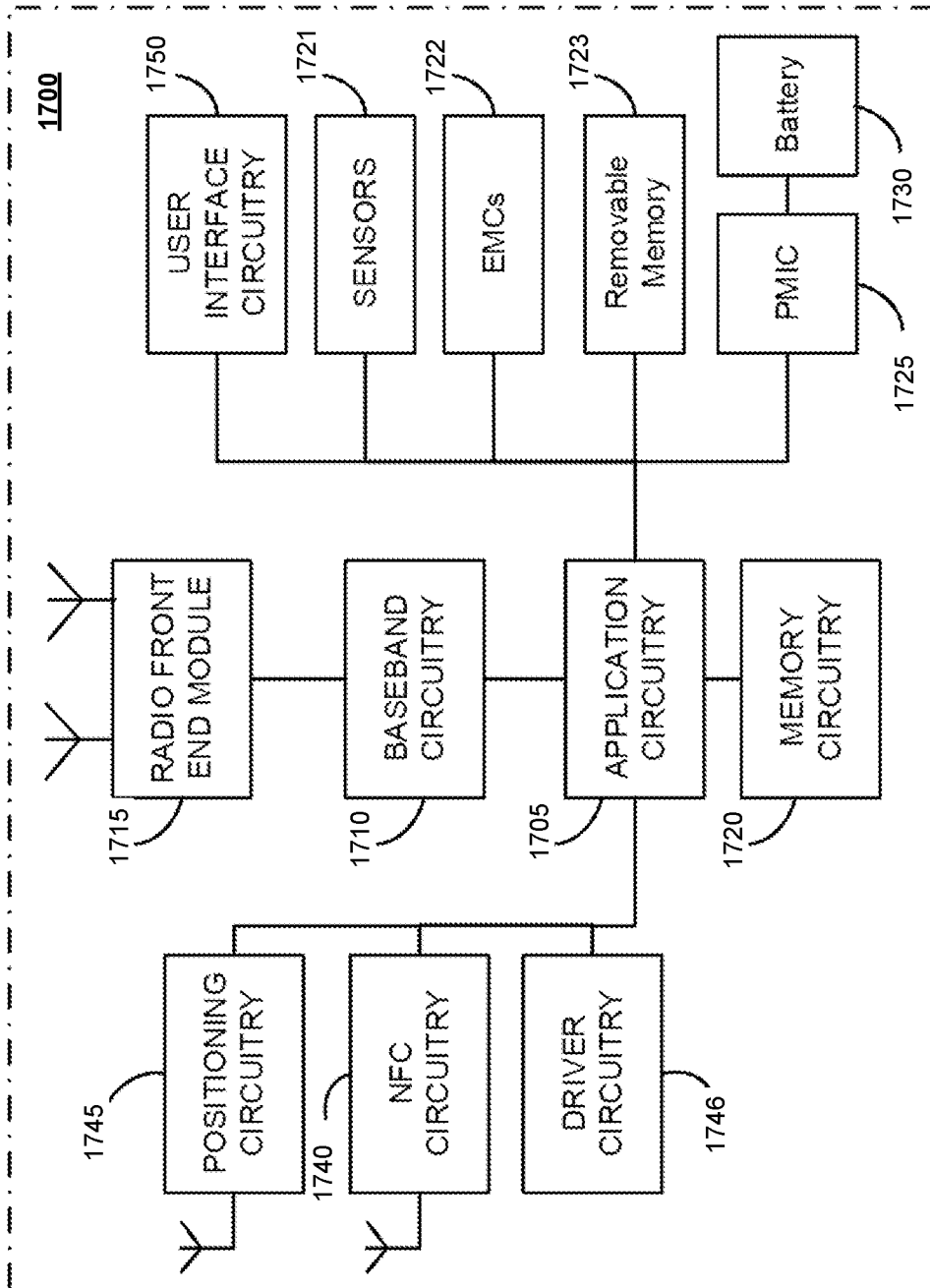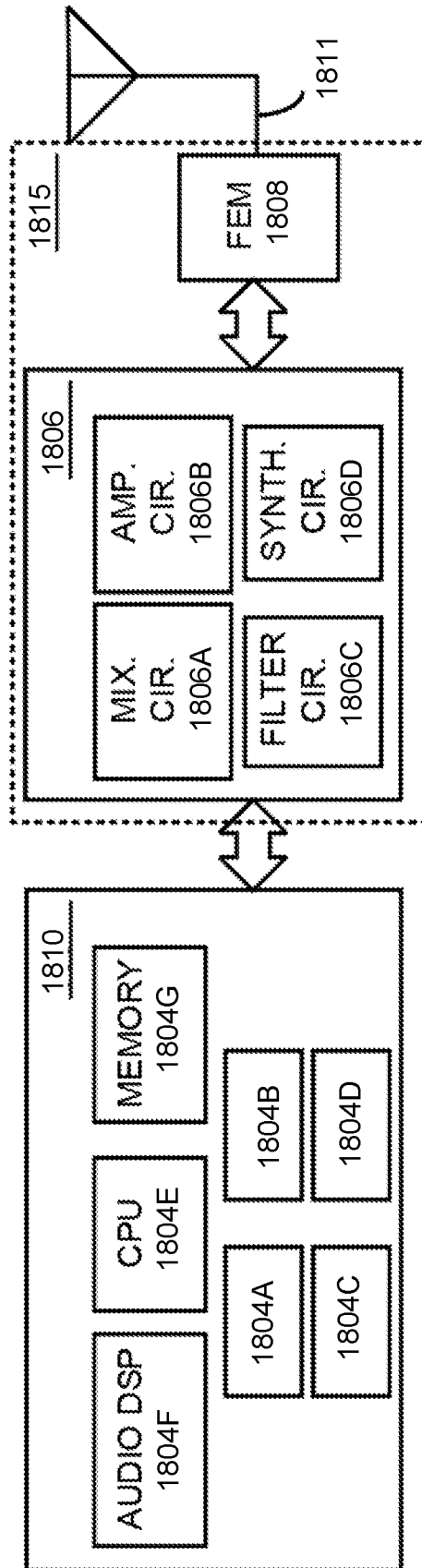
Figure 12

Figure 13

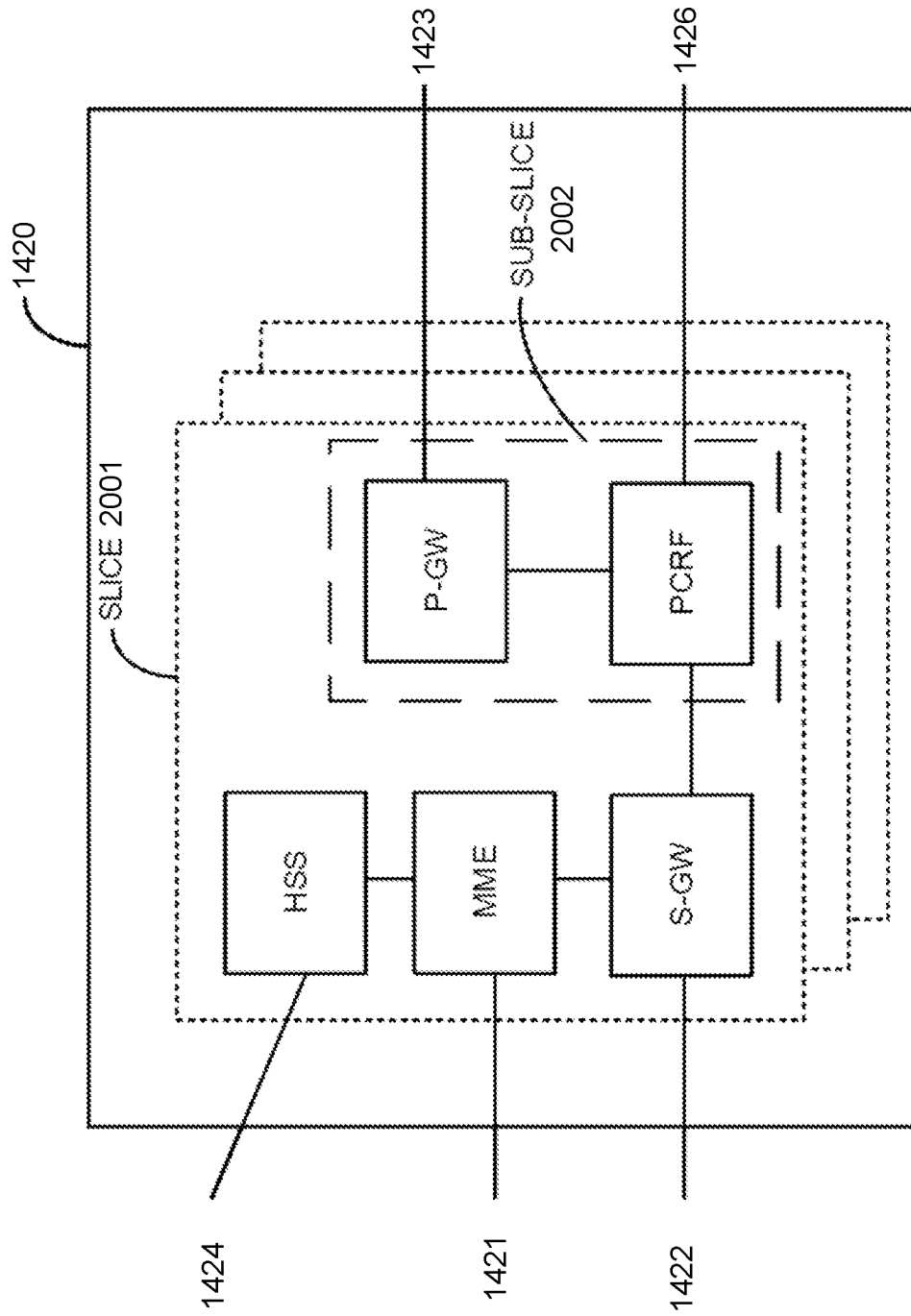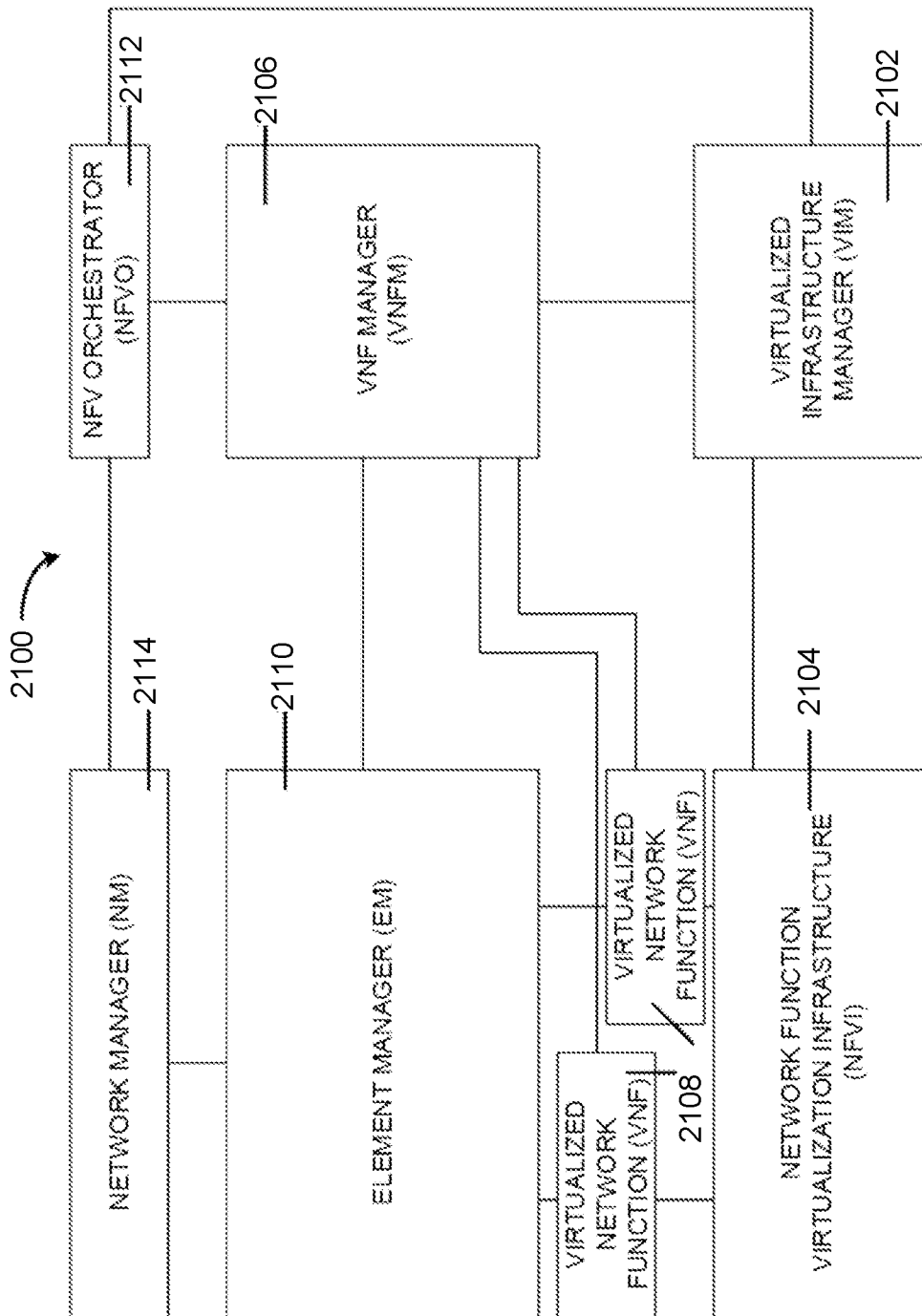**Figure 14**
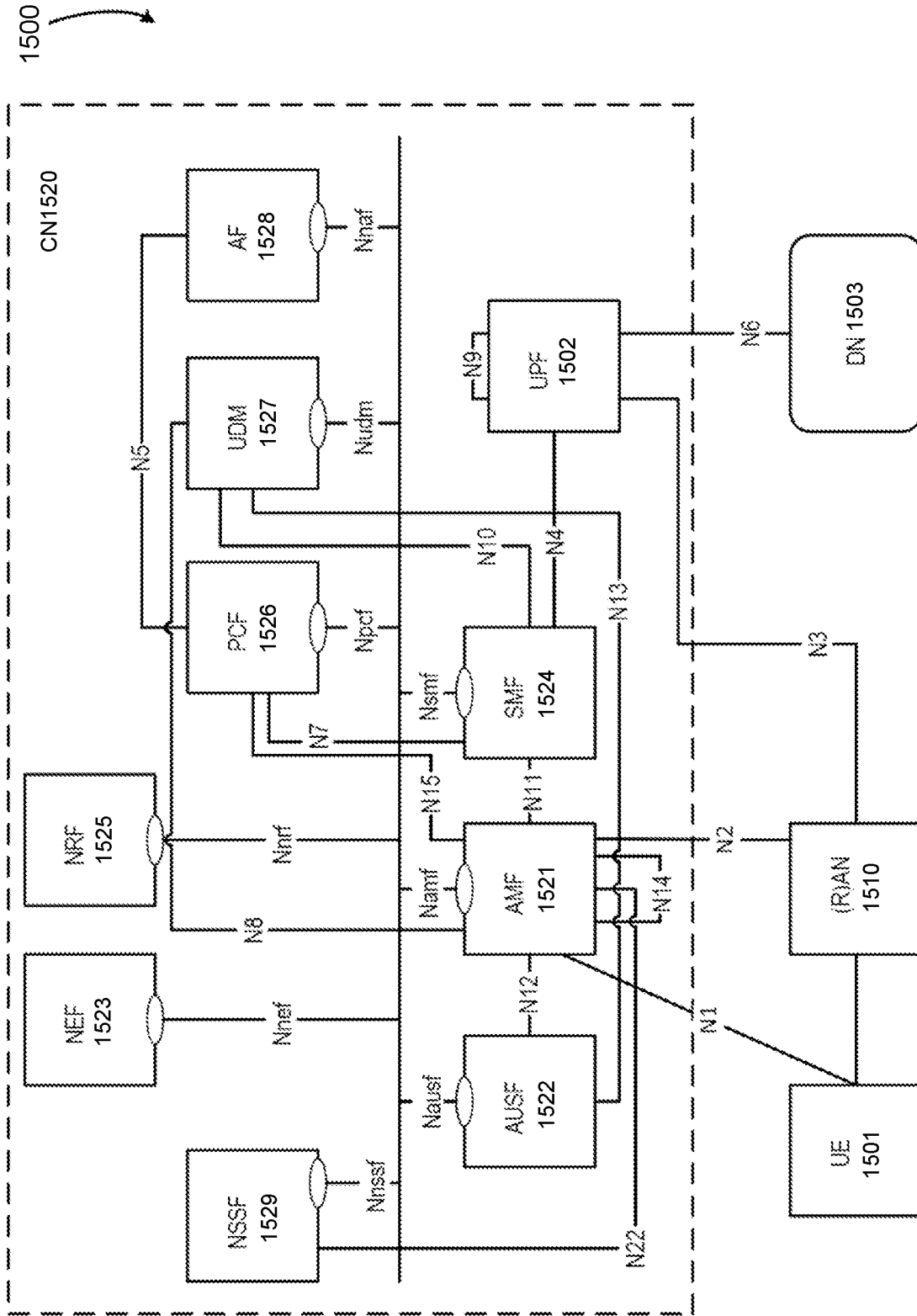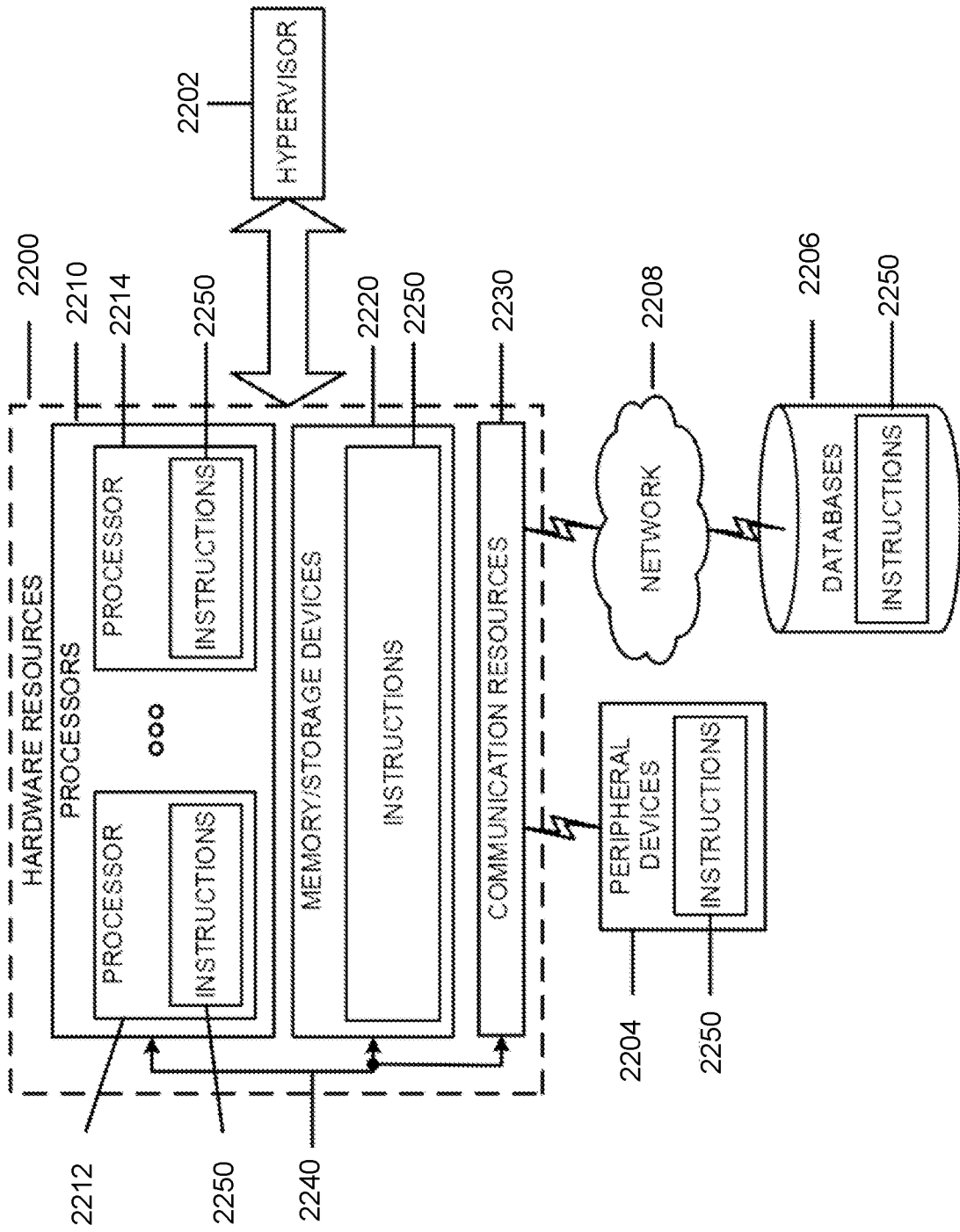
Figure 15
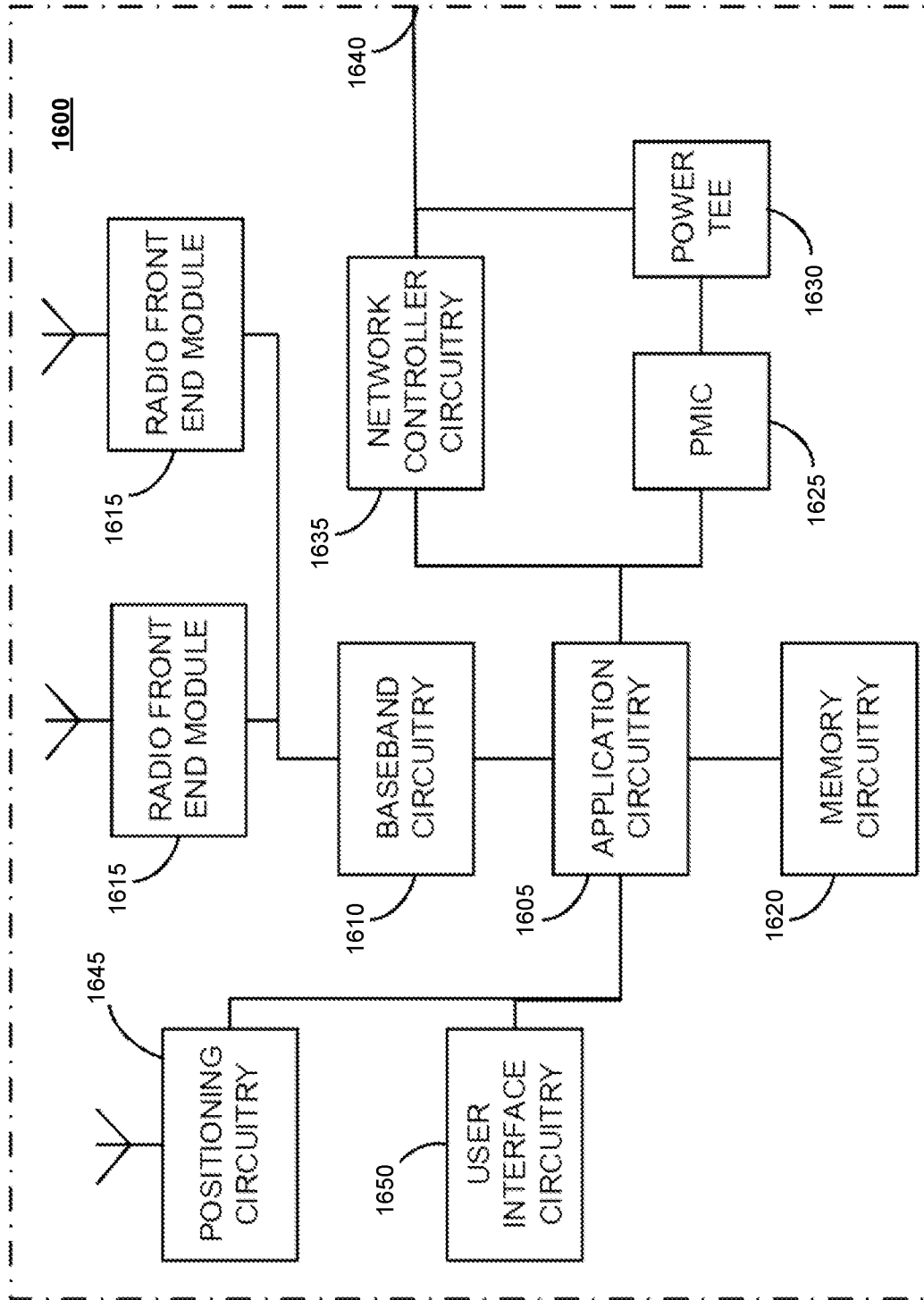
Figure 16
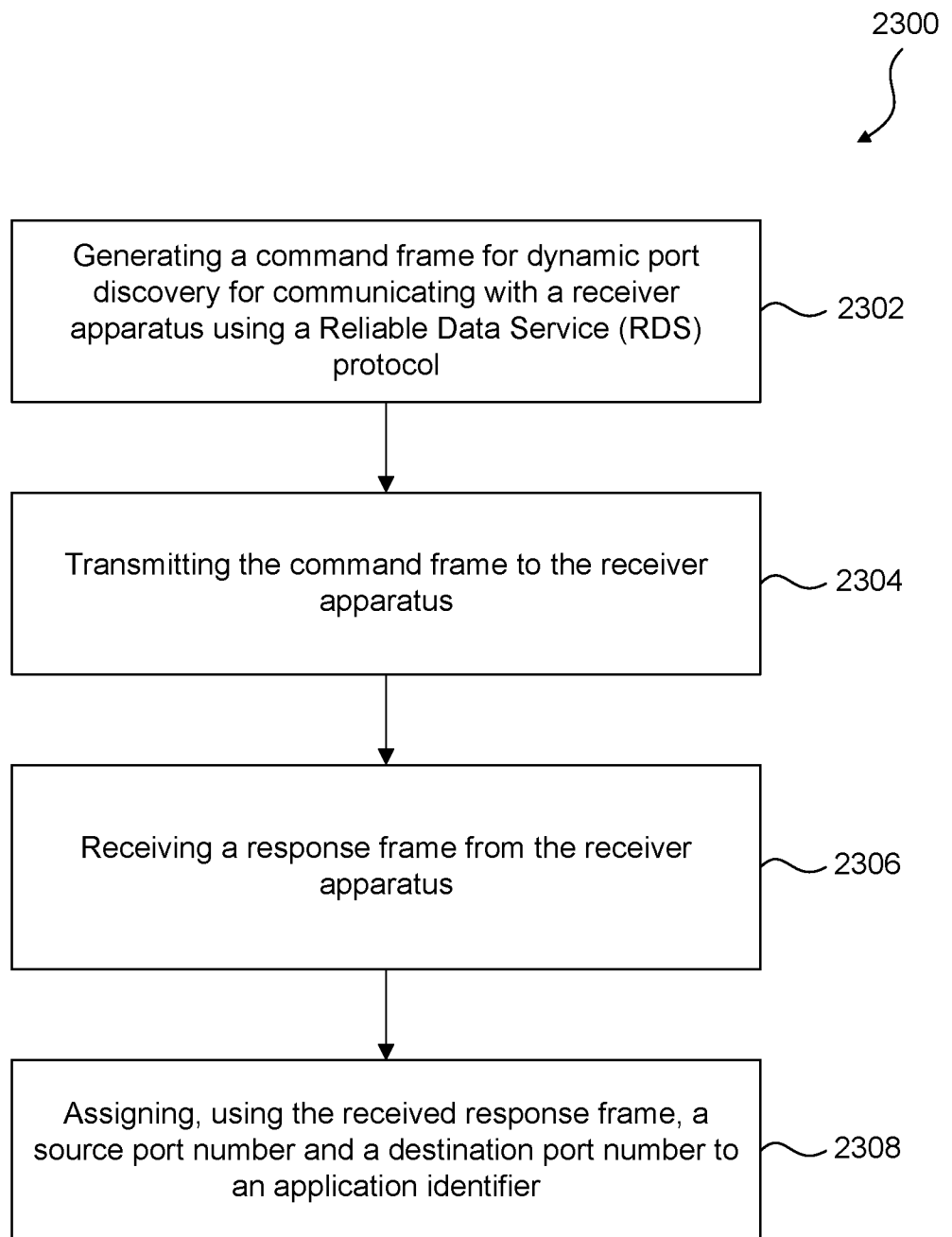
Figure 17

Figure 18
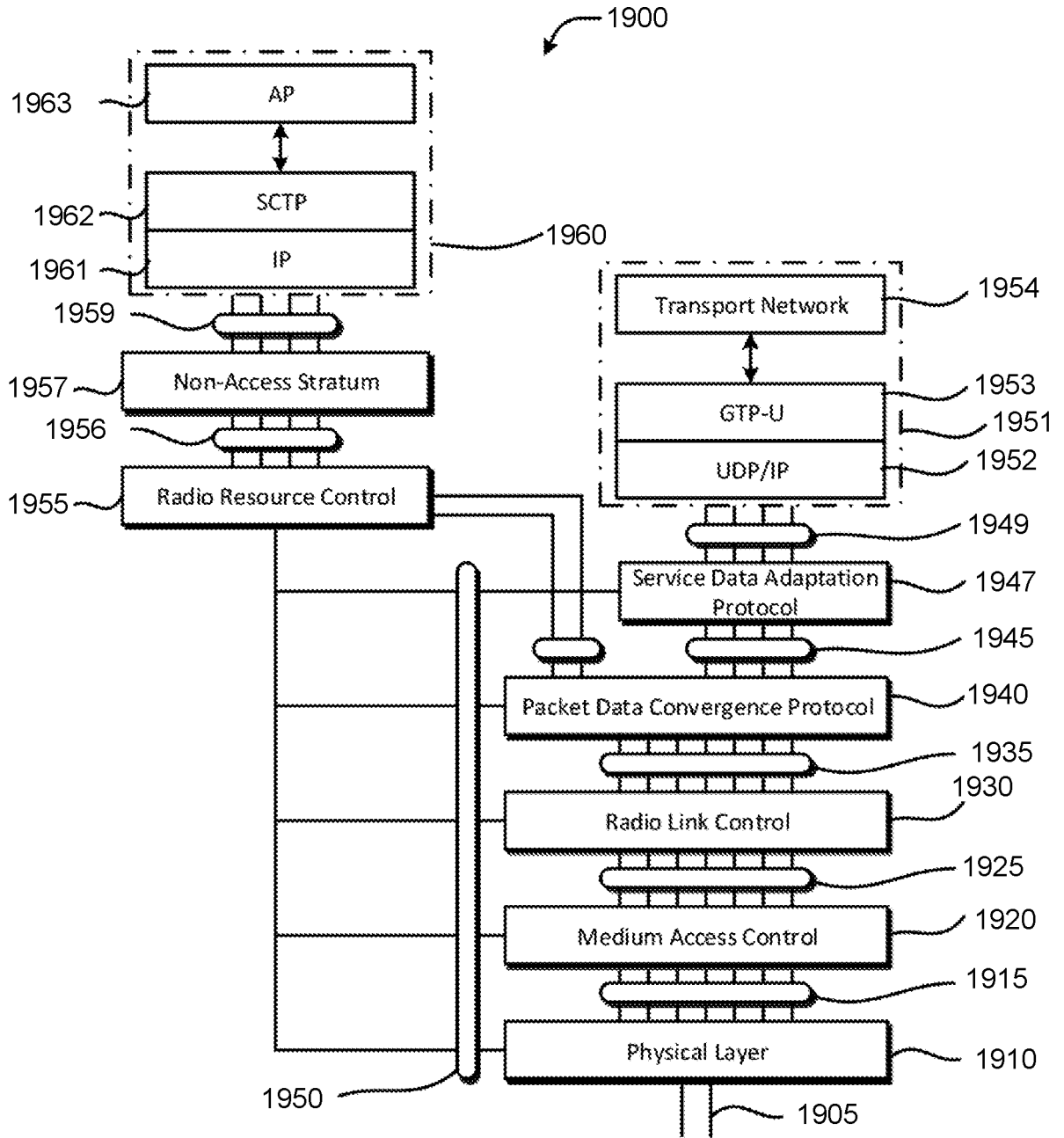
Figure 19

Figure 20

Figure 21

Figure 22

2300

Generating a command frame for dynamic port
discovery for communicating with a receiver
apparatus using a Reliable Data Service (RDS)
protocol   — 2302

Transmitting the command frame to the receiver
apparatus   — 2304

Receiving a response frame from the receiver
apparatus   — 2306

Assigning, using the received response frame, a
source port number and a destination port number to   — 2308
an application identifier

Figure 23

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
INV. G06F9/54
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

G06F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2018/144249 A1 (GUPTA VIVEK [US]; ZAUS ROBERT [DE]; JAIN PUNEET [US]) 9 August 2018 (2018-08-09) paragraphs [0091], [0139], [0140], [0148] - [0152], [0172], [0176], [0184], [0185], [0209], [0210], [0221] - [0223] -----	1-20
X	US 7 685 223 B1 (BASAVAIAH MURALI [US] ET AL) 23 March 2010 (2010-03-23) column 1, line 61 - line 67 column 2, line 1 - line 59 column 5 - column 6 -----	1-20

☐ Further documents are listed in the continuation of Box C.   ☒ See patent family annex.

* Special categories of cited documents :

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

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

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

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
31 March 2020	14/04/2020

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Buzgan, C

Form PCT/ISA/210 (second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

Information on patent family members

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
WO 2018144249	A1	09-08-2018	EP	3577941 A1	11-12-2019
			WO	2018144249 A1	09-08-2018
US 7685223	B1	23-03-2010	NONE		