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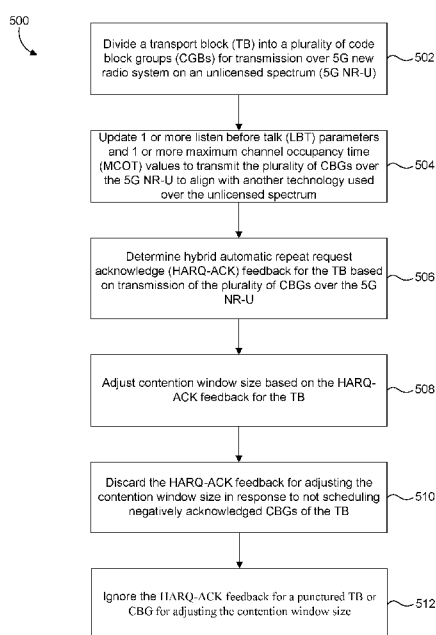
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OPERATING ON UNLICENSED SPECTRUM

FIG. 5

(57) Abstract: Systems, apparatuses, methods, and computer-readable media are provided for wireless communication using an unlicensed spectrum. An access point (AP) operating in the unlicensed spectrum includes a processor circuitry, a transmitter, and a receiver. The processor circuitry is configured to perform a listen before talk (LBT) procedure using an LBT parameter and a maximum channel occupancy time (MCOT) that is compatible with another wireless protocol using the unlicensed spectrum. The processor circuitry is configured to divide a transport block (TB) into a plurality of code block groups (CBGs) for transmission over the unlicensed spectrum. The transmitter is configured to transmit the plurality of CBGs to a destination, and a receiver is configured to receive hybrid automatic repeat and request acknowledgment (HARQ-ACK) information corresponding to the transmitted plurality of CBGs. The processor circuitry is further configured to determine a HARQ-ACK assessment for the TB based on the HARQ-ACK information corresponding to the transmitted plurality of CBGs, and adjust a contention window size based on the HARQ-ACK assessment for the TB.

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CONTENTION WINDOW SIZE UPDATE FOR CAT.4 LBT FOR CBG BASED
RETRANSMISSION IN NR SYSTEMS OPERATING ON UNLICENSED
SPECTRUM

CROSS REFERENCE TO RELATED APPLICATIONS

- [0001]** This application claims the benefit of U.S. Provisional Application No. 62/790,376, filed January 9, 2019, which is hereby incorporated by reference in its entirety.

BACKGROUND

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

BRIEF SUMMARY

- [0003]** The summary provides a brief description of one or more of embodiments and/or examples found within this disclosure.
- [0004]** This disclosure describes an access point (AP), or an apparatus thereof, for wireless communication using an unlicensed spectrum. The AP includes processor circuitry configured to perform a listen before talk (LBT) procedure using an LBT parameter and a maximum channel occupancy time (MCOT) that is compatible with another wireless protocol using the unlicensed spectrum. The processor circuitry is configured divide a transport block (TB) into a plurality of code block groups (CBGs) for transmission over the unlicensed spectrum. The AP includes a transmitter configured to transmit the plurality of CBGs to a destination, and a receiver configured to receive hybrid automatic repeat and request acknowledgement (HARQ-ACK) information corresponding to the transmitted plurality of CBGs. The processor circuitry is further configured to determine a HARQ-ACK assessment for the TB based on the HARQ-ACK information corresponding to the transmitted plurality of CBGs, and adjust a contention window size based on the HARQ-ACK assessment for the TB. In some embodiments, the other wireless protocol is Wi-Fi.

[0005] This disclosure also describes a method being performed by an access point for wireless communication on an unlicensed spectrum. The method includes performing a listen before talk (LBT) procedure using an LBT parameter and a maximum channel occupancy time (MCOT) that is compatible with another wireless protocol using an unlicensed spectrum. The method includes dividing a transport block (TB) into a plurality of code block groups (CBGs) for transmission over the unlicensed spectrum, and transmitting the plurality of CBGs to a destination. The method includes receiving hybrid automatic repeat and request acknowledgment (HARQ-ACK) information corresponding to the transmitted plurality of CBGs. The method includes determining HARQ-ACK assessment for the TB based on the HARQ-ACK information corresponding to the transmitted plurality of CBGs, and adjusting a contention window size based on the HARQ-ACK assessment for the TB. In some embodiments, the other wireless protocol is Wi-Fi.

[0006] This disclosure also describes computer-readable media (CRM) including computer instructions to be executed by one or more processors of an access point (AP) of a wireless communication system on an unlicensed spectrum. The computer instructions cause the one or more processors to perform a listen before talk (LBT) procedure using an LBT parameter and a maximum channel occupancy time (MCOT) that is compatible with another wireless protocol using an unlicensed spectrum. The instructions cause the one or more processors to divide a transport block (TB) into a plurality of code block groups (CBGs) for transmission over the unlicensed spectrum. The instructions cause the one or more processors to transmit the plurality of CBGs to a destination, and receive hybrid automatic repeat and request acknowledgment (HARQ-ACK) information corresponding to the transmitted plurality of CBGs. The instructions cause the one or more processors to determine HARQ-ACK assessment for the TB based on the HARQ-ACK information corresponding to transmitted plurality of CBGs, and adjust a contention window size based on the HARQ-ACK assessment for the TB. In some embodiments, the other wireless protocol is Wi-Fi.

BRIEF DESCRIPTION OF THE FIGURES

[0007] Figure 1 depicts an example of reference downlink (DL) burst in accordance with some embodiments.

- [0008] Figure 2 depicts another example of reference downlink (DL) burst in accordance with some embodiments.
- [0009] Figure 3 depicts an illustration of timing between uplink (UL) reference burst and CORESET containing UL grant reception or configured-grant downlink control information (DCI) in accordance with some embodiments.
- [0010] Figure 4 depicts an illustration of a partial physical uplink shared channel (PUSCH) repetition used as a reference burst in accordance with some embodiments.
- [0011] Figure 5 depicts an example procedure in accordance with some embodiments.
- [0012] Figure 6 depicts an architecture of a system of a network in accordance with some embodiments.
- [0013] Figure 7 depicts an architecture of a system including a first core network in accordance with some embodiments.
- [0014] Figure 8 depicts an architecture of a system including a second core network in accordance with some embodiments.
- [0015] Figure 9 depicts an example of infrastructure equipment in accordance with various embodiments.
- [0016] Figure 10 depicts example components of a platform in accordance with various embodiments.
- [0017] Figure 11 depicts example components of baseband circuitry and radio frequency circuitry in accordance with some embodiments.
- [0018] Figure 12 depicts an illustration of various protocol functions that may be used for various protocol stacks in accordance with various embodiments.
- [0019] Figure 13 illustrates components of a core network in accordance with various embodiments.
- [0020] Figure 14 is a block diagram illustrating components, according to some example embodiments, of a system to support network functions virtualization (NFV).
- [0021] Figure 15 depicts a block diagram illustrating components, according to some example embodiments, able to read instructions from a machine-readable or computer-readable medium (e.g., a non-transitory machine-readable storage medium) and perform any one or more of the methodologies discussed herein.

DETAILED DESCRIPTION

[0022] 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).

[0023] Each year, the number of mobile devices connected to wireless networks significantly increases. In order to keep up with the demand in mobile data traffic, necessary changes have to be made to system requirements to be able to meet these demands. Three critical areas that need to be enhanced in order to deliver this increase in traffic are larger bandwidth, lower latency, and higher data rates.

[0024] One of the major limiting factors in wireless innovation is the availability in spectrum. To mitigate this, the unlicensed spectrum has been an area of interest to expand the availability of LTE. In this context, one of the major enhancement for LTE in 3GPP Release 13 has been to enable its operation in the unlicensed spectrum via Licensed-Assisted Access (LAA), which expands the system bandwidth by utilizing the flexible carrier aggregation (CA) framework introduced by the LTE-Advanced system.

[0025] Now that the main building blocks for the framework of NR have been established, a natural enhancement is to allow this to also operate on unlicensed spectrum. The work to introduce shared/unlicensed spectrum in 5G NR has already been kicked off, and a new study item on “NR-Based Access to Unlicensed Spectrum” was approved in TSG RAN Meeting #77. The objective of this new SI is to study NR-based operation in unlicensed spectrum including:

1. Physical channels inheriting the choices of duplex mode, waveform, carrier bandwidth, subcarrier spacing, frame structure, and physical layer design made as

part of the NR study and avoiding unnecessary divergence with decisions made in the NR WI:

- Consider unlicensed bands both below and above 6GHz, up to 52.6GHz
 - Consider unlicensed bands above 52.6GHz to the extent that waveform design principles remain unchanged with respect to below 52.6GHz bands
 - Consider similar forward compatibility principles made in the NR WI
2. Initial access, channel access. Scheduling/HARQ, and mobility including connected/inactive/idle mode operation and radio-link monitoring/failure
 3. Coexistence methods within NR-based and between NR-based operation in unlicensed and LTE-based LAA and with other incumbent RATs in accordance with regulatory requirements in e.g., 5GHz , 37GHz, 60GHz bands

[0026] Coexistence methods already defined for 5GHz band in LTE-based LAA context should be assumed as the baseline for 5GHz operation. Enhancements in 5GHz over these methods should not be precluded. NR-based operation in unlicensed spectrum should not impact deployed Wi-Fi services (data, video and voice services) more than an additional Wi-Fi network on the same carrier.

[0027] While this SI is at its initial stage, it is important to identify aspects of the design that can be enhanced for NR when operating in unlicensed spectrum. One of the challenges in this case is that this system must maintain fair coexistence with other incumbent technologies, and in order to do so depending on the particular band in which it might operate some restriction might be taken into account when designing this system. For instance, if operating in the 5GHz band, a listen before talk (LBT) procedure needs to be performed in some parts of the world to acquire the medium before a transmission can occur.

[0028] In Rel. 15 NR, among other enhancements of the PHY layer, the HARQ procedure was improved and modified. In fact, Rel. 15 NR introduces the concept of code block groups (CBGs), wherein essentially a transport block (TB) is divided into smaller subsets, called CBGs. These groups are decoded by the UE, and the UE then sends HARQ feedback for each CBG. The aim for the CBGs based retransmission is to cope with the fact that NR supports very large transport block sizes (TBS) and as in legacy LTE the scheduler works with 10% BLER target. This implies that if the gNB is transmitting data to the UE with a large TBS, around 10% of this data is subject to

retransmission. However, if the TB is divided into smaller subsets, the UE will send NACK for only the failed subsets and the gNB only need to retransmit the failed subsets instead of the whole TB. This can effectively reduce the overhead of retransmission, and improve spectral efficiency, even though on the other side this will increase the HARQ feedback overhead, since the UE will no longer need to transmit a single bit per TB, but it will need to send multiple bits for each TB based on the number of CBGs. In order to reduce this overhead, the CBG-based (re)transmission procedure is configurable. In fact, a UE is semi-statically configured by RRC signaling to enable CBG-based retransmission, and the max number of CBGs per TB can be configured by RRC to be {2,4,6,8}. By changing the number of CBGs per TB, the number of code block (CB) per CBG changes also according to the TBS. In Rel. 15 NR, the CBG-based (re)-transmission is allowed only for the TB of a HARQ process. The CBG-based (re)transmission procedure is also separately configurable for UL and DL.

[0029] When operating the NR system on an unlicensed spectrum, before initiating any transmission the LBT procedure should be performed. In Rel-13 and Rel-14, the LBT priority classes, LBT parameters, and MCOT values provided in Table I for DL and Table II for UL were agreed.

Table I - LBT parameters and MCOT values for DL

LBT Priority Class	n	CW _{min}	CW _{max}	MCOT	Set of CW sizes
1	1	3	7	2 ms	{3,7}
2	1	7	15	3 ms	{7,15}
3	3	15	63	8 or 10 ms	{15,31,63}
4	7	15	1023	8 or 10 ms	{15,31,63,127,255,511,1023}
Channel Access Priority Class (<i>P</i>)					

Table II - LBT parameters and MCOT values for UL

<u>LBT</u> <u>priority</u> <u>class</u>	<u>n</u>	<u>CWmin</u>	<u>CWmax</u>	<u>MCOT</u>	<u>Set of CW sizes</u>
1	2	3	7	2 <u>ms</u>	{3,7}
2	2	7	15	4 <u>ms</u>	{7,15}
3	3	15	1023	6ms (see note 1) or 10 <u>ms</u> (see note 2)	{15,31,63,127,255,511,1023}
4	7	15	1023	6ms (see note 1) or 10 <u>ms</u> (see note 2)	{15,31,63,127,255,511,1023}
NOTE 1: The <u>MCOT</u> of 6 <u>ms</u> may be increased to 8 <u>ms</u> by inserting one or more gaps. The minimum duration of a pause shall be 100 μs. The maximum duration (Channel Occupancy) before including any such gap shall be 6 <u>ms</u>. The gap duration is not included in the channel occupancy time. NOTE 2: If the absence of any other technology sharing the carrier can be guaranteed on a long term basis (e.g. by level of regulation), the maximum channel occupancy time (<u>MCOT</u>) for <u>LBT</u> priority classes 3 and 4 is for 10 <u>ms</u>, otherwise, the <u>MCOT</u> for <u>LBT</u> priority classes 3 and 4 is 6ms as in note 1.					

[0030] In legacy LAA, the contention windows size (CWS) is adapted based on the HARQ-ACK feedback.

[0031] For DL: Given a reference subframe set (which is the first DL subframe of the latest DL data burst for which HARQ-ACK feedback is available) the CWS is increased if at least 80% of the HARQ-ACK feedback values for a reference subframe are NACK. Otherwise, the CWS is reset to the minimum value.

[0032] For UL: Given a reference subframe (which is the first subframe with UL-SCH that was transmitted at least 4 ms prior to the UL grant reception in the most recent transmitted burst of contiguous subframes that is transmitted after performing a category 4 LBT procedure) and the HARQ_ID_ref, which is the HARQ ID of the reference subframe, the CWS of all priority classes at the UE is reset for all the priority classes if an UL grant is received and the NDI bit for at least one of the active HARQ processes (i.e. TB not disabled) of HARQ_ID_ref is toggled. Otherwise (i.e. HARQ_ID_ref not scheduled or NDI of the active HARQ process(es) of HARQ_ID_ref not toggled) the

contention window size of all priority classes at the UE is increased to the next higher value. Furthermore, the CWS is reset to the minimum value if the maximum CWS is used for K consecutive LBT attempts for transmission only for the priority class for which maximum CWS is used for K consecutive LBT attempts, where K is selected by UE implementation from the set of values from (1, ...,8).

[0033] While it is likely that for NR operating on unlicensed spectrum Table I and Table II will be re-used as they are, the CWS adjustment procedure for DL and UL might be instead modified. In fact, while in legacy LAA, a TB-based (re)transmission procedure is used, and the CWS adjustment is tailored based on it, in NR-U a CBG-based retransmission procedure is used. This disclosure provides multiple options on how to update the CWS when a CBG-based (re)transmission procedure is used.

[0034] When operating a cellular system on an unlicensed spectrum, the LBT procedure might be required by the regional regulation, and a CWS adjustment procedure which maintains fair coexistence with other incumbent technologies is needed. In LTE LAA, the CWS adjustment procedure is based on the HARQ-ACK feedback, where a TB-based retransmission procedure is used. In Rel.15 NR, a CBG-based (re)transmission was introduced, and for this reason the legacy CWS adjustment procedure cannot be reused. In this disclosure, multiple options on how to update the CWS are provided.

[0035] In Rel. 15 NR, among other enhancements of the PHY layer the concept of code block groups (CBGs) based transmission was introduced to reduce overhead and increase spectral efficiency when data packet with large TBS is transmitted. A TB is divided into multiple CBSs, and upon decoding the CBGs a UE sends HARQ-ACK feedback for each individual CBG rather than for the TB, and the gNB only retransmits the CBGs that were not received or decoded. While this procedure is efficient for large TBS, this might induce large overhead for the HARQ-ACK feedbacks, which could overcome the benefit of reducing overhead for the retransmission for small TBSs. For this reason, the CBG-based retransmission procedure is configurable. In fact, a UE is semi-statically configured by RRC signaling to enable CBG-based retransmission, and the max number of CBGs per TB can be configured by RRC to be {2,4,6,8}, and it is separately configured for UL and DL.

[0036] When operating the NR system on an unlicensed spectrum (NR-U), before initiating any transmission the LBT procedure should be performed, and its CWS should

be adjusted based on the HARQ-ACK feedback. During the LAA WI, a CWS adjustment procedure was introduced in order to allow fair coexistence with incumbent technologies. For NR-U a similar intention should be maintained when designing the corresponding CWS adjustment procedure. While the Rel-14 LBT priority classes, LBT parameters, and MCOT values, summarized in Table I, will be reused as they are for NR-U, the same does not apply for the LTE LAA Rel-14 CWS adjustment procedure, which requires some modifications to cope with the CBG-based retransmission procedure introduced in Rel-15 for NR.

Sets for CWS adjustment

[0037] In one embodiment, the parameters from Table I and Table II are reused. In one embodiment, the LBT parameters and MCOT values for Table II are as in Table III to align NR-U toward Wi-Fi and allow the two technologies to be in par. In particular, note that for the below table as an example $CW_{max}=1023$.

Table III - LBT parameters and MCOT values for UL in terms of aCW_{max}

<u>LBT</u> priority class	<u>n</u>	<u>CW_{min}</u>	<u>CW_{max}</u>	<u>MCOT</u>	Set of <u>CW</u> sizes
1	2	$\{(aCW_{max}+1)/256-1\}$	$\{(aCW_{max}+1)/128-1\}$	2 <u>ms</u>	{3,7}
2	2	$\{(aCW_{max}+1)/128-1\}$	$\{(aCW_{max}+1)/64-1\}$	4 <u>ms</u>	{7,15}
3	3	$\{(aCW_{max}+1)/64-1\}$	<u>aCW_{max}</u>	6ms (see note 1) or 10 <u>ms</u> (see note 2)	{15,31,63,127,255,511,1023}
4	7	$\{(aCW_{max}+1)/64-1\}$	<u>aCW_{max}</u>	6ms (see note 1) or 10 <u>ms</u> (see note 2)	{15,31,63,127,255,511,1023}
NOTE 1: The <u>MCOT</u> of 6 <u>ms</u> may be increased to 8 <u>ms</u> by inserting one or more gaps. The minimum duration of a pause shall be 100 μs. The maximum duration (Channel Occupancy) before including any such gap shall be 6 <u>ms</u>. The gap duration is not included in the channel occupancy time. NOTE 2: If the absence of any other technology sharing the carrier can be guaranteed on a long term basis (e.g. by level of regulation), the maximum channel occupancy time (<u>MCOT</u>) for <u>LBT</u> priority classes 3 and 4 is for 10 <u>ms</u>, otherwise, the <u>MCOT</u> for <u>LBT</u> priority classes 3 and 4 is 6ms as in note 1.					

CWS Adjustment in NR-U for DL

[0038] In Rel.13, the following was agreed: CWS is increased to the next higher value if at least 80% of the HARQ-ACK feedback values for a reference subframe set are NACK. Otherwise, the CWS is reset to the minimum value.

[0039] As in NR, a CBG-based (re)-transmission is introduced, therefore the CWS adjustment procedure defined for LAA might be modified to clarify how the feedbacks for each CBG are counted toward X% of the HARQ-ACK feedbacks, where X is in one example 80.

- [0040] In some embodiments, a reference DL burst is defined for the CWS adjustment as shown in FIG. 1. As shown in FIG. 1, the reference burst 104 is always 1 ms long independently from the subcarrier spacing and starts from the beginning of the DL burst 102.
- [0041] In some embodiments, the reference burst 204 is composed of the partial subframe (SF) or slot from the beginning of the DL burst 202 + following SF or slot 206 independently from the subcarrier spacing, as illustrated in FIG. 2.
- [0042] In some embodiments, when the partial subframe is the only subframe included in the reference DL burst, only the partial subframe is used for CWS adjustment.
- [0043] In some embodiments, the reference burst is composed of N symbols (e.g., 14) from the start of the DL burst, where N is RRC configured, and N may be larger than the number of symbols in the partial slot.
- [0044] In some embodiments, the reference burst is composed of the partial slot only.
- [0045] In some embodiments, the reference burst is composed of T ms, or μ s, starting from the beginning of the DL burst, where T, for example, is 1 ms.
- [0046] In some embodiments, when the CBG-based transmission is configured, the NACKs are counted such that if a NACK is received for at least one of the CBG for a specific TB, all other CBG feedbacks for that TB within the reference slot set are also counted as NACK.
- [0047] In some embodiments, when the CBG-based transmission is configured, each feedback is counted individually for each CBG within a TB as either a NACK or an ACK independently of the value of the other CBG feedback for that TB.
- [0048] In some embodiments, the ACK/NACK is counted per TB, which requires a representation of ACK/NACK for each TB with CBG based HARQ ACK feedback. In this case in one embodiment, a TB can be counted as NACK, if 1) all the CBGs comprising the TB are NACK'ed, 2) at least one CBG is NACK'ed, or 3) X % of CBGs are NACK'ed.
- [0049] In some embodiments, when CBG-based transmission is configured, the NACK is counted on a per TB basis, meaning that all the CBGs per TB are bundled into one bit. In this case if the gNB doesn't schedule at least one or all unsuccessful CBGs of a TB, we see 2 choices: either the TB is be considered as a NACK even though all scheduled CBG are correctly received, or the TB is not counted for CWS adjustment in this case. By way

of non-limiting example, only the currently scheduled CBGs are considered to derive bundled HARQ-ACK for CWS adjustment.

[0050] In some embodiments, a TB can be counted as NACK, if 1) all the currently scheduled CBGs of the TB are NACK'ed, 2) at least one of the currently scheduled CBG is NACK'ed, or 3) X % of currently scheduled CBGs are NACK'ed.

[0051] In some embodiments, since some UEs may be configured with CBG-based transmission while others would perform TB based transmission, the percentage of NACKs Z is evaluated through one of the following ways:

$$\begin{aligned} 1. \quad Z &= (c * NACK_{CBG} + t * NACK_{TB}) / (c * N_{CBG} + t * N_{TB}) \quad (1) \\ 2. \quad Z &= (u * NACK_{CBG} + (1-u) * NACK_{TB}) / (u * N_{CBG} + (1-u) * N_{TB}) \quad (2) \end{aligned}$$

where $NACK_{CBG}$ is the number of NACKs per CBG in the reference DL burst, $NACK_{TB}$ is the number of NACKs per TB in the reference DL burst, N_{CBG} is the total number of CBGs feedbacks in the DL reference burst, N_{TB} is the total number of TBs feedbacks in the DL reference burst.

[0052] In some embodiments, if equ. (1) is used, then “c” and “t” are two variables, where for example $0 \leq c \leq 1$ and $0 \leq t \leq 1$. Note that the variables “c” and “t” may be defined as a function of maximum number of CBG within a slot for UEs or 8. In another option, these two values may depend on the number of TB and/or CBG transmissions scheduled in the window or DL burst.

[0053] In some embodiments, the value of c and/or t are RRC configurable or depends on the configuration.

[0054] In some embodiments, if equ. (2) is used, “u” is a variable such that $0 \leq u \leq 1$. The value of u is RRC configurable or depends on the configuration.

[0055] In some embodiments, the TBs/CBGs/ CBs feedbacks for one or more of the following cases are not used for the CWS adjustment:

1. TB/CBG/CB that is punctured by others, e.g., URLLC
 2. In the initial partial slot, the TB/CBG/CB is punctured due to late channel occupation
 3. Due to BWP switch, UE doesn't report HARQ-ACK for certain PDSCH.
- In this case, the transmission is considered a NACK as default or it is ignored for the CWS adjustment.

4. If gNB doesn't schedule at least one or all unsuccessful CBGs of a TB, such TB is not counted.

[0056] In some embodiments, for self-scheduling DTX is considered as an indication of collision and as a NACK in the matter of the CWS adjustment mechanism. In one embodiment, for cross-carrier scheduling, DTX is ignored for the matter of the CWS adjustment mechanism. In one embodiment, for cross-carrier scheduling, DTX is considered as an indication of collision and as a NACK in the matter of the CWS adjustment for the scheduling cell. In one embodiment, DTX is considered as an indication of collision and as a NACK in the matter of the CWS adjustment in case that the related PDCCH is transmitted in a DL burst followed by CAT-4 LBT. In one embodiment, DTX is considered as an indication of collision and as a NACK in the matter of the CWS adjustment in case that the related PDCCH is transmitted in the reference burst within a DL burst followed by CAT-4 LBT.

[0057] Another aspect that needs to be considered is the CWS update for the gNB when the acquired COT is shared with grant-free or scheduled UEs, or when PDSCH transmission is not performed by the gNB.

[0058] In some embodiments, if the gNB performs PDSCH transmissions, and part of the acquired MCOT is configured for UL transmissions with overlapping time-domain resources for scheduled or grant-free transmissions, in one embodiment, the CWS update is performed as described above.

[0059] In some embodiments, if the gNB does not perform any PDSCH transmissions, part of the acquired MCOT is configured for UL transmissions with overlapping time-domain resources.

[0060] In some embodiments, if eNB schedules UL transport blocks (TBs) with 25 μ s LBT in a shared COT without any PDSCH, the gNB increases the CWS if less than X% of the scheduled UL TBs are not successfully received or if less than X% of the CBGs for the scheduled UL are not successfully received, where X is as an example 10, or in case $Q*100$ is less than X, where Q is given by one of the following equations:

$$1. \quad Q = (c * NACK_{CBG} + t * NACK_{TB}) / (c * N_{CBG} + t * N_{TB}), \quad (3)$$

$$2. \quad Q = (u * NACK_{CBG} + (1-u) * NACK_{TB}) / (u * N_{CBG} + (1-u) * N_{TB}), \quad (4)$$

where $NACK_{CBG}$ is the number of NACKs per scheduled UL CBG in the reference DL burst, $NACK_{TB}$ is the number of NACKs per UL scheduled TB in the reference DL burst,

N_{CBG} is the total number of scheduled UL CBGs feedbacks in the DL reference burst, N_{TB} is the total number of UL scheduled TBs feedbacks in the DL reference burst.

- [0061] In some embodiments, if equ. (3) is used “c” and “t” are two variables. In another option, these two values may depend on the number of TB and/or CBG transmissions scheduled in the shared COT.
- [0062] In some embodiments, the value of “c” and/or “t” are RRC configurable or depends on the configuration.
- [0063] In some embodiments, if equ. (4) is used, “u” is a variable such that $0 \leq u \leq 1$. The value of u is RRC configurable or depends on the configuration
- [0064] In some embodiments, if gNB schedules UL transport blocks (TBs) with 25 μ s LBT in a shared COT without any PDSCH, and also shares the MCOT with grant-free UEs, the CWS update is performed based on the schedule and/or grant-free TBs or CBGs that have been detected by the gNB.

CWS Adjustment in NR-U for UL

- [0065] In some embodiments, for the Category 4 LBT for UL transmission, the CWS is adjusted per UE and at UE.
- [0066] In some embodiments, a reference UL burst is defined for the CWS adjustment as follows.
- [0067] In some embodiments, the reference UL burst is always 1 ms long independently from the subcarrier spacing and starts from the beginning of the UL burst.
- [0068] In some embodiments, the reference burst is composed by the partial SF from the beginning of the UL burst + following SF independently from the subcarrier spacing. In case the partial subframe is the only subframe included in the reference UL burst, only the partial subframe is used for CWS adjustment
- [0069] In some embodiments, the reference burst is composed by N symbols from the start of the UL burst, where N is RRC configured, and N may be larger than the number of symbols that compose the initial partial slot.
- [0070] In some embodiments, the reference burst is composed by the initial partial slot only.
- [0071] In some embodiments, the reference burst is composed by T ms starting from the beginning of the UL burst, where T is for example 1 ms.

[0072] In some embodiments, the gNB configures a number of symbols N , so that the reference burst occurs at least in symbol $ns-N$, where ns is the first or last symbol of the CORESET containing the UL grant or a DFI DCI. In one embodiment, N is evaluated as

$$N = N_x + Y, \quad (5)$$

where N_x is the processing delay based on gNB capability for PUSCH decoding (which depends on the subcarrier spacing), and y is a margin to give gNB freedom for scheduling.

[0073] By way of non-limiting example, in some embodiments, N is evaluated as

$$N = N_x + TA + Y, \quad (6)$$

where N_x is the processing delay based on gNB capability for PUSCH decoding (which depends on the subcarrier spacing), and y is a margin to give gNB freedom for scheduling, and TA is the time advance of the UE.

[0074] In some embodiments, similarly as in legacy LTE-LAA, the gNB configures a number of slot N_{306} , so that the UL reference burst 302 occurs before $ns-N$, where ns is here the slot containing the UL grant or the DFI DCI 304 as illustrated in FIG. 3.

[0075] In some embodiments, the $HARQ_ID_ref$ is defined as the HARQ process identifier (ID) of the reference burst.

[0076] In some embodiments, for scheduled UEs if the NDI bit for at least one of the active HARQ processes of $HARQ_ID_ref$ in the reference burst is toggled, the contention window size at the UE is reset for all the priority classes.

[0077] In some embodiments, if the $HARQ_ID_ref$ is not scheduled or NDI of the active HARQ process(es) of $HARQ_ID_ref$ is not toggled, the contention window size of all priority classes at the UE is increased to the next higher value.

[0078] In one embodiment, if CBG-based transmission is configured, the individual bits of the CBG Transmit Information (CBGTI) = 1 is considered as failure when the NDI is not toggled (i.e. retransmission) for the same HARQ process, i.e. NACK, otherwise it is considered as successful, i.e. ACK. In one embodiment, the CBGs are bundled to represent the information on TB failure/success in the CWS adjustment mechanism.

[0079] In some embodiments, if CBG-based transmission is configured, all CBGs of a TB transmitted in the reference burst is considered in CWS adjustment.

- [0080] In some embodiments, if CBG-based transmission is configured, only the currently transmitted CBGs of a TB transmitted in the reference burst is considered for CWS adjustment.
- [0081] In some embodiments, when the CBG-base transmission is configured, the NACK are counted such that if a NACK is received for at least one of the CBG for a specific TB, all other CBG feedbacks for that TB within the reference burst set are also counted as NACK. By way of non-limiting example, in some embodiments, when the CBG-based transmission is configured, each feedback is counted individually for each CBG within a TB as either a NACK or an ACK independently of the value of the other CBG feedback for that TB.
- [0082] In some embodiments, the ACK/NACK is counted per TB, which requires a representation of ACK/NACK for each TB with CBG based HARQ ACK feedback. In this case in one embodiment, a TB can be counted as NACK, if 1) all the CBGs comprising the TB are NACK'ed, 2) at least one CBG is NACK'ed, or 3) X % of CBGs are NACK'ed.
- [0083] In some embodiments, the percentage of NACKs X is evaluated through one of the following equations:
1. $X = (c * NACK_{CBG} + t * NACK_{TB}) / (c * N_{CBG} + t * N_{TB}), (7)$
 2. $X = (u * NACK_{CBG} + (u-1) * NACK_{TB}) / (u * N_{CBG} + (u-1) * N_{TB}), (8)$
- where $NACK_{CBG}$ is the number of NACKs per CBG in the reference UL burst, $NACK_{TB}$ is the number of NACKs per TB in the reference UL burst, N_{CBG} is the total number of CBGs feedbacks in the UL reference burst, N_{TB} is the total number of TBs feedbacks in the UL reference burst.
- [0084] In some embodiments, if equ. (7) is used, “c” and “t” are two variables. In another option, these two values may depend on the number of TB and/or CBG transmissions scheduled in the UL burst. The value of “c” and/or “t” are RRC configurable or depends on the configuration.
- [0085] In some embodiments, if equ. (8) is used, “u” is a variable such that $0 \leq u \leq 1$. The value of u is RRC configurable or depends on the configuration.
- [0086] In some embodiments, as in Rel-14, the CWS is reset to the minimum value if the maximum CWS is used for K consecutive LBT attempts for transmission only for the

priority class for which maximum CWS is used for K consecutive LBT attempts, and the value of K is left up to UE's implementation.

[0087] For grant-free uplink transmission in NR-U, in some embodiments, if an UL grant or a DFI-DCI is received, the CWS is reset for all the priority classes if a UL grant is received and the NDI bit for at least one of the active HARQ processes associated with HARQ_ID_ref is toggled or an DFI-DCI is received and indicates ACK for all the CBGs for at least one of the active HARQ processes associated with HARQ_ID_ref, ACK for one of the CBGs for at least one of the active HARQ processes associated with HARQ_ID_ref, or ACK for Y% of the CBGs for at least one of the active HARQ processes associated with HARQ_ID_ref.

[0088] In some embodiments, the CWS of all priority classes at the UE is increased to the next higher value if a UL grant is received and the NDI bit(s) of all the active HARQ process(es) for the reference burst are not toggled, or a UL grant is received and does not schedule any active HARQ process for the reference burst or a DFI-DCI is received which does not indicate ACK for all the CBGs for at least one of the active HARQ processes for the reference burst, ACK for X% of all the CBGs for at least one of the active HARQ processes for the reference burst, or ACK for X% of the CBGs for at least one of the active HARQ processes associated with HARQ_ID_ref.

[0089] In some embodiments, as in Rel-14, the CWS is reset to the minimum value if the maximum CWS is used for K consecutive LBT attempts for transmission only for the priority class for which maximum CWS is used for K consecutive LBT attempts, and the value of K is left up to UE's implementation.

[0090] If there exist at least one previous Category 4 (Cat-4) LBT UL transmission, from the start slot of which, N or more slots have elapsed and neither UL grant nor DFI-DCI is received, where as an example $N = \max(X, \text{corresponding UL burst length} + 1)$ if $X > 0$ and $N = 0$ otherwise, where X is RRC configured. For each previous Cat-4 LBT (SUL/AUL) transmission from the start slot of which, N or more slots have elapsed and neither UL grant nor DFI-DCI is received CWS for all priority classes at the UE is increased to the next higher value, and each such previous Cat-4 LBT transmission is used to adjust the CWS only once.

[0091] If the UE starts a new Cat-4 LBT UL transmission before N slots have elapsed from the previous Cat-4 LBT and neither UL grant nor DFI-DCI is received, the CWS is unchanged.

- [0092] If the UE receives feedback for one or more previous Cat-4 LBT (SUL/AUL) transmission from the start slot of which, N or more slots have elapsed and neither UL grant nor DFI-DCI was received, it may re-compute the CWS as follows: i) it reverts the CWS to the value used to transmit the first burst of such previous Cat-4 LBT transmission(s); ii) it updates the CWS sequentially in order of the transmission of bursts as follows. If the feedback indicates ACK for all the CBGs for the first slot of the burst, or ACK for X% of all CBGs for the first slot of the burst, CWS is reset else the CWS is doubled. If the UE CWS changes while a Cat-4 LBT procedure is ongoing, the UE draws a new random back-off counter and applies it to the ongoing LBT procedure.
- [0093] In some embodiments, only the PUSCH for one or more of the following cases are used for the CWS adjustment:
- I. Only PUSCH whose starting symbol is within the reference burst;
 - II. Only PUSCH within the reference burst;
 - III. Only the earliest PUSCH within the reference burst
- [0094] In some embodiments, when TB/CBG is punctured by others, e.g., URLLC, the TB/CBGs, or the TB/CBG is punctured due to late channel occupation in the initial partial slot, the TB/CBG is not used for the CWS adjustment.
- [0095] In some embodiments, for multi-slot PUSCH of N symbols 412 for Cat-4 LBT 402, one of the following options can be enforced to prevent that a partial PUSCH repetition might be used as a reference burst as illustrated in FIG. 4:
- [0096] In some embodiments, gNB can be implemented to guarantee that after getting a reference timing $ns-N$, there will always be a PUSCH with a full repetitions, e.g. rep1 404, rep2 406, rep3 408, rep4 410, etc., which can be used as reference burst.
- [0097] By way of non-limiting example, in some embodiments, if the reference timing $ns-N$ is in the middle of the repetitions of a TB, UE can skip this TB, and use some even earlier PUSCH transmission as reference burst.
- [0098] In some embodiments, a threshold can be configured to decide whether a TB can be used within the reference burst. The threshold can be a number of repetitions. Let the reference timing $ns-N$ is in the middle of the repetitions of a TB, if the number of repetitions received by gNB is higher than threshold, the HARQ-ACK for the TB can still be a good reference for CWS; otherwise, UE can skip this TB, and use some even earlier PUSCH transmission as reference burst.

[0099] By way of non-limiting example, a threshold can be used to determine the number of repetitions used by gNB. The threshold can be a maximum coding rate. Let the reference timing $ns-N$ is in the middle of the repetitions of a TB, if coding rate of repetitions received by gNB is lower than the threshold, the current TB can be used within the reference burst. Otherwise, UE can skip this TB, and use some even earlier PUSCH transmission as reference burst.

[0100] Regardless on the reference timing $ns-N$, in this case if at least one of the repetitions follow with the reference burst, all the repetitions will be used for the CWS adjustment.

[0101] In some embodiments, for example, there can be multiple PUSCHs transmitted in the reference burst with a multi-slot PUSCH in the reference burst, when only part of its repetitions is received by gNB, only other PUSCHs are considered in CWS adjustment.

SYSTEMS AND IMPELEMENTATIONS

[0102] Figure 5 illustrates an example procedure, in accordance with some embodiments. The example procedure may be executed in a system or apparatus as described herein with respect to Figure 6 through 15. In accordance with some embodiments, at step 502, a transport block (TB) is divided into a plurality of code block groups (CBGs) for transmission over 5G New Radio system on an unlicensed spectrum (5G NR-U). Similar to LTE, in 5G New Radio (5G NR) system, a TB is split into multiple code blocks (CBs). Thus, one TB may include a plurality of CBGs and one CBG may include a plurality of CBs. By way of non-limiting example, a TB may include a CBG that may include a plurality of CBs, or a TB may include a CBG that may include a CB. As described above, the CBGs are essentially smaller subsets of the TB and are decoded by the UE. The UE then sends HARQ feedback for each CBG.

[0103] In accordance with some embodiments, at step 504, listen before talk (LBT) parameters and maximum channel occupancy time (MCOT) values are updated to transmit the plurality of CBGs over the 5G NR-U to align with another technology used over the unlicensed spectrum. As described above, by updating one or more LBT parameters and one or more MCOT values according to Table 3 described above, 5G NR-U system is brought in par with the other technology, for example, Wi-Fi. Accordingly, the 5G NR-U system is configured for the LBT parameters and MCOT values that are consistent for the Wi-Fi and 5G NR-U systems.

- [0104] In accordance with some embodiments, at step 506, hybrid automatic repeat request acknowledge (HARQ-ACK) feedback is determined for the TB that is transmitted as a plurality of CBGs over the 5G NR-U. As described above at step 502, the TB for transmission is divided into a plurality of CBGs, and the UE may send HARQ-ACK feedback for each CBG received at the UE. Since, CBG based HARQ-ACK feedback is sent by the UE, only CBGs that were not received by the UE or not decoded successfully by the UE, i.e., negatively acknowledged (NACKed) are retransmitted.
- [0105] In accordance with some embodiments, at step 508, contention widow size (CWS) is adjusted based on the HARQ-ACK feedback for the TB. By way of non-limiting example, as described herein, for CWS adjustment based on the HARQ-ACK feedback, the TB is considered as negatively acknowledged (NACKed) when it is determined that at least one CBG of the plurality of CBGs is NACKed. In accordance with some embodiments, the TB is considered as negatively acknowledged (NACKed) when a percentage of negatively acknowledged CBGs of the TB exceeds a preconfigured percentage threshold. By way of non-limiting example, the preconfigured percentage threshold may be not less than 80 percentage.
- [0106] In accordance with some embodiments, at step 510, the HARQ-ACK feedback may be discarded for adjusting the CWS in response to not scheduling the NACKed CBGs of the TB. Similarly, at step 512, the HARQ-ACK feedback may be ignored for adjusting the CWS when transmission of the CBG or the TB is punctured.
- [0107] Figure 6 illustrates an example architecture of a system 600 of a network, in accordance with various embodiments. The following description is provided for an example system 600 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.
- [0108] As shown by Figure 6, the system 600 includes UE 601a and UE 601b (collectively referred to as “UEs 601” or “UE 601”). In this example, UEs 601 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.

[0109] In some embodiments, any of the UEs 601 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.

[0110] The UEs 601 may be configured to connect, for example, communicatively couple, with an or RAN 610. In embodiments, the RAN 610 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 610 that operates in an NR or 5G system 600, and the term “E-UTRAN” or the like may refer to a RAN 610 that operates in an LTE or 4G system 600. The UEs 601 utilize connections (or channels) 603 and 604, respectively, each of which comprises a physical communications interface or layer (discussed in further detail below).

[0111] In this example, the connections 603 and 604 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 601 may directly exchange communication data via a ProSe interface 605. The ProSe interface 605 may alternatively be referred to as a SL interface 605 and may comprise one or more logical channels, including but not limited to a PSCCH, a PSSCH, a PSDCH, and a PSBCH.

[0112] The UE 601b is shown to be configured to access an AP 606 (also referred to as “WLAN node 606,” “WLAN 606,” “WLAN Termination 606,” “WT 606” or the like) via connection 607. The connection 607 can comprise a local wireless connection, such as a connection consistent with any IEEE 802.11 protocol, wherein the AP 606 would comprise a wireless fidelity (Wi-Fi®) router. In this example, the AP 606 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 601b, RAN 610, and AP 606 may be configured to utilize LWA operation and/or LWIP operation. The LWA operation may involve the UE 601b in RRC_CONNECTED being configured by a RAN node 611a-b to utilize radio resources of LTE and WLAN. LWIP operation may involve the UE 601b using WLAN radio resources (e.g., connection 607) via IPsec protocol tunneling to authenticate and encrypt packets (e.g., IP packets) sent over the connection 607. 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.

[0113] The RAN 610 can include one or more AN nodes or RAN nodes 611a and 611b (collectively referred to as “RAN nodes 611” or “RAN node 611”) that enable the connections 603 and 604. As used herein, the terms “access node,” “access point,” or the like may describe equipment that provides the radio baseband functions for data and/or voice connectivity between a network and one or more users. These access nodes can be referred to as BS, gNBs, RAN nodes, eNBs, NodeBs, RSUs, TRxPs or TRPs, and so forth, and can comprise ground stations (e.g., terrestrial access points) or satellite stations providing coverage within a geographic area (e.g., a cell). As used herein, the term “NG RAN node” or the like may refer to a RAN node 611 that operates in an NR or 5G system 600 (for example, a gNB), and the term “E-UTRAN node” or the like may refer to a RAN node 611 that operates in an LTE or 4G system 600 (e.g., an eNB). According to various embodiments, the RAN nodes 611 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.

[0114] In some embodiments, all or parts of the RAN nodes 611 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 611; 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 611; 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 611. This virtualized framework allows the freed-up processor cores of the RAN nodes 611 to perform other virtualized applications. In some implementations, an individual RAN node 611 may represent individual gNB-DUs that are connected to a gNB-CU via individual F1 interfaces (not shown by Figure 6). In these implementations, the gNB-DUs may include one or more remote radio heads or RFEMs (see, e.g., Figure 9), and the gNB-CU may be operated by a server that is located in the RAN 610 (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 611 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 601, and are connected to a 5GC (e.g., CN 820 of Figure 8) via an NG interface (discussed infra).

[0115] In V2X scenarios one or more of the RAN nodes 611 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 601 (vUEs 601). 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.

[0116] Any of the RAN nodes 611 can terminate the air interface protocol and can be the first point of contact for the UEs 601. In some embodiments, any of the RAN nodes 611 can fulfill various logical functions for the RAN 610 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.

[0117] In embodiments, the UEs 601 can be configured to communicate using OFDM communication signals with each other or with any of the RAN nodes 611 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.

[0118] In some embodiments, a downlink resource grid can be used for downlink transmissions from any of the RAN nodes 611 to the UEs 601, 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.

[0119] According to various embodiments, the UEs 601, 602 and the RAN nodes 611, 612 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.

[0120] To operate in the unlicensed spectrum, the UEs 601, 602 and the RAN nodes 611, 612 may operate using LAA, eLAA, and/or feLAA mechanisms. In these implementations, the UEs 601, 602 and the RAN nodes 611, 612 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.

[0121] LBT is a mechanism whereby equipment (for example, UEs 601, 602, RAN nodes 611, 612, 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.

[0122] 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 601 or 602, AP 606, or the like) intends to transmit, the WLAN node may first perform CCA before transmission. Additionally, a backoff mechanism is used to avoid collisions in situations where more than one WLAN node senses the channel as idle and transmits at the same time. The backoff mechanism may be a counter that is drawn randomly within the CWS, which is increased exponentially upon the occurrence of collision and reset to a minimum value when the transmission succeeds. The LBT mechanism designed for LAA is somewhat similar to the CSMA/CA of WLAN. In some implementations, the LBT procedure for DL or UL transmission bursts including PDSCH or PUSCH transmissions, respectively, may have an LAA contention window that is variable in length between X and Y ECCA slots, where X and Y are minimum and maximum values for the CWSs for LAA. In one example, the minimum CWS for an LAA transmission may be 9 microseconds (μ s); however, the size of the CWS and a MCOT (for example, a transmission burst) may be based on governmental regulatory requirements.

[0123] 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.

[0124] 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 601, 602 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.

[0125] The PDSCH carries user data and higher-layer signaling to the UEs 601. 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 601 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 601b within a cell) may be performed at any of the RAN nodes 611 based on channel quality information fed back from any of the UEs 601. The downlink resource assignment information may be sent on the PDCCH used for (e.g., assigned to) each of the UEs 601.

[0126] 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).

[0127] 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.

[0128] The RAN nodes 611 may be configured to communicate with one another via interface 612. In embodiments where the system 600 is an LTE system (e.g., when CN 620 is an EPC 720 as in Figure 7), the interface 612 may be an X2 interface 612. The X2 interface may be defined between two or more RAN nodes 611 (e.g., two or more eNBs and the like) that connect to EPC 620, and/or between two eNBs connecting to EPC 620. 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 601 from an SeNB for user data; information of PDCP PDUs that were not delivered to a UE 601; 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.

[0129] In embodiments where the system 600 is a 5G or NR system (e.g., when CN 620 is an 5GC 820 as in Figure 8), the interface 612 may be an Xn interface 612. The Xn interface is defined between two or more RAN nodes 611 (e.g., two or more gNBs and the like) that connect to 5GC 620, between a RAN node 611 (e.g., a gNB) connecting to 5GC 620 and an eNB, and/or between two eNBs connecting to 5GC 620. In some implementations, the Xn interface may include an Xn user plane (Xn-U) interface and an Xn control plane (Xn-C) interface. The Xn-U may provide non-guaranteed delivery of user plane PDUs and support/provide data forwarding and flow control functionality. The Xn-C may provide management and error handling functionality, functionality to manage the Xn-C interface; mobility support for UE 601 in a connected mode (e.g., CM-CONNECTED) including functionality to manage the UE mobility for connected mode between one or more RAN nodes 611. The mobility support may include context transfer from an old (source) serving RAN node 611 to new (target) serving RAN node 611; and control of user plane tunnels between old (source) serving RAN node 611 to new (target) serving RAN node 611. 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.

[0130] The RAN 610 is shown to be communicatively coupled to a core network—in this embodiment, core network (CN) 620. The CN 620 may comprise a plurality of network elements 622, which are configured to offer various data and telecommunications services to customers/subscribers (e.g., users of UEs 601) who are connected to the CN 620 via the RAN 610. The components of the CN 620 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 620 may be referred to as a network slice, and a logical instantiation of a portion of the CN 620 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.

[0131] Generally, the application server 630 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 630 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 601 via the EPC 620.

[0132] In embodiments, the CN 620 may be a 5GC (referred to as “5GC 620” or the like), and the RAN 610 may be connected with the CN 620 via an NG interface 613. In embodiments, the NG interface 613 may be split into two parts, an NG user plane (NG-U) interface 614, which carries traffic data between the RAN nodes 611 and a UPF, and the S1 control plane (NG-C) interface 615, which is a signaling interface between the RAN nodes 611 and AMFs. Embodiments where the CN 620 is a 5GC 620 are discussed in more detail with regard to Figure 8.

[0133] In embodiments, the CN 620 may be a 5G CN (referred to as “5GC 620” or the like), while in other embodiments, the CN 620 may be an EPC). Where CN 620 is an EPC (referred to as “EPC 620” or the like), the RAN 610 may be connected with the CN 620 via an S1 interface 613. In embodiments, the S1 interface 613 may be split into two parts, an S1 user plane (S1-U) interface 614, which carries traffic data between the RAN nodes 611 and the S-GW, and the S1-MME interface 615, which is a signaling interface between the RAN nodes 611 and MMEs. An example architecture wherein the CN 620 is an EPC 620 is shown by Figure 7.

[0134] Figure 7 illustrates an example architecture of a system 700 including a first CN 720, in accordance with various embodiments. In this example, system 700 may implement the LTE standard wherein the CN 720 is an EPC 720 that corresponds with CN 620 of Figure 6. Additionally, the UE 701 may be the same or similar as the UEs 601 of Figure 6, and the E-UTRAN 710 may be a RAN that is the same or similar to the RAN 610 of Figure 6, and which may include RAN nodes 611 discussed previously. The CN 720 may comprise MMEs 721, an S-GW 722, a P-GW 723, a HSS 724, and a SGSN 725.

[0135] The MMEs 721 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 701. The MMEs 721 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 701, provide user identity confidentiality, and/or perform other like services to users/subscribers. Each UE 701 and the MME 721 may include an MM or EMM sublayer, and an MM context may be established in the UE 701 and the MME 721 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 701. The MMEs 721 may be coupled with the HSS 724 via an S6a reference point, coupled with the SGSN 725 via an S3 reference point, and coupled with the S-GW 722 via an S11 reference point.

[0136] The SGSN 725 may be a node that serves the UE 701 by tracking the location of an individual UE 701 and performing security functions. In addition, the SGSN 725 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 721; handling of UE 701 time zone functions as specified by the MMEs 721; and MME selection for handovers to E-UTRAN 3GPP access network. The S3 reference point between the MMEs 721 and the SGSN 725 may enable user and bearer information exchange for inter-3GPP access network mobility in idle and/or active states.

[0137] The HSS 724 may comprise a database for network users, including subscription-related information to support the network entities' handling of communication sessions. The EPC 720 may comprise one or several HSSs 724, depending on the number of mobile subscribers, on the capacity of the equipment, on the organization of the network, etc. For example, the HSS 724 can provide support for routing/roaming, authentication, authorization, naming/addressing resolution, location dependencies, etc. An S6a reference point between the HSS 724 and the MMEs 721 may enable transfer of subscription and authentication data for authenticating/authorizing user access to the EPC 720 between HSS 724 and the MMEs 721.

[0138] The S-GW 722 may terminate the S1 interface 613 ("S1-U" in Figure 7) toward the RAN 710, and routes data packets between the RAN 710 and the EPC 720. In addition, the S-GW 722 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 722 and the MMEs 721 may provide a control plane between the MMEs 721 and the S-GW 722. The S-GW 722 may be coupled with the P-GW 723 via an S5 reference point.

[0139] The P-GW 723 may terminate an SGi interface toward a PDN 730. The P-GW 723 may route data packets between the EPC 720 and external networks such as a network including the application server 630 (alternatively referred to as an "AF") via an

IP interface 625 (see e.g., Figure 6). In embodiments, the P-GW 723 may be communicatively coupled to an application server (application server 630 of Figure 6 or PDN 730 in Figure 7) via an IP communications interface 625 (see, e.g., Figure 6). The S5 reference point between the P-GW 723 and the S-GW 722 may provide user plane tunneling and tunnel management between the P-GW 723 and the S-GW 722. The S5 reference point may also be used for S-GW 722 relocation due to UE 701 mobility and if the S-GW 722 needs to connect to a non-collocated P-GW 723 for the required PDN connectivity. The P-GW 723 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 723 and the packet data network (PDN) 730 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 723 may be coupled with a PCRF 726 via a Gx reference point.

[0140] PCRF 726 is the policy and charging control element of the EPC 720. In a non-roaming scenario, there may be a single PCRF 726 in the Home Public Land Mobile Network (HPLMN) associated with a UE 701'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 701'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 726 may be communicatively coupled to the application server 730 via the P-GW 723. The application server 730 may signal the PCRF 726 to indicate a new service flow and select the appropriate QoS and charging parameters. The PCRF 726 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 730. The Gx reference point between the PCRF 726 and the P-GW 723 may allow for the transfer of QoS policy and charging rules from the PCRF 726 to PCEF in the P-GW 723. An Rx reference point may reside between the PDN 730 (or "AF 730") and the PCRF 726.

[0141] Figure 8 illustrates an architecture of a system 800 including a second CN 820 in accordance with various embodiments. The system 800 is shown to include a UE 801, which may be the same or similar to the UEs 601 and UE 701 discussed previously; a (R)AN 810, which may be the same or similar to the RAN 610 and RAN 710 discussed

previously, and which may include RAN nodes 611 discussed previously; and a DN 803, which may be, for example, operator services, Internet access or 3rd party services; and a 5GC 820. The 5GC 820 may include an AUSF 822; an AMF 821; a SMF 824; a NEF 823; a PCF 826; a NRF 825; a UDM 827; an AF 828; a UPF 802; and a NSSF 829.

[0142] The UPF 802 may act as an anchor point for intra-RAT and inter-RAT mobility, an external PDU session point of interconnect to DN 803, and a branching point to support multi-homed PDU session. The UPF 802 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 802 may include an uplink classifier to support routing traffic flows to a data network. The DN 803 may represent various network operator services, Internet access, or third party services. DN 803 may include, or be similar to, application server 630 discussed previously. The UPF 802 may interact with the SMF 824 via an N4 reference point between the SMF 824 and the UPF 802.

[0143] The AUSF 822 may store data for authentication of UE 801 and handle authentication-related functionality. The AUSF 822 may facilitate a common authentication framework for various access types. The AUSF 822 may communicate with the AMF 821 via an N12 reference point between the AMF 821 and the AUSF 822; and may communicate with the UDM 827 via an N13 reference point between the UDM 827 and the AUSF 822. Additionally, the AUSF 822 may exhibit an Nausf service-based interface.

[0144] The AMF 821 may be responsible for registration management (e.g., for registering UE 801, etc.), connection management, reachability management, mobility management, and lawful interception of AMF-related events, and access authentication and authorization. The AMF 821 may be a termination point for the an N11 reference point between the AMF 821 and the SMF 824. The AMF 821 may provide transport for SM messages between the UE 801 and the SMF 824, and act as a transparent proxy for routing SM messages. AMF 821 may also provide transport for SMS messages between UE 801 and an SMSF (not shown by Figure 8). AMF 821 may act as SEAF, which may

include interaction with the AUSF 822 and the UE 801, receipt of an intermediate key that was established as a result of the UE 801 authentication process. Where USIM based authentication is used, the AMF 821 may retrieve the security material from the AUSF 822. AMF 821 may also include a SCM function, which receives a key from the SEA that it uses to derive access-network specific keys. Furthermore, AMF 821 may be a termination point of a RAN CP interface, which may include or be an N2 reference point between the (R)AN 810 and the AMF 821; and the AMF 821 may be a termination point of NAS (N1) signalling, and perform NAS ciphering and integrity protection.

[0145] AMF 821 may also support NAS signalling with a UE 801 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 810 and the AMF 821 for the control plane, and may be a termination point for the N3 reference point between the (R)AN 810 and the UPF 802 for the user plane. As such, the AMF 821 may handle N2 signalling from the SMF 824 and the AMF 821 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 801 and AMF 821 via an N1 reference point between the UE 801 and the AMF 821, and relay uplink and downlink user-plane packets between the UE 801 and UPF 802. The N3IWF also provides mechanisms for IPsec tunnel establishment with the UE 801. The AMF 821 may exhibit an Namf service-based interface, and may be a termination point for an N14 reference point between two AMFs 821 and an N17 reference point between the AMF 821 and a 5G-EIR (not shown by Figure 8).

[0146] The UE 801 may need to register with the AMF 821 in order to receive network services. RM is used to register or deregister the UE 801 with the network (e.g., AMF 821), and establish a UE context in the network (e.g., AMF 821). The UE 801 may operate in an RM-REGISTERED state or an RM-DEREGISTERED state. In the RM-DEREGISTERED state, the UE 801 is not registered with the network, and the UE context in AMF 821 holds no valid location or routing information for the UE 801 so the UE 801 is not reachable by the AMF 821. In the RM-REGISTERED state, the UE 801 is registered with the network, and the UE context in AMF 821 may hold a valid location or

routing information for the UE 801 so the UE 801 is reachable by the AMF 821. In the RM-REGISTERED state, the UE 801 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 801 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.

[0147] The AMF 821 may store one or more RM contexts for the UE 801, 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 821 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 821 may store a CE mode B Restriction parameter of the UE 801 in an associated MM context or RM context. The AMF 821 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).

[0148] CM may be used to establish and release a signaling connection between the UE 801 and the AMF 821 over the N1 interface. The signaling connection is used to enable NAS signaling exchange between the UE 801 and the CN 820, 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 801 between the AN (e.g., RAN 810) and the AMF 821. The UE 801 may operate in one of two CM states, CM-IDLE mode or CM-CONNECTED mode. When the UE 801 is operating in the CM-IDLE state/mode, the UE 801 may have no NAS signaling connection established with the AMF 821 over the N1 interface, and there may be (R)AN 810 signaling connection (e.g., N2 and/or N3 connections) for the UE 801. When the UE 801 is operating in the CM-CONNECTED state/mode, the UE 801 may have an established NAS signaling connection with the AMF 821 over the N1 interface, and there may be a (R)AN 810 signaling connection (e.g., N2 and/or N3 connections) for the UE 801. Establishment of an N2 connection between the (R)AN 810 and the AMF 821 may cause the UE 801 to transition from CM-IDLE mode to CM-CONNECTED mode, and the UE 801 may transition from the CM-CONNECTED mode to the CM-IDLE mode when N2 signaling between the (R)AN 810 and the AMF 821 is released.

[0149] The SMF 824 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 801 and a data network (DN) 803 identified by a Data Network Name (DNN). PDU sessions may be established upon UE 801 request, modified upon UE 801 and 5GC 820 request, and released upon UE 801 and 5GC 820 request using NAS SM signaling exchanged over the N1 reference point between the UE 801 and the SMF 824. Upon request from an application server, the 5GC 820 may trigger a specific application in the UE 801. In response to receipt of the trigger message, the UE 801 may pass the trigger message (or relevant parts/information of the trigger message) to one or more identified applications in the UE 801. The identified application(s) in the UE 801 may establish a PDU session to a specific DNN. The SMF 824 may check whether the UE 801 requests are compliant with user subscription information associated with the UE 801. In this regard, the SMF 824 may retrieve and/or request to receive update notifications on SMF 824 level subscription data from the UDM 827.

[0150] The SMF 824 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 824 may be included in the system 800, which may be between another SMF 824 in a visited network and the SMF 824 in the home network in roaming scenarios. Additionally, the SMF 824 may exhibit the Nsmf service-based interface.

[0151] The NEF 823 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 828), edge computing or fog computing systems, etc. In such embodiments, the NEF 823 may authenticate, authorize, and/or throttle the AFs. NEF 823 may also translate information exchanged with the AF 828 and information exchanged with internal network functions. For example, the NEF 823 may translate between an AF-Service-Identifier and an internal 5GC information. NEF 823 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 823 as structured data, or at a data storage NF using standardized interfaces. The stored information can then be re-exposed by the NEF 823 to other NFs and AFs, and/or used for other purposes such as analytics. Additionally, the NEF 823 may exhibit an Nnef service-based interface.

[0152] The NRF 825 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 825 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 825 may exhibit the Nnrf service-based interface.

[0153] The PCF 826 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 826 may also implement an FE to access subscription information relevant for policy decisions in a UDR of the UDM 827. The PCF 826 may communicate with the AMF 821 via an N15 reference point between the PCF 826 and the AMF 821, which may include a PCF 826 in a visited network and the AMF 821 in case of roaming scenarios. The PCF 826 may communicate with the AF 828 via an N5 reference point between the PCF 826 and the AF 828; and with the SMF 824 via an N7 reference point between the PCF 826 and the SMF 824. The system 800 and/or CN 820 may also include an N24 reference point between the PCF 826 (in the home network) and a PCF 826 in a visited network. Additionally, the PCF 826 may exhibit an Npcf service-based interface.

[0154] The UDM 827 may handle subscription-related information to support the network entities' handling of communication sessions, and may store subscription data of UE 801. For example, subscription data may be communicated between the UDM 827

and the AMF 821 via an N8 reference point between the UDM 827 and the AMF. The UDM 827 may include two parts, an application FE and a UDR (the FE and UDR are not shown by Figure 8). The UDR may store subscription data and policy data for the UDM 827 and the PCF 826, and/or structured data for exposure and application data (including PFDs for application detection, application request information for multiple UEs 801) for the NEF 823. The Nudr service-based interface may be exhibited by the UDR 221 to allow the UDM 827, PCF 826, and NEF 823 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 824 via an N10 reference point between the UDM 827 and the SMF 824. UDM 827 may also support SMS management, wherein an SMS-FE implements the similar application logic as discussed previously. Additionally, the UDM 827 may exhibit the Nudm service-based interface.

[0155] The AF 828 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 820 and AF 828 to provide information to each other via NEF 823, 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 801 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 802 close to the UE 801 and execute traffic steering from the UPF 802 to DN 803 via the N6 interface. This may be based on the UE subscription data, UE location, and information provided by the AF 828. In this way, the AF 828 may influence UPF (re)selection and traffic routing. Based on operator deployment, when AF 828 is considered to be a trusted entity, the network operator may permit AF 828 to interact directly with relevant NFs. Additionally, the AF 828 may exhibit an Naf service-based interface.

- [0156] The NSSF 829 may select a set of network slice instances serving the UE 801. The NSSF 829 may also determine allowed NSSAI and the mapping to the subscribed S-NSSAIs, if needed. The NSSF 829 may also determine the AMF set to be used to serve the UE 801, or a list of candidate AMF(s) 821 based on a suitable configuration and possibly by querying the NRF 825. The selection of a set of network slice instances for the UE 801 may be triggered by the AMF 821 with which the UE 801 is registered by interacting with the NSSF 829, which may lead to a change of AMF 821. The NSSF 829 may interact with the AMF 821 via an N22 reference point between AMF 821 and NSSF 829; and may communicate with another NSSF 829 in a visited network via an N31 reference point (not shown by Figure 8). Additionally, the NSSF 829 may exhibit an Nnssf service-based interface.
- [0157] As discussed previously, the CN 820 may include an SMSF, which may be responsible for SMS subscription checking and verification, and relaying SM messages to/from the UE 801 to/from other entities, such as an SMS-GMSC/IW MSC/SMS-router. The SMS may also interact with AMF 821 and UDM 827 for a notification procedure that the UE 801 is available for SMS transfer (e.g., set a UE not reachable flag, and notifying UDM 827 when UE 801 is available for SMS).
- [0158] The CN 120 may also include other elements that are not shown by Figure 8, 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 8). 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 8). The 5G-EIR may be an NF that checks the status of PEI for determining whether particular equipment/entities are blacklisted from the network; and the SEPP may be a non-transparent proxy that performs topology hiding, message filtering, and policing on inter-PLMN control plane interfaces.
- [0159] 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 8 for clarity. In one example, the CN 820 may include an Nx interface, which is an inter-CN interface between the MME (e.g., MME

721) and the AMF 821 in order to enable interworking between CN 820 and CN 720.

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.

[0160] Figure 9 illustrates an example of infrastructure equipment 900 in accordance with various embodiments. The infrastructure equipment 900 (or “system 900”) may be implemented as a base station, radio head, RAN node such as the RAN nodes 611 and/or AP 606 shown and described previously, application server(s) 630, and/or any other element/device discussed herein. In other examples, the system 900 could be implemented in or by a UE.

[0161] The system 900 includes application circuitry 905, baseband circuitry 910, one or more radio front end modules (RFEMs) 915, memory circuitry 920, power management integrated circuitry (PMIC) 925, power tee circuitry 930, network controller circuitry 935, network interface connector 940, satellite positioning circuitry 945, and user interface 950. In some embodiments, the device 900 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.

[0162] Application circuitry 905 includes circuitry such as, but not limited to one or more processors (or processor cores), cache memory, and one or more of low drop-out voltage regulators (LDOs), interrupt controllers, serial interfaces such as SPI, I²C or universal programmable serial interface module, real time clock (RTC), timer-counters including interval and watchdog timers, general purpose input/output (I/O or IO), memory card controllers such as Secure Digital (SD) MultiMediaCard (MMC) or similar, Universal Serial Bus (USB) interfaces, Mobile Industry Processor Interface (MIPI) interfaces and Joint Test Access Group (JTAG) test access ports. The processors (or cores) of the application circuitry 905 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 900. 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.

[0163] The processor(s) of application circuitry 905 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 905 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 905 may include one or more Intel Pentium®, Core®, or Xeon® processor(s); Advanced Micro Devices (AMD) Ryzen® processor(s), Accelerated Processing Units (APUs), or Epyc® processors; ARM-based processor(s) licensed from ARM Holdings, Ltd. such as the ARM Cortex-A family of processors and the ThunderX2® provided by Cavium(TM), Inc.; a MIPS-based design from MIPS Technologies, Inc. such as MIPS Warrior P-class processors; and/or the like. In some embodiments, the system 900 may not utilize application circuitry 905, and instead may include a special-purpose processor/controller to process IP data received from an EPC or 5GC, for example.

[0164] In some implementations, the application circuitry 905 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 905 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 905 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.

[0165] The baseband circuitry 910 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 910 are discussed infra with regard to Figure 11.

[0166] User interface circuitry 950 may include one or more user interfaces designed to enable user interaction with the system 900 or peripheral component interfaces designed to enable peripheral component interaction with the system 900. User interfaces may include, but are not limited to, one or more physical or virtual buttons (e.g., a reset button), one or more indicators (e.g., light emitting diodes (LEDs)), a physical keyboard or keypad, a mouse, a touchpad, a touchscreen, speakers or other audio emitting devices, microphones, a printer, a scanner, a headset, a display screen or display device, etc. Peripheral component interfaces may include, but are not limited to, a nonvolatile memory port, a universal serial bus (USB) port, an audio jack, a power supply interface, etc.

[0167] The radio front end modules (RFEMs) 915 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 1111 of Figure 11 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 915, which incorporates both mmWave antennas and sub-mmWave.

[0168] The memory circuitry 920 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 920 may be implemented as one or more of solder down packaged integrated circuits, socketed memory modules and plug-in memory cards.

[0169] The PMIC 925 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 930 may provide for electrical power drawn from a network cable to provide both power supply and data connectivity to the infrastructure equipment 900 using a single cable.

[0170] The network controller circuitry 935 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 900 via network interface connector 940 using a physical connection, which may be electrical (commonly referred to as a “copper interconnect”), optical, or wireless. The network controller circuitry 935 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 935 may include multiple controllers to provide connectivity to other networks using the same or different protocols.

[0171] The positioning circuitry 945 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 945 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 945 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 945 may also be part of, or interact with, the baseband circuitry 910 and/or RFEMs 915 to communicate with the nodes and components of the positioning network. The positioning circuitry 945 may also provide position data and/or time data to the application circuitry 905, which may use the data to synchronize operations with various infrastructure (e.g., RAN nodes 611, etc.), or the like.

[0172] The components shown by Figure 9 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.

[0173] Figure 10 illustrates an example of a platform 1000 (or “device 1000”) in accordance with various embodiments. In embodiments, the computer platform 1000 may be suitable for use as UEs 601, 602, 701, application servers 630, and/or any other element/device discussed herein. The platform 1000 may include any combinations of the components shown in the example. The components of platform 1000 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 1000, or as components otherwise incorporated within a chassis of a larger system. The block diagram of Figure 10 is intended to show a high level view of components of the computer platform 1000. 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.

[0174] Application circuitry 1005 includes circuitry such as, but not limited to one or more processors (or processor cores), cache memory, and one or more of 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 1005 may be coupled with or may include memory/storage elements and may be configured to execute instructions stored in the memory/storage to enable various applications or operating systems to run on the system 1000. In some implementations, the memory/storage elements may be on-chip memory circuitry, which may include any suitable volatile and/or non-volatile memory, such as DRAM, SRAM, EPROM, EEPROM, Flash memory, solid-state memory, and/or any other type of memory device technology, such as those discussed herein.

[0175] The processor(s) of application circuitry 905 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 905 may comprise, or may be, a special-purpose processor/controller to operate according to the various embodiments herein.

[0176] As examples, the processor(s) of application circuitry 1005 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 1005 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 1005 may be a part of a system on a chip (SoC) in which the application circuitry 1005 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.

[0177] Additionally or alternatively, application circuitry 1005 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 1005 may comprise logic blocks or logic fabric, and other interconnected resources that may be programmed to perform various functions, such as the procedures, methods, functions, etc. of the various embodiments discussed herein. In such embodiments, the circuitry of application circuitry 1005 may include memory cells (e.g., erasable programmable read-only memory (EPROM), electrically erasable programmable read-only memory (EEPROM), flash memory, static memory (e.g., static random access memory (SRAM), anti-fuses, etc.)) used to store logic blocks, logic fabric, data, etc. in look-up tables (LUTs) and the like.

[0178] The baseband circuitry 1010 may be implemented, for example, as a solder-down substrate including one or more integrated circuits, a single packaged integrated circuit soldered to a main circuit board or a multi-chip module containing two or more integrated circuits. The various hardware electronic elements of baseband circuitry 1010 are discussed infra with regard to Figure 11.

[0179] The RFEMs 1015 may comprise a millimeter wave (mmWave) RFEM and one or more sub-mmWave radio frequency integrated circuits (RFICs). In some implementations, the one or more sub-mmWave RFICs may be physically separated from the mmWave RFEM. The RFICs may include connections to one or more antennas or antenna arrays (see e.g., antenna array 1111 of Figure 11 infra), and the RFEM may be connected to multiple antennas. In alternative implementations, both mmWave and sub-mmWave radio functions may be implemented in the same physical RFEM 1015, which incorporates both mmWave antennas and sub-mmWave.

[0180] The memory circuitry 1020 may include any number and type of memory devices used to provide for a given amount of system memory. As examples, the memory circuitry 1020 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 1020 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 1020 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 1020 may be on-die memory or registers associated with the application circuitry 1005. To provide for persistent storage of information such as data, applications, operating systems and so forth, memory circuitry 1020 may include one or more mass storage devices, which may include, inter alia, a solid state disk drive (SSDD), hard disk drive (HDD), a micro HDD, resistance change memories, phase change memories, holographic memories, or chemical memories, among others. For example, the computer platform 1000 may incorporate the three-dimensional (3D) cross-point (XPOINT) memories from Intel® and Micron®.

[0181] Removable memory circuitry 1023 may include devices, circuitry, enclosures/housings, ports or receptacles, etc. used to couple portable data storage devices with the platform 1000. 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.

[0182] The platform 1000 may also include interface circuitry (not shown) that is used to connect external devices with the platform 1000. The external devices connected to the platform 1000 via the interface circuitry include sensor circuitry 1021 and electro-mechanical components (EMCs) 1022, as well as removable memory devices coupled to removable memory circuitry 1023.

[0183] The sensor circuitry 1021 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.

[0184] EMCs 1022 include devices, modules, or subsystems whose purpose is to enable platform 1000 to change its state, position, and/or orientation, or move or control a mechanism or (sub)system. Additionally, EMCs 1022 may be configured to generate and send messages/signalling to other components of the platform 1000 to indicate a current state of the EMCs 1022. Examples of the EMCs 1022 include one or more power switches, relays including electromechanical relays (EMRs) and/or solid state relays (SSRs), actuators (e.g., valve actuators, etc.), an audible sound generator, a visual warning device, motors (e.g., DC motors, stepper motors, etc.), wheels, thrusters, propellers, claws, clamps, hooks, and/or other like electro-mechanical components. In embodiments, platform 1000 is configured to operate one or more EMCs 1022 based on one or more captured events and/or instructions or control signals received from a service provider and/or various clients.

[0185] In some implementations, the interface circuitry may connect the platform 1000 with positioning circuitry 1045. The positioning circuitry 1045 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 1045 comprises various hardware elements (e.g., including hardware devices such as switches, filters, amplifiers, antenna elements, and the like to facilitate OTA communications) to communicate with components of a positioning network, such as navigation satellite constellation nodes. In some embodiments, the positioning circuitry

1045 may include a Micro-PNT IC that uses a master timing clock to perform position tracking/estimation without GNSS assistance. The positioning circuitry 1045 may also be part of, or interact with, the baseband circuitry 910 and/or RFEMs 1015 to communicate with the nodes and components of the positioning network. The positioning circuitry 1045 may also provide position data and/or time data to the application circuitry 1005, which may use the data to synchronize operations with various infrastructure (e.g., radio base stations), for turn-by-turn navigation applications, or the like

[0186] In some implementations, the interface circuitry may connect the platform 1000 with Near-Field Communication (NFC) circuitry 1040. NFC circuitry 1040 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 1040 and NFC-enabled devices external to the platform 1000 (e.g., an “NFC touchpoint”). NFC circuitry 1040 comprises an NFC controller coupled with an antenna element and a processor coupled with the NFC controller. The NFC controller may be a chip/IC providing NFC functionalities to the NFC circuitry 1040 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 1040, or initiate data transfer between the NFC circuitry 1040 and another active NFC device (e.g., a smartphone or an NFC-enabled POS terminal) that is proximate to the platform 1000.

[0187] The driver circuitry 1046 may include software and hardware elements that operate to control particular devices that are embedded in the platform 1000, attached to the platform 1000, or otherwise communicatively coupled with the platform 1000. The driver circuitry 1046 may include individual drivers allowing other components of the platform 1000 to interact with or control various input/output (I/O) devices that may be present within, or connected to, the platform 1000. For example, driver circuitry 1046 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 1000, sensor drivers to obtain sensor readings of sensor circuitry 1021 and control and

allow access to sensor circuitry 1021, EMC drivers to obtain actuator positions of the EMCs 1022 and/or control and allow access to the EMCs 1022, 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.

[0188] The power management integrated circuitry (PMIC) 1025 (also referred to as “power management circuitry 1025”) may manage power provided to various components of the platform 1000. In particular, with respect to the baseband circuitry 1010, the PMIC 1025 may control power-source selection, voltage scaling, battery charging, or DC-to-DC conversion. The PMIC 1025 may often be included when the platform 1000 is capable of being powered by a battery 1030, for example, when the device is included in a UE 601, 602, 701.

[0189] In some embodiments, the PMIC 1025 may control, or otherwise be part of, various power saving mechanisms of the platform 1000. For example, if the platform 1000 is in an RRC_Connected state, where it is still connected to the RAN node as it expects to receive traffic shortly, then it may enter a state known as Discontinuous Reception Mode (DRX) after a period of inactivity. During this state, the platform 1000 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 1000 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 1000 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 1000 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.

[0190] A battery 1030 may power the platform 1000, although in some examples the platform 1000 may be mounted deployed in a fixed location, and may have a power supply coupled to an electrical grid. The battery 1030 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 1030 may be a typical lead-acid automotive battery.

[0191] In some implementations, the battery 1030 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 1000 to track the state of charge (SoCh) of the battery 1030. The BMS may be used to monitor other parameters of the battery 1030 to provide failure predictions, such as the state of health (SoH) and the state of function (SoF) of the battery 1030. The BMS may communicate the information of the battery 1030 to the application circuitry 1005 or other components of the platform 1000. The BMS may also include an analog-to-digital (ADC) convertor that allows the application circuitry 1005 to directly monitor the voltage of the battery 1030 or the current flow from the battery 1030. The battery parameters may be used to determine actions that the platform 1000 may perform, such as transmission frequency, network operation, sensing frequency, and the like.

[0192] A power block, or other power supply coupled to an electrical grid may be coupled with the BMS to charge the battery 1030. In some examples, the power block XS30 may be replaced with a wireless power receiver to obtain the power wirelessly, for example, through a loop antenna in the computer platform 1000. 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 1030, 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.

[0193] User interface circuitry 1050 includes various input/output (I/O) devices present within, or connected to, the platform 1000, and includes one or more user interfaces designed to enable user interaction with the platform 1000 and/or peripheral component interfaces designed to enable peripheral component interaction with the platform 1000. The user interface circuitry 1050 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 1000. 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 1021 may be used as the input device circuitry (e.g., an image capture device, motion capture device, or the like) and one or more EMCs may be used as the output device circuitry (e.g., an actuator to provide haptic feedback or the like). In another example, NFC circuitry comprising an NFC controller coupled with an antenna element and a processing device may be included to read electronic tags and/or connect with another NFC-enabled device. Peripheral component interfaces may include, but are not limited to, a non-volatile memory port, a USB port, an audio jack, a power supply interface, etc.

[0194] Although not shown, the components of platform 1000 may communicate with one another using a suitable bus or interconnect (IX) technology, which may include any number of technologies, including ISA, EISA, PCI, PCIx, PCIe, a Time-Trigger Protocol (TTP) system, a FlexRay system, or any number of other technologies. The bus/IX may be a proprietary bus/IX, for example, used in a SoC based system. Other bus/IX systems may be included, such as an I²C interface, an SPI interface, point-to-point interfaces, and a power bus, among others.

[0195] Figure 11 illustrates example components of baseband circuitry 1110 and radio front end modules (RFEM) 1115 in accordance with various embodiments. The baseband circuitry 1110 corresponds to the baseband circuitry 910 and 1010 of Figures 9 and 10, respectively. The RFEM 1115 corresponds to the RFEM 915 and 1015 of Figures 9 and 10, respectively. As shown, the RFEMs 1115 may include Radio Frequency (RF) circuitry 1106, front-end module (FEM) circuitry 1108, antenna array 1111 coupled together at least as shown.

[0196] The baseband circuitry 1110 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 1106. 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 1110 may include Fast-Fourier Transform (FFT), precoding, or constellation mapping/demapping functionality. In some embodiments, encoding/decoding circuitry of the baseband circuitry 1110 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 1110 is configured to process baseband signals received from a receive signal path of the RF circuitry 1106 and to generate baseband signals for a transmit signal path of the RF circuitry 1106. The baseband circuitry 1110 is configured to interface with application circuitry 905/1005 (see Figures 9 and 10) for generation and processing of the baseband signals and for controlling operations of the RF circuitry 1106. The baseband circuitry 1110 may handle various radio control functions.

[0197] The aforementioned circuitry and/or control logic of the baseband circuitry 1110 may include one or more single or multi-core processors. For example, the one or more processors may include a 3G baseband processor 1104A, a 4G/LTE baseband processor 1104B, a 5G/NR baseband processor 1104C, or some other baseband processor(s) 1104D 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 1104A-D may be included in modules stored in the memory 1104G and executed via a Central Processing Unit (CPU) 1104E. In other embodiments, some or all of the functionality of baseband processors 1104A-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 1104G may store program code of a real-time OS (RTOS), which when executed by the CPU 1104E (or other baseband processor), is to cause the CPU 1104E (or other baseband processor) to manage resources of the baseband circuitry 1110, 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 1110 includes one or more audio digital signal processor(s) (DSP) 1104F. The audio DSP(s) 1104F include elements for compression/decompression and echo cancellation and may include other suitable processing elements in other embodiments.

[0198] In some embodiments, each of the processors 1104A-1104E include respective memory interfaces to send/receive data to/from the memory 1104G. The baseband circuitry 1110 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 1110; an application circuitry interface to send/receive data to/from the application circuitry 905/1005 of FIGS. 9-XT); an RF circuitry interface to send/receive data to/from RF circuitry 1106 of Figure 11; 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 1025.

[0199] In alternate embodiments (which may be combined with the above described embodiments), baseband circuitry 1110 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 1110 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 1115).

[0200] Although not shown by Figure 11, in some embodiments, the baseband circuitry 1110 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 1110 and/or RF circuitry 1106 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 1110 and/or RF circuitry 1106 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., 1104G) 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 1110 may also support radio communications for more than one wireless protocol.

[0201] The various hardware elements of the baseband circuitry 1110 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 1110 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 1110 and RF circuitry 1106 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 1110 may be implemented as a separate SoC that is communicatively coupled with and RF circuitry 1106 (or multiple instances of RF circuitry 1106). In yet another example, some or all of the constituent components of the baseband circuitry 1110 and the application circuitry 905/1005 may be implemented together as individual SoCs mounted to a same circuit board (e.g., a “multi-chip package”).

[0202] In some embodiments, the baseband circuitry 1110 may provide for communication compatible with one or more radio technologies. For example, in some embodiments, the baseband circuitry 1110 may support communication with an E-UTRAN or other WMAN, a WLAN, a WPAN. Embodiments in which the baseband circuitry 1110 is configured to support radio communications of more than one wireless protocol may be referred to as multi-mode baseband circuitry.

[0203] RF circuitry 1106 may enable communication with wireless networks using modulated electromagnetic radiation through a non-solid medium. In various embodiments, the RF circuitry 1106 may include switches, filters, amplifiers, etc. to facilitate the communication with the wireless network. RF circuitry 1106 may include a receive signal path, which may include circuitry to down-convert RF signals received from the FEM circuitry 1108 and provide baseband signals to the baseband circuitry 1110. RF circuitry 1106 may also include a transmit signal path, which may include circuitry to up-convert baseband signals provided by the baseband circuitry 1110 and provide RF output signals to the FEM circuitry 1108 for transmission.

[0204] In some embodiments, the receive signal path of the RF circuitry 1106 may include mixer circuitry 1106a, amplifier circuitry 1106b and filter circuitry 1106c. In some embodiments, the transmit signal path of the RF circuitry 1106 may include filter circuitry 1106c and mixer circuitry 1106a. RF circuitry 1106 may also include synthesizer circuitry 1106d for synthesizing a frequency for use by the mixer circuitry 1106a of the receive signal path and the transmit signal path. In some embodiments, the mixer circuitry 1106a of the receive signal path may be configured to down-convert RF signals received from the FEM circuitry 1108 based on the synthesized frequency provided by synthesizer circuitry 1106d. The amplifier circuitry 1106b may be configured to amplify the down-converted signals and the filter circuitry 1106c 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 1110 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 1106a of the receive signal path may comprise passive mixers, although the scope of the embodiments is not limited in this respect.

[0205] In some embodiments, the mixer circuitry 1106a of the transmit signal path may be configured to up-convert input baseband signals based on the synthesized frequency provided by the synthesizer circuitry 1106d to generate RF output signals for the FEM circuitry 1108. The baseband signals may be provided by the baseband circuitry 1110 and may be filtered by filter circuitry 1106c.

[0206] In some embodiments, the mixer circuitry 1106a of the receive signal path and the mixer circuitry 1106a 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 1106a of the receive signal path and the mixer circuitry 1106a 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 1106a of the receive signal path and the mixer circuitry 1106a of the transmit signal path may be arranged for direct downconversion and direct upconversion, respectively. In some embodiments, the mixer circuitry 1106a of the receive signal path and the mixer circuitry 1106a of the transmit signal path may be configured for super-heterodyne operation.

[0207] 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 1106 may include analog-to-digital converter (ADC) and digital-to-analog converter (DAC) circuitry and the baseband circuitry 1110 may include a digital baseband interface to communicate with the RF circuitry 1106.

- [0208] 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.
- [0209] In some embodiments, the synthesizer circuitry 1106d 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 1106d may be a delta-sigma synthesizer, a frequency multiplier, or a synthesizer comprising a phase-locked loop with a frequency divider.
- [0210] The synthesizer circuitry 1106d may be configured to synthesize an output frequency for use by the mixer circuitry 1106a of the RF circuitry 1106 based on a frequency input and a divider control input. In some embodiments, the synthesizer circuitry 1106d may be a fractional $N/N+1$ synthesizer.
- [0211] 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 1110 or the application circuitry 905/1005 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 905/1005.
- [0212] Synthesizer circuitry 1106d of the RF circuitry 1106 may include a divider, a delay-locked loop (DLL), a multiplexer and a phase accumulator. In some embodiments, the divider may be a dual modulus divider (DMD) and the phase accumulator may be a digital phase accumulator (DPA). In some embodiments, the DMD may be configured to divide the input signal by either N or N+1 (e.g., based on a carry out) to provide a fractional division ratio. In some example embodiments, the DLL may include a set of cascaded, tunable, delay elements, a phase detector, a charge pump and a D-type flip-flop. In these embodiments, the delay elements may be configured to break a VCO period up into N_d equal packets of phase, where N_d is the number of delay elements in the delay line. In this way, the DLL provides negative feedback to help ensure that the total delay through the delay line is one VCO cycle.
- [0213] In some embodiments, synthesizer circuitry 1106d 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 1106 may include an IQ/polar converter.

[0214] FEM circuitry 1108 may include a receive signal path, which may include circuitry configured to operate on RF signals received from antenna array 1111, amplify the received signals and provide the amplified versions of the received signals to the RF circuitry 1106 for further processing. FEM circuitry 1108 may also include a transmit signal path, which may include circuitry configured to amplify signals for transmission provided by the RF circuitry 1106 for transmission by one or more of antenna elements of antenna array 1111. In various embodiments, the amplification through the transmit or receive signal paths may be done solely in the RF circuitry 1106, solely in the FEM circuitry 1108, or in both the RF circuitry 1106 and the FEM circuitry 1108.

[0215] In some embodiments, the FEM circuitry 1108 may include a TX/RX switch to switch between transmit mode and receive mode operation. The FEM circuitry 1108 may include a receive signal path and a transmit signal path. The receive signal path of the FEM circuitry 1108 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 1106). The transmit signal path of the FEM circuitry 1108 may include a power amplifier (PA) to amplify input RF signals (e.g., provided by RF circuitry 1106), and one or more filters to generate RF signals for subsequent transmission by one or more antenna elements of the antenna array 1111.

[0216] The antenna array 1111 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 1110 is converted into analog RF signals (e.g., modulated waveform) that will be amplified and transmitted via the antenna elements of the antenna array 1111 including one or more antenna elements (not shown). The antenna elements may be omnidirectional, direction, or a combination thereof. The antenna elements may be formed in a multitude of arrangements as are known and/or discussed herein. The antenna array 1111 may comprise microstrip antennas or printed antennas that are

fabricated on the surface of one or more printed circuit boards. The antenna array 1111 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 1106 and/or FEM circuitry 1108 using metal transmission lines or the like.

[0217] Processors of the application circuitry 905/1005 and processors of the baseband circuitry 1110 may be used to execute elements of one or more instances of a protocol stack. For example, processors of the baseband circuitry 1110, alone or in combination, may be used execute Layer 3, Layer 2, or Layer 1 functionality, while processors of the application circuitry 905/1005 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.

[0218] Figure 12 illustrates various protocol functions that may be implemented in a wireless communication device according to various embodiments. In particular, Figure 12 includes an arrangement 1200 showing interconnections between various protocol layers/entities. The following description of Figure 12 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 12 may be applicable to other wireless communication network systems as well.

[0219] The protocol layers of arrangement 1200 may include one or more of PHY 1210, MAC 1220, RLC 1230, PDCP 1240, SDAP 1247, RRC 1255, and NAS layer 1257, in addition to other higher layer functions not illustrated. The protocol layers may include one or more service access points (e.g., items 1259, 1256, 1250, 1249, 1245, 1235, 1225, and 1215 in Figure 12) that may provide communication between two or more protocol layers.

[0220] The PHY 1210 may transmit and receive physical layer signals 1205 that may be received from or transmitted to one or more other communication devices. The physical layer signals 1205 may comprise one or more physical channels, such as those discussed herein. The PHY 1210 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 1255. The PHY 1210 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 1210 may process requests from and provide indications to an instance of MAC 1220 via one or more PHY-SAP 1215. According to some embodiments, requests and indications communicated via PHY-SAP 1215 may comprise one or more transport channels.

[0221] Instance(s) of MAC 1220 may process requests from, and provide indications to, an instance of RLC 1230 via one or more MAC-SAPs 1225. These requests and indications communicated via the MAC-SAP 1225 may comprise one or more logical channels. The MAC 1220 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 1210 via the transport channels, de-multiplexing MAC SDUs to one or more logical channels from TBs delivered from the PHY 1210 via transport channels, multiplexing MAC SDUs onto TBs, scheduling information reporting, error correction through HARQ, and logical channel prioritization.

[0222] Instance(s) of RLC 1230 may process requests from and provide indications to an instance of PDCP 1240 via one or more radio link control service access points (RLC-SAP) 1235. These requests and indications communicated via RLC-SAP 1235 may comprise one or more RLC channels. The RLC 1230 may operate in a plurality of modes of operation, including: Transparent Mode (TM), Unacknowledged Mode (UM), and Acknowledged Mode (AM). The RLC 1230 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 1230 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.

[0223] Instance(s) of PDCP 1240 may process requests from and provide indications to instance(s) of RRC 1255 and/or instance(s) of SDAP 1247 via one or more packet data convergence protocol service access points (PDCP-SAP) 1245. These requests and

indications communicated via PDCP-SAP 1245 may comprise one or more radio bearers. The PDCP 1240 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.).

[0224] Instance(s) of SDAP 1247 may process requests from and provide indications to one or more higher layer protocol entities via one or more SDAP-SAP 1249. These requests and indications communicated via SDAP-SAP 1249 may comprise one or more QoS flows. The SDAP 1247 may map QoS flows to DRBs, and vice versa, and may also mark QFIs in DL and UL packets. A single SDAP entity 1247 may be configured for an individual PDU session. In the UL direction, the NG-RAN 610 may control the mapping of QoS Flows to DRB(s) in two different ways, reflective mapping or explicit mapping. For reflective mapping, the SDAP 1247 of a UE 601 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 1247 of the UE 601 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 810 may mark DL packets over the Uu interface with a QoS flow ID. The explicit mapping may involve the RRC 1255 configuring the SDAP 1247 with an explicit QoS flow to DRB mapping rule, which may be stored and followed by the SDAP 1247. In embodiments, the SDAP 1247 may only be used in NR implementations and may not be used in LTE implementations.

[0225] The RRC 1255 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 1210, MAC 1220, RLC 1230, PDCP 1240 and SDAP 1247. In embodiments, an instance of RRC 1255 may process requests from and provide indications to one or more NAS entities 1257 via one or more RRC-SAPs 1256. The main services and functions of the RRC 1255 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 601 and RAN 610 (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.

[0226] The NAS 1257 may form the highest stratum of the control plane between the UE 601 and the AMF 821. The NAS 1257 may support the mobility of the UEs 601 and the session management procedures to establish and maintain IP connectivity between the UE 601 and a P-GW in LTE systems.

[0227] According to various embodiments, one or more protocol entities of arrangement 1200 may be implemented in UEs 601, RAN nodes 611, AMF 821 in NR implementations or MME 721 in LTE implementations, UPF 802 in NR implementations or S-GW 722 and P-GW 723 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 601, gNB 611, AMF 821, 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 611 may host the RRC 1255, SDAP 1247, and PDCP 1240 of the gNB that controls the operation of one or more gNB-DUs, and the gNB-DUs of the gNB 611 may each host the RLC 1230, MAC 1220, and PHY 1210 of the gNB 611.

[0228] In a first example, a control plane protocol stack may comprise, in order from highest layer to lowest layer, NAS 1257, RRC 1255, PDCP 1240, RLC 1230, MAC 1220, and PHY 1210. In this example, upper layers 1260 may be built on top of the NAS 1257, which includes an IP layer 1261, an SCTP 1262, and an application layer signaling protocol (AP) 1263.

[0229] In NR implementations, the AP 1263 may be an NG application protocol layer (NGAP or NG-AP) 1263 for the NG interface 613 defined between the NG-RAN node 611 and the AMF 821, or the AP 1263 may be an Xn application protocol layer (XnAP or

Xn-AP) 1263 for the Xn interface 612 that is defined between two or more RAN nodes 611.

[0230] The NG-AP 1263 may support the functions of the NG interface 613 and may comprise Elementary Procedures (EPs). An NG-AP EP may be a unit of interaction between the NG-RAN node 611 and the AMF 821. The NG-AP 1263 services may comprise two groups: UE-associated services (e.g., services related to a UE 601, 602) and non-UE-associated services (e.g., services related to the whole NG interface instance between the NG-RAN node 611 and AMF 821). These services may include functions including, but not limited to: a paging function for the sending of paging requests to NG-RAN nodes 611 involved in a particular paging area; a UE context management function for allowing the AMF 821 to establish, modify, and/or release a UE context in the AMF 821 and the NG-RAN node 611; a mobility function for UEs 601 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 601 and AMF 821; a NAS node selection function for determining an association between the AMF 821 and the UE 601; 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 611 via CN 620; and/or other like functions.

[0231] The XnAP 1263 may support the functions of the Xn interface 612 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 611 (or E-UTRAN 710), 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 601, such as Xn interface setup and reset procedures, NG-RAN update procedures, cell activation procedures, and the like.

- [0232] In LTE implementations, the AP 1263 may be an S1 Application Protocol layer (S1-AP) 1263 for the S1 interface 613 defined between an E-UTRAN node 611 and an MME, or the AP 1263 may be an X2 application protocol layer (X2AP or X2-AP) 1263 for the X2 interface 612 that is defined between two or more E-UTRAN nodes 611.
- [0233] The S1 Application Protocol layer (S1-AP) 1263 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 611 and an MME 721 within an LTE CN 620. The S1-AP 1263 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.
- [0234] The X2AP 1263 may support the functions of the X2 interface 612 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 620, 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 601, such as X2 interface setup and reset procedures, load indication procedures, error indication procedures, cell activation procedures, and the like.
- [0235] The SCTP layer (alternatively referred to as the SCTP/IP layer) 1262 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 1262 may ensure reliable delivery of signaling messages between the RAN node 611 and the AMF 821/MME 721 based, in part, on the IP protocol, supported by the IP 1261. The Internet Protocol layer (IP) 1261 may be used to perform packet addressing and routing functionality. In some implementations the IP layer 1261 may use point-to-point transmission to deliver and convey PDUs. In this regard, the RAN node 611 may comprise L2 and L1 layer communication links (e.g., wired or wireless) with the MME/AMF to exchange information.

- [0236] In a second example, a user plane protocol stack may comprise, in order from highest layer to lowest layer, SDAP 1247, PDCP 1240, RLC 1230, MAC 1220, and PHY 1210. The user plane protocol stack may be used for communication between the UE 601, the RAN node 611, and UPF 802 in NR implementations or an S-GW 722 and P-GW 723 in LTE implementations. In this example, upper layers 1251 may be built on top of the SDAP 1247, and may include a user datagram protocol (UDP) and IP security layer (UDP/IP) 1252, a General Packet Radio Service (GPRS) Tunneling Protocol for the user plane layer (GTP-U) 1253, and a User Plane PDU layer (UP PDU) 1263.
- [0237] The transport network layer 1254 (also referred to as a “transport layer”) may be built on IP transport, and the GTP-U 1253 may be used on top of the UDP/IP layer 1252 (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.
- [0238] The GTP-U 1253 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 1252 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 611 and the S-GW 722 may utilize an S1-U interface to exchange user plane data via a protocol stack comprising an L1 layer (e.g., PHY 1210), an L2 layer (e.g., MAC 1220, RLC 1230, PDCP 1240, and/or SDAP 1247), the UDP/IP layer 1252, and the GTP-U 1253. The S-GW 722 and the P-GW 723 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 1252, and the GTP-U 1253. As discussed previously, NAS protocols may support the mobility of the UE 601 and the session management procedures to establish and maintain IP connectivity between the UE 601 and the P-GW 723.
- [0239] Moreover, although not shown by Figure 12, an application layer may be present above the AP 1263 and/or the transport network layer 1254. The application layer may be a layer in which a user of the UE 601, RAN node 611, or other network element interacts with software applications being executed, for example, by application circuitry 905 or

application circuitry 1005, respectively. The application layer may also provide one or more interfaces for software applications to interact with communications systems of the UE 601 or RAN node 611, such as the baseband circuitry 1110. 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).

[0240] Figure 13 illustrates components of a core network in accordance with various embodiments. The components of the CN 720 may be implemented in one physical node or separate physical nodes including components to read and execute instructions from a machine-readable or computer-readable medium (e.g., a non-transitory machine-readable storage medium). In embodiments, the components of CN 820 may be implemented in a same or similar manner as discussed herein with regard to the components of CN 720. 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 720 may be referred to as a network slice 1301, and individual logical instantiations of the CN 720 may provide specific network capabilities and network characteristics. A logical instantiation of a portion of the CN 720 may be referred to as a network sub-slice 1302 (e.g., the network sub-slice 1302 is shown to include the P-GW 723 and the PCRF 726).

[0241] 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.

[0242] With respect to 5G systems (see, e.g., Figure 8), 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 801 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.

[0243] A network slice may include the CN 820 control plane and user plane NFs, NG-RANs 810 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 801 (e.g., enterprise users). For example, individual network slices may deliver different committed service(s) and/or may be dedicated to a particular customer or enterprise. In this example, each network slice may have different S-NSSAIs with the same SST but with different slice differentiators. Additionally, a single UE may be served with one or more network slice instances simultaneously via a 5G AN and associated with eight different S-NSSAIs. Moreover, an AMF 821 instance serving an individual UE 801 may belong to each of the network slice instances serving that UE.

[0244] Network Slicing in the NG-RAN 810 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 810 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 810 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 810 selects the RAN part of the network slice using assistance information provided by the UE 801 or the 5GC 820, which unambiguously identifies one or more of the pre-configured network slices in the PLMN. The NG-RAN 810 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 810 may also apply an appropriate RRM policy for the SLA in place to each supported slice. The NG-RAN 810 may also support QoS differentiation within a slice.

- [0245] The NG-RAN 810 may also use the UE assistance information for the selection of an AMF 821 during an initial attach, if available. The NG-RAN 810 uses the assistance information for routing the initial NAS to an AMF 821. If the NG-RAN 810 is unable to select an AMF 821 using the assistance information, or the UE 801 does not provide any such information, the NG-RAN 810 sends the NAS signaling to a default AMF 821, which may be among a pool of AMFs 821. For subsequent accesses, the UE 801 provides a temp ID, which is assigned to the UE 801 by the 5GC 820, to enable the NG-RAN 810 to route the NAS message to the appropriate AMF 821 as long as the temp ID is valid. The NG-RAN 810 is aware of, and can reach, the AMF 821 that is associated with the temp ID. Otherwise, the method for initial attach applies.
- [0246] The NG-RAN 810 supports resource isolation between slices. NG-RAN 810 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 810 resources to a certain slice. How NG-RAN 810 supports resource isolation is implementation dependent.
- [0247] Some slices may be available only in part of the network. Awareness in the NG-RAN 810 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 810 and the 5GC 820 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 810.
- [0248] The UE 801 may be associated with multiple network slices simultaneously. In case the UE 801 is associated with multiple slices simultaneously, only one signaling connection is maintained, and for intra-frequency cell reselection, the UE 801 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 801 camps. The 5GC 820 is to validate that the UE 801 has the rights to access a network slice. Prior to receiving an Initial Context Setup Request message, the NG-RAN 810 may be allowed to apply some provisional/local policies, based on awareness of a particular slice that the UE 801 is

requesting to access. During the initial context setup, the NG-RAN 810 is informed of the slice for which resources are being requested.

[0249] 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.

[0250] Figure 14 is a block diagram illustrating components, according to some example embodiments, of a system 1400 to support NFV. The system 1400 is illustrated as including a VIM 1402, an NFVI 1404, an VNFM 1406, VNFs 1408, an EM 1410, an NFVO 1412, and a NM 1414.

[0251] The VIM 1402 manages the resources of the NFVI 1404. The NFVI 1404 can include physical or virtual resources and applications (including hypervisors) used to execute the system 1400. The VIM 1402 may manage the life cycle of virtual resources with the NFVI 1404 (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.

[0252] The VNFM 1406 may manage the VNFs 1408. The VNFs 1408 may be used to execute EPC components/functions. The VNFM 1406 may manage the life cycle of the VNFs 1408 and track performance, fault and security of the virtual aspects of VNFs 1408. The EM 1410 may track the performance, fault and security of the functional aspects of VNFs 1408. The tracking data from the VNFM 1406 and the EM 1410 may comprise, for example, PM data used by the VIM 1402 or the NFVI 1404. Both the VNFM 1406 and the EM 1410 can scale up/down the quantity of VNFs of the system 1400.

[0253] The NFVO 1412 may coordinate, authorize, release and engage resources of the NFVI 1404 in order to provide the requested service (e.g., to execute an EPC function, component, or slice). The NM 1414 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 1410).

- [0254] Figure 15 is a block diagram illustrating components, according to some example embodiments, able to read instructions from a machine-readable or computer-readable medium (e.g., a non-transitory machine-readable storage medium) and perform any one or more of the methodologies discussed herein. Specifically, Figure 15 shows a diagrammatic representation of hardware resources 1500 including one or more processors (or processor cores) 1510, one or more memory/storage devices 1520, and one or more communication resources 1530, each of which may be communicatively coupled via a bus 1540. For embodiments where node virtualization (e.g., NFV) is utilized, a hypervisor 1502 may be executed to provide an execution environment for one or more network slices/sub-slices to utilize the hardware resources 1500.
- [0255] The processors 1510 may include, for example, a processor 1512 and a processor 1514. The processor(s) 1510 may be, for example, a central processing unit (CPU), a reduced instruction set computing (RISC) processor, a complex instruction set computing (CISC) processor, a graphics processing unit (GPU), a DSP such as a baseband processor, an ASIC, an FPGA, a radio-frequency integrated circuit (RFIC), another processor (including those discussed herein), or any suitable combination thereof.
- [0256] The memory/storage devices 1520 may include main memory, disk storage, or any suitable combination thereof. The memory/storage devices 1520 may include, but are not limited to, any type of volatile or nonvolatile memory such as dynamic random access memory (DRAM), static random access memory (SRAM), erasable programmable read-only memory (EPROM), electrically erasable programmable read-only memory (EEPROM), Flash memory, solid-state storage, etc.
- [0257] The communication resources 1530 may include interconnection or network interface components or other suitable devices to communicate with one or more peripheral devices 1504 or one or more databases 1506 via a network 1508. For example, the communication resources 1530 may include wired communication components (e.g., for coupling via USB), cellular communication components, NFC components, Bluetooth® (or Bluetooth® Low Energy) components, Wi-Fi® components, and other communication components..
- [0258] Instructions 1550 may comprise software, a program, an application, an applet, an app, or other executable code for causing at least any of the processors 1510 to perform any one or more of the methodologies discussed herein. The instructions 1550 may

reside, completely or partially, within at least one of the processors 1510 (e.g., within the processor's cache memory), the memory/storage devices 1520, or any suitable combination thereof. Furthermore, any portion of the instructions 1550 may be transferred to the hardware resources 1500 from any combination of the peripheral devices 1504 or the databases 1506. Accordingly, the memory of processors 1510, the memory/storage devices 1520, the peripheral devices 1504, and the databases 1506 are examples of computer-readable and machine-readable media.

[0259] For one or more embodiments, at least one of the components set forth in one or more of the preceding figures may be configured to perform one or more operations, techniques, processes, and/or methods as set forth in the example section below. For example, the baseband circuitry as described above in connection with one or more of the preceding figures may be configured to operate in accordance with one or more of the examples set forth below. For another example, circuitry associated with a UE, base station, network element, etc. as described above in connection with one or more of the preceding figures may be configured to operate in accordance with one or more of the examples set forth below in the example section.

EXAMPLES

[0260] Example 1 includes a method comprising utilizing a CWS update mechanism for NR-U or when CBG-based transmissions are configured.

[0261] Example 2 includes the method of example 1 or some other example herein, further comprising re-using parameters from Table I or II.

[0262] Example 3 includes the method of example 2 or some other example herein, wherein LBT parameters and MCOT values for Table II are as in Table III to align NR-U toward Wi-Fi, which may, for example, allowed the two technologies to be in par.

[0263] Example 4 may include the method of example 1 or some other example herein, wherein for DL CWS adjustment, a reference DL burst is defined for the CWS adjustment as one or more of the following options:

- the reference burst is always 1 ms long independently from the subcarrier spacing and starts from the beginning of the DL burst;
- the reference burst is composed of the partial SF (subframe) from the beginning of the DL burst + following SF independently from the subcarrier

spacing. In case the partial subframe is the only subframe included in the reference DL burst, only the partial subframe is used for CWS adjustment;

- the reference burst is composed of N symbols (e.g. 14) from the start of the DL burst, where N is RRC configured, and N may be larger than the number of symbols in the partial slot;
- the reference burst is composed of the partial slot only; or
- the reference burst is composed of T ms, or us, starting from the beginning of the DL burst, where T, for example, is 1 ms.

[0264] Example 5 includes the method of example 1 or some other example herein, wherein when the CBG-based transmission is configured, the NACKs are counted such that if a NACK is received for at least one of the CBG for a specific TB, all other CBG feedbacks for that TB within the reference slot set are also counted as NACK.

[0265] Example 6 includes the method of example 1 or some other example herein, wherein when the CBG-based transmission is configured, each feedback is counted individually for each CBG within a TB as either a NACK or an ACK independently of the value of the other CBG feedback for that TB.

[0266] Example 7 includes the method of example 1 or some other example herein, wherein the ACK/NACK is counted per TB, which requires a representation of ACK/NACK for each TB with CBG based HARQ ACK feedback.

[0267] Example 8 includes the method of example 7 or some other example herein, wherein a TB can be counted as NACK, if 1) all the CBGs comprising the TB are NACK'ed, 2) at least one CBG is NACK'ed, or 3) X % of CBGs are NACK'ed.

[0268] Example 9 includes the method of example 1 or some other example herein, wherein when CBG-based transmission is configured, the NACK is counted on a per TB basis, meaning that all the CBGs per TB are bundled into one bit. In this case if the gNB doesn't schedule at least one or all unsuccessful CBGs of a TB, we see 2 choices: either the TB is be considered as a NACK even though all scheduled CBG are correctly received, or the TB is not counted for CWS adjustment in this case.

[0269] Example 10 includes the method of example 1 or some other example herein, wherein only the currently scheduled CBGs are considered to derive bundled HARQ-ACK for CWS adjustment.

[0270] Example 11 includes the method of example 1 or some other example herein, wherein a TB can be counted as NACK, if 1) all the currently scheduled CBGs of the TB are NACK'ed, 2) at least one of the currently scheduled CBG is NACK'ed, or 3) X % of currently scheduled CBGs are NACK'ed.

[0271] Example 12 includes the method of example 1 or some other example herein, wherein since some UEs may be configured with CBG-based transmission while others would perform TB based transmission, the percentage of NACKs Z is evaluated through one of the following ways:

$$1. Z = (c * NACK_{CBG} + t * NACK_{TB}) / (c * N_{CBG} + t * N_{TB}) \quad (1)$$

$$2. Z = (u * NACK_{CBG} + (1-u) * NACK_{TB}) / (u * N_{CBG} + (1-u) * N_{TB}) \quad (2)$$

[0272] In one embodiment, the TBs/CBGs/ CBs feedbacks for one or more of the following cases are not used for the CWS adjustment:

- a. TB/CBG/CB that is punctured by others e.g. URLLC;
- b. In the initial partial slot, the TB/CBG/CB punctured due to late channel occupation;
- c. Due to BWP switch, UE doesn't report HARQ-ACK for certain PDSCH. In this case, the transmission is considered a NACK as default or it is ignored for the CWS adjustment; or
- d. If gNB doesn't schedule at least one or all unsuccessful CBGs of a TB, such TB is not counted.

[0273] Example 13 includes the method of example 1 or some other example herein, wherein for self-scheduling DTX is considered as an indication of collision and as a NACK in the matter of the CWS adjustment mechanism.

[0274] Example 14 includes the method of example 1 or some other example herein, wherein for cross-carrier scheduling, DTX is ignored for the matter of the CWS adjustment mechanism.

[0275] Example 15 includes the method of example 1 or some other example herein, wherein another aspect that needs to be considered is the CWS update for the gNB when the acquired COT is shared with grant-free or scheduled UEs, or when PDSCH transmission is not performed by the gNB:

- a. If the gNB performs PDSCH transmissions, and part of the acquired MCOT is configured for UL transmissions with overlapping time-domain resources for

scheduled or grant-free transmissions, in one embodiment, the CWS update is performed as described above.

- b. If the gNB does not perform any PDSCH transmissions, and part of the acquired MCOT is configured for UL transmissions with overlapping time-domain resources:
- if eNB schedules UL transport blocks (TBs) with 25 us LBT in a shared COT without any PDSCH, the gNB increases the CWS if less than X% of the scheduled UL TBs are not successfully received or if less than X% of the CBGs for the scheduled UL are not successfully received, where X is as an example 10, or in case $Q \cdot 100$ is less than X, where Q is given by one of the following equations:
 - i. $Q = (c \cdot NACK_{CBG} + t \cdot NACK_{TB}) / (c \cdot N_{CBG} + t \cdot N_{TB}), (3)$
 - ii. $Q = (u \cdot NACK_{CBG} + (1-u) \cdot NACK_{TB}) / (u \cdot N_{CBG} + (1-u) \cdot N_{TB}), (4)$
 - if gNB schedules UL transport blocks (TBs) with 25 us LBT in a shared COT without any PDSCH, and also shares the MCOT with grant-free UEs, the CWS update is performed based on the schedule and/or grant-free TBs or CBGs that have been detected by the gNB.

[0276] Example 16 includes the method of example 1 or some other example herein, wherein for the Cat. 4 LBT for UL transmission, the CWS is adjusted per UE and at UE.

[0277] Example 17 includes the method of example 1 or some other example herein, wherein a reference UL burst is defined for the CWS adjustment according to one of the following options:

the reference burst is always 1 ms long independently from the subcarrier spacing and starts from the beginning of the UL burst;

the reference burst is composed by the partial SF from the beginning of the UL burst + following SF independently from the subcarrier spacing. In case the partial subframe is the only subframe included in the reference UL burst, only the partial subframe is used for CWS adjustment;

the reference burst is composed by N symbols from the start of the UL burst, where N is RRC configured, and N may be larger than the number of symbols that compose the initial partial slot;

the reference burst is composed by the initial partial slot only; or

the reference burst is composed by T ms starting from the beginning of the UL burst, where T is for example 1 ms.

[0278] Example 18 includes the method of example 1 or some other example herein, wherein the gNB configures a number of symbol N, so that the reference burst occurs at least in symbol ns-N, where ns is the first or last symbol of the CORESET containing the UL grant or a DFI DCI.

[0279] Example 19 includes any one of the methods of examples 1-18 or some other example herein, wherein N is evaluated as

$$N = N_x + y, (5); \text{ or}$$

$$N = N_x + TA + y, (6).$$

[0280] Example 20 includes any one of the methods of examples 1-19 or some other example herein, wherein the gNB configures a number of slot N, so that the reference burst occurs before ns-N, where ns is here the slot containing the UL grant or the DFI DCI.

[0281] Example 21 includes the method of example 1 or some other example herein, wherein HARQ_ID_ref is defined as the HARQ process ID of the reference burst.

[0282] Example 22 includes the method of example 1 or some other example herein, wherein for scheduled UEs if the NDI bit for at least one of the active HARQ processes of HARQ_ID_ref in the reference burst is toggled, the contention window size at the UE is reset for all the priority classes.

[0283] Example 23 includes the method of example 1 or some other example herein, wherein if the HARQ_ID_ref is not scheduled or NDI of the active HARQ process(es) of HARQ_ID_ref is not toggled, the contention window size of all priority classes at the UE is increased to the next higher value.

[0284] Example 24 includes the method of example 1 or some other example herein, wherein if CBG-based transmission is configured, CBGTI=1 is considered as failure, e.g., NACK.

[0285] Example 25 includes the method of example 1 or some other example herein, wherein the CBGs are bundled to represent the information on TB failure/success in the CWS adjustment mechanism.

- [0286] Example 26 includes the method of example 1 or some other example herein, wherein if CBG-based transmission is configured, all CBGs of a TB transmitted in the reference burst is considered in CWS adjustment.
- [0287] Example 27 includes the method of example 1 or some other example herein, wherein if CBG-based transmission is configured, only the currently transmitted CBGs of a TB transmitted in the reference burst is considered for CWS adjustment.
- [0288] Example 28 includes the method of example 1 or some other example herein, wherein when the CBG-based transmission is configured, the NACK are counted such that if a NACK is received for at least one of the CBG for a specific TB, all other CBG feedbacks for that TB within the reference burst set are also counted as NACK.
- [0289] Example 29 includes the method of example 1 or some other example herein, wherein when the CBG-based transmission is configured, each feedback is counted individually for each CBG within a TB as either a NACK or an ACK independently of the value of the other CBG feedback for that TB.
- [0290] Example 30 includes the method of example 1 or some other example herein, wherein the ACK/NACK is counted per TB, which requires a representation of ACK/NACK for each TB with CBG based HARQ ACK feedback. In this case in one embodiment, a TB can be counted as NACK, if 1) all the CBGs comprising the TB are NACK'ed, 2) at least one CBG is NACK'ed, or 3) X % of CBGs are NACK'ed.
- [0291] Example 31 includes the method of example 1 or some other example herein, the percentage of NACKs X is evaluated through one of the following equations:

$$X = (c * NACK_{CBG} + t * NACK_{TB}) / (c * N_{CBG} + t * N_{TB}), \text{ or}$$

$$X = (u * NACK_{CBG} + (u-1) * NACK_{TB}) / (u * N_{CBG} + (u-1) * N_{TB})$$
- [0292] Example 32 includes the method of example 1 or some other example herein, wherein the CWS is reset to the minimum value if the maximum CWS is used for K consecutive LBT attempts for transmission only for the priority class for which maximum CWS is used for K consecutive LBT attempts, and the value of K is left up to UE's implementation.
- [0293] Example 33 includes the method of example 1 or some other example herein, wherein for grant-free uplink transmission in NR-U, if an UL grant or a DFI-DCI is received, the CWS is reset for all the priority classes if a UL grant is received and the

NDI bit for at least one of the active HARQ processes associated with HARQ_ID_ref is toggled or an DFI-DCI is received and indicates

- ACK for all the CBGs for at least one of the active HARQ processes associated with HARQ_ID_ref;
- ACK for one of the CBGs for at least one of the active HARQ processes associated with HARQ_ID_ref; or
- ACK for Y% of the CBGs for at least one of the active HARQ processes associated with HARQ_ID_ref.

[0294] The CWS of all priority classes at the UE is increased to the next higher value if a UL grant is received and the NDI bit(s) of all the active HARQ process(es) for the reference burst are not toggled, or a UL grant is received and does not schedule any active HARQ process for the reference burst or a DFI-DCI is received which

- does not indicate ACK for all the CBGs for at least one of the active HARQ processes for the reference burst;
- does not indicate ACK for X% of all the CBGs for at least one of the active HARQ processes for the reference burst;
- does not indicate ACK for X% of the CBGs for at least one of the active HARQ processes associated with HARQ_ID_ref;

the CWS is reset to the minimum value if the maximum CWS is used for K consecutive LBT attempts for transmission only for the priority class for which maximum CWS is used for K consecutive LBT attempts, and the value of K is left up to UE's implementation.

[0295] If there exist at least one previous Cat.4 LBT UL transmission, from the start slot of which, N or more slots have elapsed and neither UL grant nor DFI-DCI is received, where as an example $N = \max(X, \text{corresponding UL burst length} + 1)$ if $X > 0$ and $N = 0$ otherwise, where X is RRC configured. For each previous Cat-4 LBT (SUL/AUL) transmission from the start slot of which, N or more slots have elapsed and neither UL grant nor DFI-DCI is received CWS for all priority classes at the UE is increased to the next higher value, and each such previous Cat-4 LBT transmission is used to adjust the CWS only once.

[0296] If the UE starts a new Cat-4 LBT UL transmission before N slots have elapsed from the previous Cat-4 LBT and neither UL grant nor DFI-DCI is received, the CWS is unchanged.

[0297] If the UE receives feedback for one or more previous Cat-4 LBT (SUL/AUL) transmission from the start slot of which, N or more slots have elapsed and neither UL grant nor DFI-DCI was received, it may re-compute the CWS as follows: i) it reverts the CWS to the value used to transmit the first burst of such previous Cat-4 LBT transmission(s); ii) it updates the CWS sequentially in order of the transmission of bursts as follows. If the feedback indicates

- ACK for all the CBGs for the first slot of the burst,
- Or ACK for X% of all CBGs for the first slot of the burst

[0298] CWS is reset else the CWS is doubled. If the UE CWS changes while a Cat-4 LBT procedure is ongoing, the UE draws a new random back-off counter and applies it to the ongoing LBT procedure.

[0299] Example 34 includes the method of example 1 or some other example herein, wherein only the PUSCH for one or more of the following cases are used for the CWS adjustment:

- a. Only PUSCH whose starting symbol is within the reference burst;
- b. Only PUSCH within the reference burst; or
- c. Only the earliest PUSCH within the reference burst.

[0300] Example 35 includes the method of example 1 or some other example herein, wherein the TB/CBGs for one or more of the following are not used for the CWS adjustment:

- TB/CBG that is punctured by others e.g. URLLC;
- In the initial partial slot, the TB/CBG punctured due to late channel occupation.

[0301] Example 36 includes the method of example 1 or some other example herein, wherein for multi-slot PUSCH, one of the following options can be enforced to prevent that a partial PUSCH repetition might be used as a reference burst:

- It is gNB's implementation to guarantee that after getting a reference timing $ns-N$, there will always be a PUSCH with a full repetitions, which can be used as reference burst;
- If the reference timing $ns-N$ is in the middle of the repetitions of a TB, UE can skip this TB, and use some even earlier PUSCH transmission as reference burst;
- A threshold can be configured to decide whether a TB can be used within the reference burst. The threshold can be a number of repetitions. Let the reference timing

ns-N is in the middle of the repetitions of a TB, if the number of repetitions received by gNB is higher than threshold, the HARQ-ACK for the TB can still be a good reference for CWS; otherwise, UE can skip this TB, and use some even earlier PUSCH transmission as reference burst;

- A threshold can be used to determine the number of repetitions used by gNB. The threshold can be a maximum coding rate. Let the reference timing ns-N is in the middle of the repetitions of a TB, if coding rate of repetitions received by gNB is lower than the threshold, the current TB can be used within the reference burst. Otherwise, UE can skip this TB, and use some even earlier PUSCH transmission as reference burst;
- Regardless on the reference timing ns-N, in this case if at least one of the repetitions follow with the reference burst, all the repetitions will be used for the CWS adjustment;
- Assuming there are multiple PUSCH transmitted in the reference burst, if there is a multi-slot PUSCH in the reference burst, however only part of its repetitions is received by gNB, only other PUSCHs is considered in CWS adjustment.

[0302] 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 1-36, or any other method or process described herein.

[0303] 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 1-36, or any other method or process described herein.

[0304] 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 1-36, or any other method or process described herein.

[0305] Example Z04 may include a method, technique, or process as described in or related to any of examples 1-36, or portions or parts thereof.

[0306] 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 1-36, or portions thereof.

- [0307] Example Z06 may include a signal as described in or related to any of examples 1-36, or portions or parts thereof.
- [0308] Example Z07 may include a signal in a wireless network as shown and described herein.
- [0309] Example Z08 may include a method of communicating in a wireless network as shown and described herein.
- [0310] Example Z09 may include a system for providing wireless communication as shown and described herein.
- [0311] Example Z10 may include a device for providing wireless communication as shown and described herein.
- [0312] 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

- [0313] For the purposes of the present document, the following abbreviations may apply to the examples and embodiments discussed herein.
- | | | |
|--------|------|---|
| [0314] | 3GPP | Third Generation Partnership Project |
| [0315] | 4G | Fourth Generation |
| [0316] | 5G | Fifth Generation |
| [0317] | 5GC | 5G Core network |
| [0318] | ACK | Acknowledgement |
| [0319] | AF | Application Function |
| [0320] | AM | Acknowledged Mode |
| [0321] | AMBR | Aggregate Maximum Bit Rate |
| [0322] | AMF | Access and Mobility Management Function |
| [0323] | AN | Access Network |
| [0324] | ANR | Automatic Neighbour Relation |

[0325]	AP	Application Protocol, Antenna Port, Access Point
[0326]	API	Application Programming Interface
[0327]	APN	Access Point Name
[0328]	ARP	Allocation and Retention Priority
[0329]	ARQ	Automatic Repeat Request
[0330]	AS	Access Stratum
[0331]	ASN.1	Abstract Syntax Notation One
[0332]	AUSF	Authentication Server Function
[0333]	AWGN	Additive White Gaussian Noise
[0334]	BCH	Broadcast Channel
[0335]	BER	Bit Error Ratio
[0336]	BFD	Beam Failure Detection
[0337]	BLER	Block Error Rate
[0338]	BPSK	Binary Phase Shift Keying
[0339]	BRAS	Broadband Remote Access Server
[0340]	BSS	Business Support System
[0341]	BS	Base Station
[0342]	BSR	Buffer Status Report
[0343]	BW	Bandwidth
[0344]	BWP	Bandwidth Part
[0345]	C-RNTI	Cell Radio Network Temporary Identity
[0346]	CA	Carrier Aggregation, Certification Authority
[0347]	CAPEX	CAPital EXpenditure
[0348]	CBRA	Contention Based Random Access
[0349]	CC	Component Carrier, Country Code, Cryptographic Checksum
[0350]	CCA	Clear Channel Assessment
[0351]	CCE	Control Channel Element
[0352]	CCCH	Common Control Channel
[0353]	CE	Coverage Enhancement
[0354]	CDM	Content Delivery Network
[0355]	CDMA	Code-Division Multiple Access
[0356]	CFRA	Contention Free Random Access

[0357]	CG	Cell Group
[0358]	CI	Cell Identity
[0359]	CID	Cell-ID (e.g., positioning method)
[0360]	CIM	Common Information Model
[0361]	CIR	Carrier to Interference Ratio
[0362]	CK	Cipher Key
[0363]	CM	Connection Management, Conditional Mandatory
[0364]	CMAS	Commercial Mobile Alert Service
[0365]	CMD	Command
[0366]	CMS	Cloud Management System
[0367]	CO	Conditional Optional
[0368]	CoMP	Coordinated Multi-Point
[0369]	CORESET	Control Resource Set
[0370]	COTS	Commercial Off-The-Shelf
[0371]	CP	Control Plane, Cyclic Prefix, Connection Point
[0372]	CPD	Connection Point Descriptor
[0373]	CPE	Customer Premise Equipment
[0374]	CPICH	Common Pilot Channel
[0375]	CQI	Channel Quality Indicator
[0376]	CPU	CSI processing unit, Central Processing Unit
[0377]	C/R	Command/Response field bit
[0378]	CRAN	Cloud Radio Access Network, Cloud RAN
[0379]	CRB	Common Resource Block
[0380]	CRC	Cyclic Redundancy Check
[0381]	CRI	Channel-State Information Resource Indicator, CSI-RS Resource Indicator
[0382]	C-RNTI	Cell RNTI
[0383]	CS	Circuit Switched
[0384]	CSAR	Cloud Service Archive
[0385]	CSI	Channel-State Information
[0386]	CSI-IM	CSI Interference Measurement
[0387]	CSI-RS	CSI Reference Signal

[0388]	CSI-RSRP	CSI reference signal received power
[0389]	CSI-RSRQ	CSI reference signal received quality
[0390]	CSI-SINR	CSI signal-to-noise and interference ratio
[0391]	CSMA	Carrier Sense Multiple Access
[0392]	CSMA/CA	CSMA with collision avoidance
[0393]	CSS	Common Search Space, Cell-specific Search Space
[0394]	CTS	Clear-to-Send
[0395]	CW	Codeword
[0396]	CWS	Contention Window Size
[0397]	D2D	Device-to-Device
[0398]	DC	Dual Connectivity, Direct Current
[0399]	DCI	Downlink Control Information
[0400]	DF	Deployment Flavour
[0401]	DL	Downlink
[0402]	DMTF	Distributed Management Task Force
[0403]	DPDK	Data Plane Development Kit
[0404]	DM-RS, DMRS	Demodulation Reference Signal
[0405]	DN	Data network
[0406]	DRB	Data Radio Bearer
[0407]	DRS	Discovery Reference Signal
[0408]	DRX	Discontinuous Reception
[0409]	DSL	Domain Specific Language. Digital Subscriber Line
[0410]	DSLAM	DSL Access Multiplexer
[0411]	DwPTS	Downlink Pilot Time Slot
[0412]	E-LAN	Ethernet Local Area Network
[0413]	E2E	End-to-End
[0414]	ECCA	extended clear channel assessment, extended CCA
[0415]	ECCE	Enhanced Control Channel Element, Enhanced CCE
[0416]	ED	Energy Detection
[0417]	EDGE	Enhanced Data rates for GSM Evolution (GSM Evolution)
[0418]	EGMF	Exposure Governance Management Function
[0419]	EGPRS	Enhanced GPRS

[0420]	EIR	Equipment Identity Register
[0421]	eLAA	enhanced Licensed Assisted Access, enhanced LAA
[0422]	EM	Element Manager
[0423]	eMBB	Enhanced Mobile Broadband
[0424]	EMS	Element Management System
[0425]	eNB	evolved NodeB, E-UTRAN Node B
[0426]	EN-DC	E-UTRA-NR Dual Connectivity
[0427]	EPC	Evolved Packet Core
[0428]	EPDCCH	enhanced PDCCH, enhanced Physical Downlink Control Channel
[0429]	EPRE	Energy per resource element
[0430]	EPS	Evolved Packet System
[0431]	EREG	enhanced REG, enhanced resource element groups
[0432]	ETSI	European Telecommunications Standards Institute
[0433]	ETWS	Earthquake and Tsunami Warning System
[0434]	eUICC	embedded UICC, embedded Universal Integrated Circuit Card
[0435]	E-UTRA	Evolved UTRA
[0436]	E-UTRAN	Evolved UTRAN
[0437]	EV2X	Enhanced V2X
[0438]	F1AP	F1 Application Protocol
[0439]	F1-C	F1 Control plane interface
[0440]	F1-U	F1 User plane interface
[0441]	FACCH	Fast Associated Control Channel
[0442]	FACCH/F	Fast Associated Control Channel/Full rate
[0443]	FACCH/H	Fast Associated Control Channel/Half rate
[0444]	FACH	Forward Access Channel
[0445]	FAUSCH	Fast Uplink Signalling Channel
[0446]	FB	Functional Block
[0447]	FBI	Feedback Information
[0448]	FCC	Federal Communications Commission
[0449]	FCCH	Frequency Correction Channel
[0450]	FDD	Frequency Division Duplex
[0451]	FDM	Frequency Division Multiplex

[0452]	FDMA	Frequency Division Multiple Access
[0453]	FE	Front End
[0454]	FEC	Forward Error Correction
[0455]	FFS	For Further Study
[0456]	FFT	Fast Fourier Transformation
[0457]	feLAA	further enhanced Licensed Assisted Access, further enhanced LAA
[0458]	FN	Frame Number
[0459]	FPGA	Field-Programmable Gate Array
[0460]	FR	Frequency Range
[0461]	G-RNTI	GERAN Radio Network Temporary Identity
[0462]	GERAN	GSM EDGE RAN, GSM EDGE Radio Access Network
[0463]	GGSN	Gateway GPRS Support Node
[0464]	GLONASS	GLOBAL'naya NAVigatsionnaya Sputnikovaya Sistema (Engl.: Global Navigation Satellite System)
[0465]	gNB	Next Generation NodeB
[0466]	gNB-CU	gNB-centralized unit, Next Generation NodeB centralized unit
[0467]	gNB-DU	gNB-distributed unit, Next Generation NodeB distributed unit
[0468]	GNSS	Global Navigation Satellite System
[0469]	GPRS	General Packet Radio Service
[0470]	GSM	Global System for Mobile Communications, Groupe Spécial Mobile
[0471]	GTP	GPRS Tunneling Protocol
[0472]	GTP-U	GPRS Tunnelling Protocol for User Plane
[0473]	GTS	Go To Sleep Signal (related to WUS)
[0474]	GUMMEI	Globally Unique MME Identifier
[0475]	GUTI	Globally Unique Temporary UE Identity
[0476]	HARQ	Hybrid ARQ, Hybrid Automatic Repeat Request
[0477]	HANDOVER, HO	Handover
[0478]	HFN	HyperFrame Number
[0479]	HHO	Hard Handover
[0480]	HLR	Home Location Register

[0481]	HN	Home Network
[0482]	HO	Handover
[0483]	HPLMN	Home Public Land Mobile Network
[0484]	HSDPA	High Speed Downlink Packet Access
[0485]	HSN	Hopping Sequence Number
[0486]	HSPA	High Speed Packet Access
[0487]	HSS	Home Subscriber Server
[0488]	HSUPA	High Speed Uplink Packet Access
[0489]	HTTP	Hyper Text Transfer Protocol
[0490]	HTTPS	Hyper Text Transfer Protocol Secure (https is http/1.1 over SSL, i.e. port 443)
[0491]	I-Block	Information Block
[0492]	ICCID	Integrated Circuit Card Identification
[0493]	ICIC	Inter-Cell Interference Coordination
[0494]	ID	Identity, identifier
[0495]	IDFT	Inverse Discrete Fourier Transform
[0496]	IE	Information element
[0497]	IBE	In-Band Emission
[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]	IS	In Sync
[0520]	IRP	Integration Reference Point
[0521]	ISDN	Integrated Services Digital Network
[0522]	ISIM	IM Services Identity Module
[0523]	ISO	International Organisation for Standardisation
[0524]	ISP	Internet Service Provider
[0525]	IWF	Interworking-Function
[0526]	I-WLAN	Interworking WLAN
[0527]	K	Constraint length of the convolutional code, USIM Individual key
[0528]	kB	Kilobyte (1000 bytes)
[0529]	kbps	kilo-bits per second
[0530]	Kc	Ciphering key
[0531]	Ki	Individual subscriber authentication key
[0532]	KPI	Key Performance Indicator
[0533]	KQI	Key Quality Indicator
[0534]	KSI	Key Set Identifier
[0535]	ksps	kilo-symbols per second
[0536]	KVM	Kernel Virtual Machine
[0537]	L1	Layer 1 (physical layer)
[0538]	L1-RSRP	Layer 1 reference signal received power
[0539]	L2	Layer 2 (data link layer)
[0540]	L3	Layer 3 (network layer)
[0541]	LAA	Licensed Assisted Access
[0542]	LAN	Local Area Network

[0543]	LBT	Listen Before Talk
[0544]	LCM	LifeCycle Management
[0545]	LCR	Low Chip Rate
[0546]	LCS	Location Services
[0547]	LCID	Logical Channel ID
[0548]	LI	Layer Indicator
[0549]	LLC	Logical Link Control, Low Layer Compatibility
[0550]	LPLMN	Local PLMN
[0551]	LPP	LTE Positioning Protocol
[0552]	LSB	Least Significant Bit
[0553]	LTE	Long Term Evolution
[0554]	LWA	LTE-WLAN aggregation
[0555]	LWIP	LTE/WLAN Radio Level Integration with IPsec Tunnel
[0556]	LTE	Long Term Evolution
[0557]	M2M	Machine-to-Machine
[0558]	MAC	Medium Access Control (protocol layering context)
[0559]	MAC	Message authentication code (security/encryption context)
[0560]	MAC-A	MAC used for authentication and key agreement (TSG T WG3 context)
[0561]	MAC-I	MAC used for data integrity of signalling messages (TSG T WG3 context)
[0562]	MANO	Management and Orchestration
[0563]	MBMS	Multimedia Broadcast and Multicast Service
[0564]	MBSFN	Multimedia Broadcast multicast service Single Frequency Network
[0565]	MCC	Mobile Country Code
[0566]	MCG	Master Cell Group
[0567]	MCOT	Maximum Channel Occupancy Time
[0568]	MCS	Modulation and coding scheme
[0569]	MDAF	Management Data Analytics Function
[0570]	MDAS	Management Data Analytics Service
[0571]	MDT	Minimization of Drive Tests

[0572]	ME	Mobile Equipment
[0573]	MeNB	master eNB
[0574]	MER	Message Error Ratio
[0575]	MGL	Measurement Gap Length
[0576]	MGRP	Measurement Gap Repetition Period
[0577]	MIB	Master Information Block, Management Information Base
[0578]	MIMO	Multiple Input Multiple Output
[0579]	MLC	Mobile Location Centre
[0580]	MM	Mobility Management
[0581]	MME	Mobility Management Entity
[0582]	MN	Master Node
[0583]	MO	Measurement Object, Mobile Originated
[0584]	MPBCH	MTC Physical Broadcast CHannel
[0585]	MPDCCH	MTC Physical Downlink Control CHannel
[0586]	MPDSCH	MTC Physical Downlink Shared CHannel
[0587]	MPRACH	MTC Physical Random Access CHannel
[0588]	MPUSCH	MTC Physical Uplink Shared Channel
[0589]	MPLS	MultiProtocol Label Switching
[0590]	MS	Mobile Station
[0591]	MSB	Most Significant Bit
[0592]	MSC	Mobile Switching Centre
[0593]	MSI	Minimum System Information, MCH Scheduling Information
[0594]	MSID	Mobile Station Identifier
[0595]	MSIN	Mobile Station Identification Number
[0596]	MSISDN	Mobile Subscriber ISDN Number
[0597]	MT	Mobile Terminated, Mobile Termination
[0598]	MTC	Machine-Type Communications
[0599]	mMTC	massive MTC, massive Machine-Type Communications
[0600]	MU-MIMO	Multi User MIMO
[0601]	MWUS	MTC wake-up signal, MTC WUS
[0602]	NACK	Negative Acknowledgement
[0603]	NAI	Network Access Identifier

[0604]	NAS	Non-Access Stratum, Non-Access Stratum layer
[0605]	NCT	Network Connectivity Topology
[0606]	NEC	Network Capability Exposure
[0607]	NE-DC	NR-E-UTRA Dual Connectivity
[0608]	NEF	Network Exposure Function
[0609]	NF	Network Function
[0610]	NFP	Network Forwarding Path
[0611]	NFPD	Network Forwarding Path Descriptor
[0612]	NFV	Network Functions Virtualization
[0613]	NFVI	NFV Infrastructure
[0614]	NFVO	NFV Orchestrator
[0615]	NG	Next Generation, Next Gen
[0616]	NGEN-DC	NG-RAN E-UTRA-NR Dual Connectivity
[0617]	NM	Network Manager
[0618]	NMS	Network Management System
[0619]	N-PoP	Network Point of Presence
[0620]	NMIB, N-MIB	Narrowband MIB
[0621]	NPBCH	Narrowband Physical Broadcast CHannel
[0622]	NPDCCH	Narrowband Physical Downlink Control CHannel
[0623]	NPDSCH	Narrowband Physical Downlink Shared CHannel
[0624]	NPRACH	Narrowband Physical Random Access CHannel
[0625]	NPUSCH	Narrowband Physical Uplink Shared CHannel
[0626]	NPSS	Narrowband Primary Synchronization Signal
[0627]	NSSS	Narrowband Secondary Synchronization Signal
[0628]	NR	New Radio, Neighbour Relation
[0629]	NRF	NF Repository Function
[0630]	NRS	Narrowband Reference Signal
[0631]	NS	Network Service
[0632]	NSA	Non-Standalone operation mode
[0633]	NSD	Network Service Descriptor
[0634]	NSR	Network Service Record
[0635]	NSSAI	Network Slice Selection Assistance Information

[0636]	S-NNSAI	Single-NSSAI
[0637]	NSSF	Network Slice Selection Function
[0638]	NW	Network
[0639]	NWUS	Narrowband wake-up signal, Narrowband WUS
[0640]	NZP	Non-Zero Power
[0641]	O&M	Operation and Maintenance
[0642]	ODU2	Optical channel Data Unit - type 2
[0643]	OFDM	Orthogonal Frequency Division Multiplexing
[0644]	OFDMA	Orthogonal Frequency Division Multiple Access
[0645]	OOB	Out-of-band
[0646]	OOS	Out of Sync
[0647]	OPEX	OPerating EXpense
[0648]	OSI	Other System Information
[0649]	OSS	Operations Support System
[0650]	OTA	over-the-air
[0651]	PAPR	Peak-to-Average Power Ratio
[0652]	PAR	Peak to Average Ratio
[0653]	PBCH	Physical Broadcast Channel
[0654]	PC	Power Control, Personal Computer
[0655]	PCC	Primary Component Carrier, Primary CC
[0656]	PCell	Primary Cell
[0657]	PCI	Physical Cell ID, Physical Cell Identity
[0658]	PCEF	Policy and Charging Enforcement Function
[0659]	PCF	Policy Control Function
[0660]	PCRF	Policy Control and Charging Rules Function
[0661]	PDCP	Packet Data Convergence Protocol, Packet Data Convergence Protocol layer
[0662]	PDCCCH	Physical Downlink Control Channel
[0663]	PDCP	Packet Data Convergence Protocol
[0664]	PDN	Packet Data Network, Public Data Network
[0665]	PD SCH	Physical Downlink Shared Channel
[0666]	PDU	Protocol Data Unit

[0667]	PEI	Permanent Equipment Identifiers
[0668]	PFD	Packet Flow Description
[0669]	P-GW	PDN Gateway
[0670]	PHICH	Physical hybrid-ARQ indicator channel
[0671]	PHY	Physical layer
[0672]	PLMN	Public Land Mobile Network
[0673]	PIN	Personal Identification Number
[0674]	PM	Performance Measurement
[0675]	PMI	Precoding Matrix Indicator
[0676]	PNF	Physical Network Function
[0677]	PNFD	Physical Network Function Descriptor
[0678]	PNFR	Physical Network Function Record
[0679]	POC	PTT over Cellular
[0680]	PP, PTP	Point-to-Point
[0681]	PPP	Point-to-Point Protocol
[0682]	PRACH	Physical RACH
[0683]	PRB	Physical resource block
[0684]	PRG	Physical resource block group
[0685]	ProSe	Proximity Services, Proximity-Based Service
[0686]	PRS	Positioning Reference Signal
[0687]	PRR	Packet Reception Radio
[0688]	PS	Packet Services
[0689]	PSBCH	Physical Sidelink Broadcast Channel
[0690]	PSDCH	Physical Sidelink Downlink Channel
[0691]	PSCCH	Physical Sidelink Control Channel
[0692]	PSSCH	Physical Sidelink Shared Channel
[0693]	PSCell	Primary SCell
[0694]	PSS	Primary Synchronization Signal
[0695]	PSTN	Public Switched Telephone Network
[0696]	PT-RS	Phase-tracking reference signal
[0697]	PTT	Push-to-Talk
[0698]	PUCCH	Physical Uplink Control Channel

[0699]	PUSCH	Physical Uplink Shared Channel
[0700]	QAM	Quadrature Amplitude Modulation
[0701]	QCI	QoS class of identifier
[0702]	QCL	Quasi co-location
[0703]	QFI	QoS Flow ID, QoS Flow Identifier
[0704]	QoS	Quality of Service
[0705]	QPSK	Quadrature (Quaternary) Phase Shift Keying
[0706]	QZSS	Quasi-Zenith Satellite System
[0707]	RA-RNTI	Random Access RNTI
[0708]	RAB	Radio Access Bearer, Random Access Burst
[0709]	RACH	Random Access Channel
[0710]	RADIUS	Remote Authentication Dial In User Service
[0711]	RAN	Radio Access Network
[0712]	RAND	RANDom number (used for authentication)
[0713]	RAR	Random Access Response
[0714]	RAT	Radio Access Technology
[0715]	RAU	Routing Area Update
[0716]	RB	Resource block, Radio Bearer
[0717]	RBG	Resource block group
[0718]	REG	Resource Element Group
[0719]	Rel	Release
[0720]	REQ	REQuest
[0721]	RF	Radio Frequency
[0722]	RI	Rank Indicator
[0723]	RIV	Resource indicator value
[0724]	RL	Radio Link
[0725]	RLC	Radio Link Control, Radio Link Control layer
[0726]	RLC AM	RLC Acknowledged Mode
[0727]	RLC UM	RLC Unacknowledged Mode
[0728]	RLF	Radio Link Failure
[0729]	RLM	Radio Link Monitoring
[0730]	RLM-RS	Reference Signal for RLM

[0731]	RM	Registration Management
[0732]	RMC	Reference Measurement Channel
[0733]	RMSI	Remaining MSI, Remaining Minimum System Information
[0734]	RN	Relay Node
[0735]	RNC	Radio Network Controller
[0736]	RNL	Radio Network Layer
[0737]	RNTI	Radio Network Temporary Identifier
[0738]	ROHC	RObust Header Compression
[0739]	RRC	Radio Resource Control, Radio Resource Control layer
[0740]	RRM	Radio Resource Management
[0741]	RS	Reference Signal
[0742]	RSRP	Reference Signal Received Power
[0743]	RSRQ	Reference Signal Received Quality
[0744]	RSSI	Received Signal Strength Indicator
[0745]	RSU	Road Side Unit
[0746]	RSTD	Reference Signal Time difference
[0747]	RTP	Real Time Protocol
[0748]	RTS	Ready-To-Send
[0749]	RTT	Round Trip Time
[0750]	Rx	Reception, Receiving, Receiver
[0751]	S1AP	S1 Application Protocol
[0752]	S1-MME	S1 for the control plane
[0753]	S1-U	S1 for the user plane
[0754]	S-GW	Serving Gateway
[0755]	S-RNTI	SRNC Radio Network Temporary Identity
[0756]	S-TMSI	SAE Temporary Mobile Station Identifier
[0757]	SA	Standalone operation mode
[0758]	SAE	System Architecture Evolution
[0759]	SAP	Service Access Point
[0760]	SAPD	Service Access Point Descriptor
[0761]	SAPI	Service Access Point Identifier
[0762]	SCC	Secondary Component Carrier, Secondary CC

[0763]	SCell	Secondary Cell
[0764]	SC-FDMA	Single Carrier Frequency Division Multiple Access
[0765]	SCG	Secondary Cell Group
[0766]	SCM	Security Context Management
[0767]	SCS	Subcarrier Spacing
[0768]	SCTP	Stream Control Transmission Protocol
[0769]	SDAP	Service Data Adaptation Protocol, Service Data Adaptation Protocol layer
[0770]	SDL	Supplementary Downlink
[0771]	SDNF	Structured Data Storage Network Function
[0772]	SDP	Service Discovery Protocol (Bluetooth related)
[0773]	SDSF	Structured Data Storage Function
[0774]	SDU	Service Data Unit
[0775]	SEAF	Security Anchor Function
[0776]	SeNB	secondary eNB
[0777]	SEPP	Security Edge Protection Proxy
[0778]	SFI	Slot format indication
[0779]	SFTD	Space-Frequency Time Diversity, SFN and frame timing difference
[0780]	SFN	System Frame Number
[0781]	SgNB	Secondary gNB
[0782]	SGSN	Serving GPRS Support Node
[0783]	S-GW	Serving Gateway
[0784]	SI	System Information
[0785]	SI-RNTI	System Information RNTI
[0786]	SIB	System Information Block
[0787]	SIM	Subscriber Identity Module
[0788]	SIP	Session Initiated Protocol
[0789]	SiP	System in Package
[0790]	SL	Sidelink
[0791]	SLA	Service Level Agreement
[0792]	SM	Session Management

[0793]	SMF	Session Management Function
[0794]	SMS	Short Message Service
[0795]	SMSF	SMS Function
[0796]	SMTC	SSB-based Measurement Timing Configuration
[0797]	SN	Secondary Node, Sequence Number
[0798]	SoC	System on Chip
[0799]	SON	Self-Organizing Network
[0800]	SpCell	Special Cell
[0801]	SP-CSI-RNTI	Semi-Persistent CSI RNTI
[0802]	SPS	Semi-Persistent Scheduling
[0803]	SQN	Sequence number
[0804]	SR	Scheduling Request
[0805]	SRB	Signalling Radio Bearer
[0806]	SRS	Sounding Reference Signal
[0807]	SS	Synchronization Signal
[0808]	SSB	Synchronization Signal Block, SS/PBCH Block
[0809]	SSBRI	SS/PBCH Block Resource Indicator, Synchronization Signal Block Resource Indicator
[0810]	SSC	Session and Service Continuity
[0811]	SS-RSRP	Synchronization Signal based Reference Signal Received Power
[0812]	SS-RSRQ	Synchronization Signal based Reference Signal Received Quality
[0813]	SS-SINR	Synchronization Signal based Signal to Noise and Interference Ratio
[0814]	SSS	Secondary Synchronization Signal
[0815]	SSSG	Search Space Set Group
[0816]	SSSIF	Search Space Set Indicator
[0817]	SST	Slice/Service Types
[0818]	SU-MIMO	Single User MIMO
[0819]	SUL	Supplementary Uplink
[0820]	TA	Timing Advance, Tracking Area
[0821]	TAC	Tracking Area Code
[0822]	TAG	Timing Advance Group

[0823]	TAU	Tracking Area Update
[0824]	TB	Transport Block
[0825]	TBS	Transport Block Size
[0826]	TBD	To Be Defined
[0827]	TCI	Transmission Configuration Indicator
[0828]	TCP	Transmission Communication Protocol
[0829]	TDD	Time Division Duplex
[0830]	TDM	Time Division Multiplexing
[0831]	TDMA	Time Division Multiple Access
[0832]	TE	Terminal Equipment
[0833]	TEID	Tunnel End Point Identifier
[0834]	TFT	Traffic Flow Template
[0835]	TMSI	Temporary Mobile Subscriber Identity
[0836]	TNL	Transport Network Layer
[0837]	TPC	Transmit Power Control
[0838]	TPMI	Transmitted Precoding Matrix Indicator
[0839]	TR	Technical Report
[0840]	TRP, TRxP	Transmission Reception Point
[0841]	TRS	Tracking Reference Signal
[0842]	TRx	Transceiver
[0843]	TS	Technical Specifications, Technical Standard
[0844]	TTI	Transmission Time Interval
[0845]	Tx	Transmission, Transmitting, Transmitter
[0846]	U-RNTI	UTRAN Radio Network Temporary Identity
[0847]	UART	Universal Asynchronous Receiver and Transmitter
[0848]	UCI	Uplink Control Information
[0849]	UE	User Equipment
[0850]	UDM	Unified Data Management
[0851]	UDP	User Datagram Protocol
[0852]	UDSF	Unstructured Data Storage Network Function
[0853]	UICC	Universal Integrated Circuit Card
[0854]	UL	Uplink

[0855]	UM	Unacknowledged Mode
[0856]	UML	Unified Modelling Language
[0857]	UMTS	Universal Mobile Telecommunications System
[0858]	UP	User Plane
[0859]	UPF	User Plane Function
[0860]	URI	Uniform Resource Identifier
[0861]	URL	Uniform Resource Locator
[0862]	URLLC	Ultra-Reliable and Low Latency
[0863]	USB	Universal Serial Bus
[0864]	USIM	Universal Subscriber Identity Module
[0865]	USS	UE-specific search space
[0866]	UTRA	UMTS Terrestrial Radio Access
[0867]	UTRAN	Universal Terrestrial Radio Access Network
[0868]	UwPTS	Uplink Pilot Time Slot
[0869]	V2I	Vehicle-to-Infrastructure
[0870]	V2P	Vehicle-to-Pedestrian
[0871]	V2V	Vehicle-to-Vehicle
[0872]	V2X	Vehicle-to-everything
[0873]	VIM	Virtualized Infrastructure Manager
[0874]	VL	Virtual Link,
[0875]	VLAN	Virtual LAN, Virtual Local Area Network
[0876]	VM	Virtual Machine
[0877]	VNF	Virtualized Network Function
[0878]	VNFFG	VNF Forwarding Graph
[0879]	VNFFGD	VNF Forwarding Graph Descriptor
[0880]	VNFM	VNF Manager
[0881]	VoIP	Voice-over-IP, Voice-over-Internet Protocol
[0882]	VPLMN	Visited Public Land Mobile Network
[0883]	VPN	Virtual Private Network
[0884]	VRB	Virtual Resource Block
[0885]	WiMAX	Worldwide Interoperability for Microwave Access
[0886]	WLAN	Wireless Local Area Network

[0887]	WMAN	Wireless Metropolitan Area Network
[0888]	WPAN	Wireless Personal Area Network
[0889]	X2-C	X2-Control plane
[0890]	X2-U	X2-User plane
[0891]	XML	eXtensible Markup Language
[0892]	XRES	EXpected user RESponse
[0893]	XOR	eXclusive OR
[0894]	ZC	Zadoff-Chu
[0895]	ZP	Zero Power

Terminology

[0896] For the purposes of the present document, the following terms and definitions are applicable to the examples and embodiments discussed herein.

[0897] 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.

[0898] 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.”

- [0899]** 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.
- [0900]** 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.
- [0901]** 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.
- [0902]** 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.
- [0903]** The term “appliance,” “computer appliance,” or the like, as used herein refers to a computer device or computer system with program code (e.g., software or firmware) that

is specifically designed to provide a specific computing resource. A “virtual appliance” is a virtual machine image to be implemented by a hypervisor-equipped device that virtualizes or emulates a computer appliance or otherwise is dedicated to provide a specific computing resource.

[0904] 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.

[0905] 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.

- [0906] 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.
- [0907] The terms “coupled,” “communicatively coupled,” along with derivatives thereof are used herein. The term “coupled” may mean two or more elements are in direct physical or electrical contact with one another, may mean that two or more elements indirectly contact each other but still cooperate or interact with each other, and/or may mean that one or more other elements are coupled or connected between the elements that are said to be coupled with each other. The term “directly coupled” may mean that two or more elements are in direct contact with one another. The term “communicatively coupled” may mean that two or more elements may be in contact with one another by a means of communication including through a wire or other interconnect connection, through a wireless communication channel or link, and/or the like.
- [0908] 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.
- [0909] The term “SMTC” refers to an SSB-based measurement timing configuration configured by *SSB-MeasurementTimingConfiguration*.
- [0910] The term “SSB” refers to an SS/PBCH block.
- [0911] 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.
- [0912] 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.
- [0913] The term “Secondary Cell” refers to a cell providing additional radio resources on top of a Special Cell for a UE configured with CA.
- [0914] 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.
- [0915] 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.

- [0916] 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/.
- [0917] 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:

1. An apparatus for wireless communication using an unlicensed spectrum, the apparatus comprising:
 - processor circuitry configured to:
 - perform a listen before talk (LBT) procedure using an LBT parameter and a maximum channel occupancy time (MCOT) that is compatible with another wireless protocol using the unlicensed spectrum; and
 - divide a transport block (TB) into a plurality of code block groups (CBGs) for transmission over the unlicensed spectrum;
 - a transmitter configured to transmit the plurality of CBGs to a destination;
 - a receiver configured to receive hybrid automatic repeat and request acknowledgment (HARQ-ACK) information corresponding to the transmitted plurality of CBGs; and
 - the processor circuitry further configured to:
 - determine a HARQ-ACK assessment for the TB based on the HARQ-ACK information corresponding to the transmitted plurality of CBGs; and
 - adjust a contention window size based on the HARQ-ACK assessment for the TB.
2. The apparatus of claim 1, wherein the other wireless protocol is Wi-Fi.
3. The apparatus of claim 1, wherein the processor circuitry determines the HARQ-ACK assessment for the TB to be a negative acknowledgement if the HARQ-ACK information includes a negative acknowledge (NACK) message for at least one CBG of the plurality of CBGs.
4. The apparatus of claim 1, wherein the processor circuitry determines the HARQ-ACK assessment for the TB to be a negative acknowledgement if the HARQ-ACK information includes a percentage of negatively acknowledged CBGs that exceeds a preconfigured percentage threshold.

5. The apparatus of claim 4, wherein the preconfigured percentage threshold is at least 80 percent.
6. The apparatus of claim 1, wherein the processor circuitry is further configured to:
discard the HARQ-ACK assessment for adjusting the contention window size in response to not scheduling a negatively acknowledged CBG of the plurality of CBGs.
7. The apparatus of claim 1, wherein the processor circuitry is further configured to:
ignore the HARQ-ACK assessment for adjusting the contention window size if the TB is a punctured TB or if at least one of the plurality of CBGs is a punctured CBG.
8. A method for wireless communication using an unlicensed spectrum, comprising:
performing, at an access point (AP), a listen before talk (LBT) procedure using an LBT parameter and a maximum channel occupancy time (MCOT) that is compatible with another wireless protocol using the unlicensed spectrum;
dividing, at the AP, a transport block (TB) into a plurality of code block groups (CBGs) for transmission over the unlicensed spectrum;
transmitting, from the AP, the plurality of CBGs to a destination;
receiving, at the AP, hybrid automatic repeat and request acknowledgment (HARQ-ACK) information corresponding to the transmitted plurality of CBGs;
determining, by the AP, HARQ-ACK assessment for the TB based on the HARQ-ACK information corresponding to the transmitted plurality of CBGs; and
adjusting, at the AP, a contention window size based on the HARQ-ACK assessment for the TB.
9. The method of claim 8, wherein the other wireless protocol is Wi-Fi.
10. The method of claim 8, further comprising determining, by the AP, the HARQ-ACK assessment for the TB to be negative acknowledgement if the HARQ-ACK information includes a negative acknowledge (NACK) message for at least one CBG of the plurality of CBGs.

11. The method of claim 8, further comprising determining, by the AP, the HARQ-ACK assessment for the TB to be negative acknowledgement if the HARQ-ACK information includes a percentage of negatively acknowledged CBGs that exceeds a preconfigured percentage threshold.
12. The method of claim 11, wherein the preconfigured percentage threshold is at least 80 percent.
13. The method of claim 8, further comprising:
 - discarding, by the AP, the HARQ-ACK assessment for adjusting the contention window size in response to not scheduling a negatively acknowledged CBG of the plurality of CBGs.
14. The method of claim 8, further comprising:
 - ignoring, by the AP, the HARQ-ACK assessment for adjusting the contention window size if the TB is a punctured TB or if at least one of the plurality of CBGs is a punctured CBG.
15. Computer-readable media (CRM) comprising computer instructions, where upon execution of the computer instructions by one or more processors of an access point (AP), causes the one or more processors to:
 - perform a listen before talk (LBT) procedure using an LBT parameter and a maximum channel occupancy time (MCOT) that is compatible with another wireless protocol using an unlicensed spectrum;
 - divide a transport block (TB) into a plurality of code block groups (CBGs) for transmission over the unlicensed spectrum;
 - transmit the plurality of CBGs to a destination;
 - receive hybrid automatic repeat and request acknowledgment (HARQ-ACK) information corresponding to the transmitted plurality of CBGs;
 - determine HARQ-ACK assessment for the TB based on the HARQ-ACK information corresponding to the transmitted plurality of CBGs; and
 - adjust a contention window size based on the HARQ-ACK assessment for the TB,

wherein the other wireless protocol is Wi-Fi.

16. The CRM of claim 15, wherein, upon execution, the computer instructions further cause the one or more processors to determine the HARQ-ACK assessment for the TB to be negative acknowledgement if the HARQ-ACK information includes a negative acknowledge (NACK) message for at least one CBG of the plurality of CBGs.
17. The CRM of claim 15, wherein, upon execution, the computer instructions further cause the one or more processors to determine the HARQ-ACK assessment for the TB to be negative acknowledgement if the HARQ-ACK information includes a percentage of negatively acknowledged CBGs that exceeds a preconfigured percentage threshold.
18. The CRM of claim 17, wherein the preconfigured percentage threshold is at least 80 percent.
19. The CRM of claim 15, wherein, upon execution, the computer instructions further cause the one or more processors to discard the HARQ-ACK assessment for adjusting the contention window size in response to not scheduling a negatively acknowledged CBG of the plurality of CBGs.
20. The CRM of claim 15, wherein, upon execution, the computer instructions further cause the one or more processors to ignore the HARQ-ACK assessment for adjusting the contention window size if the TB is a punctured TB or if at least one of the plurality of CBGs is a punctured CBG.

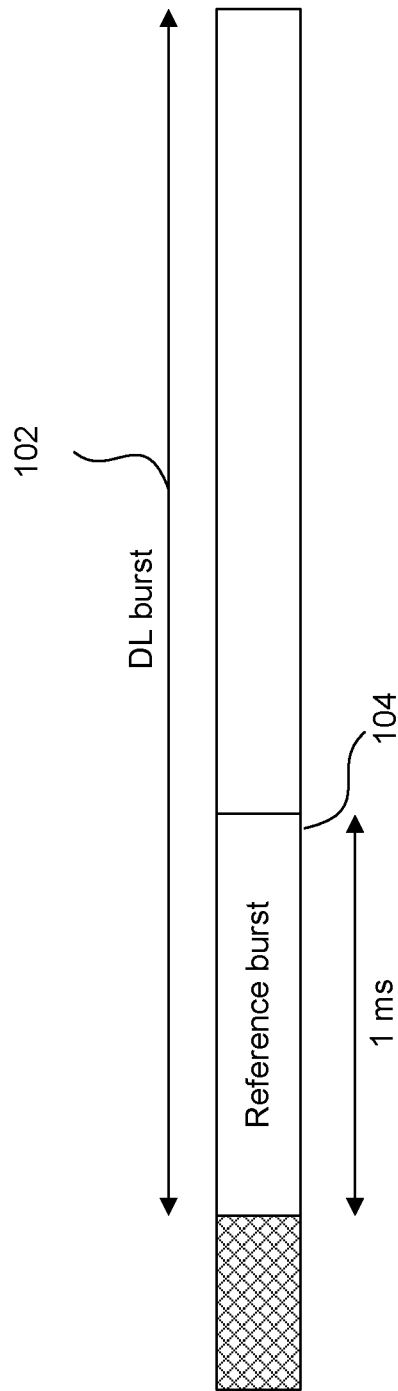


FIG. 1

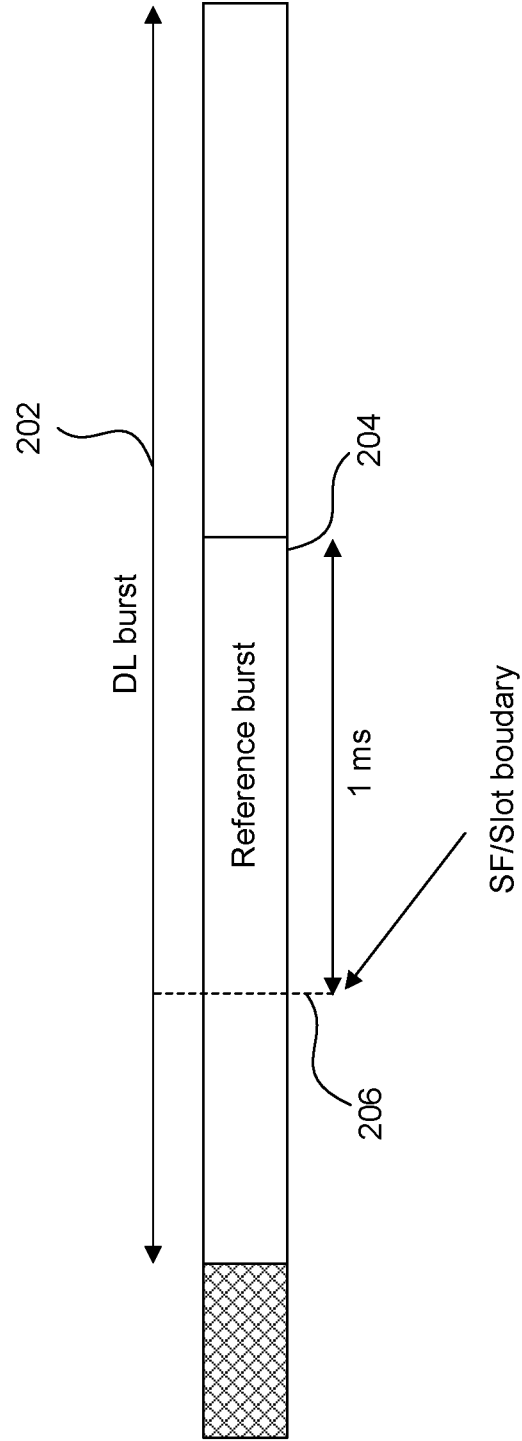


FIG. 2

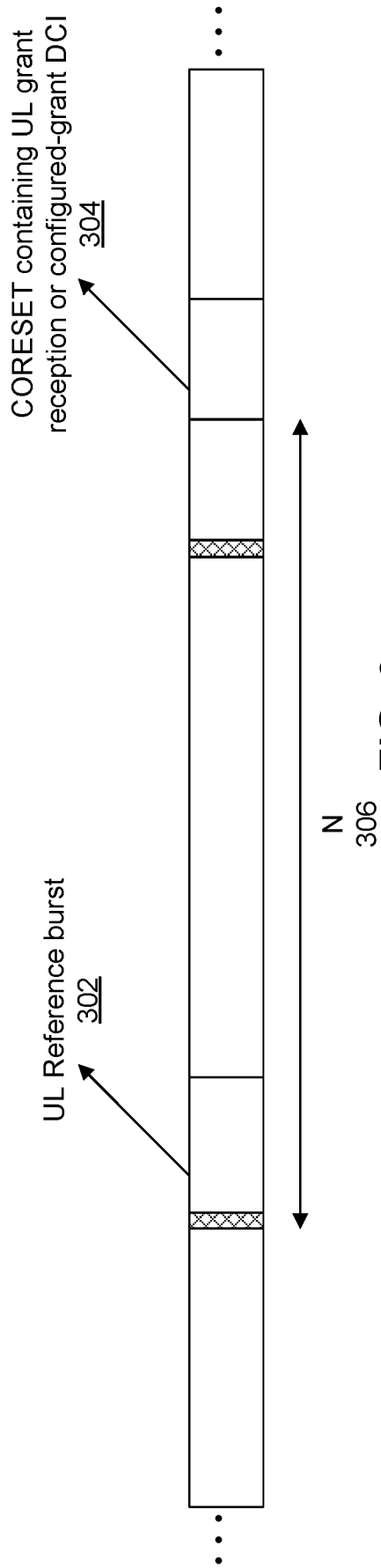


FIG. 3

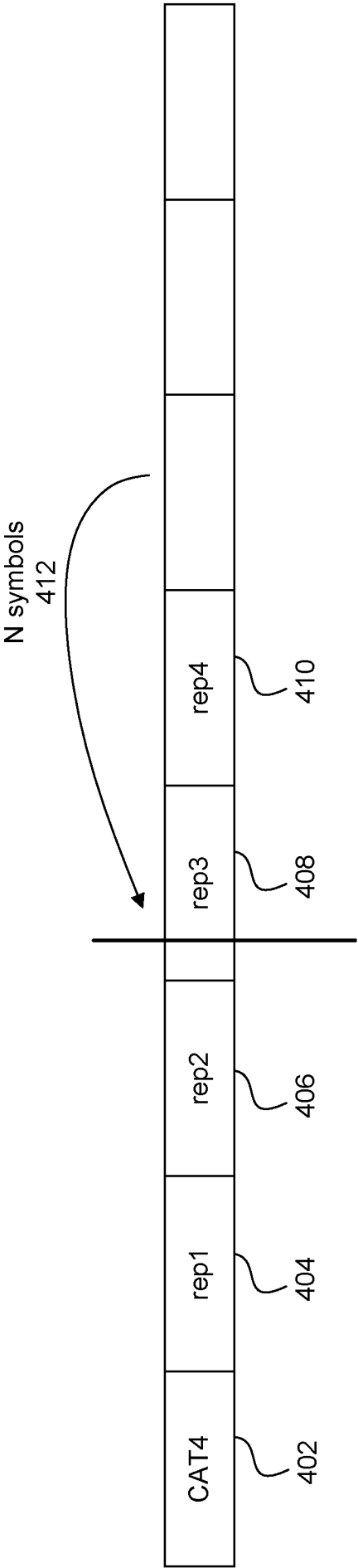


FIG. 4

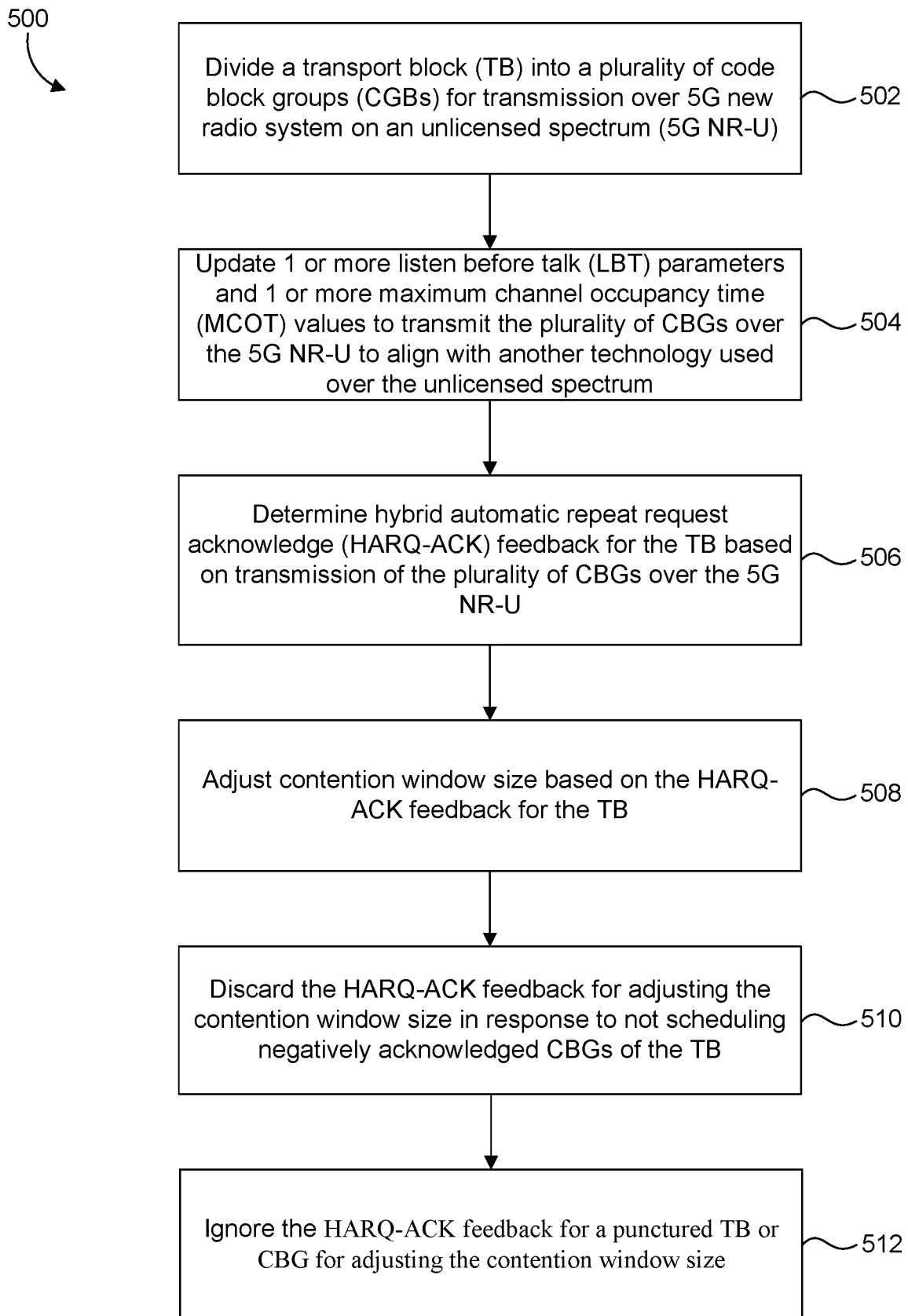


FIG. 5

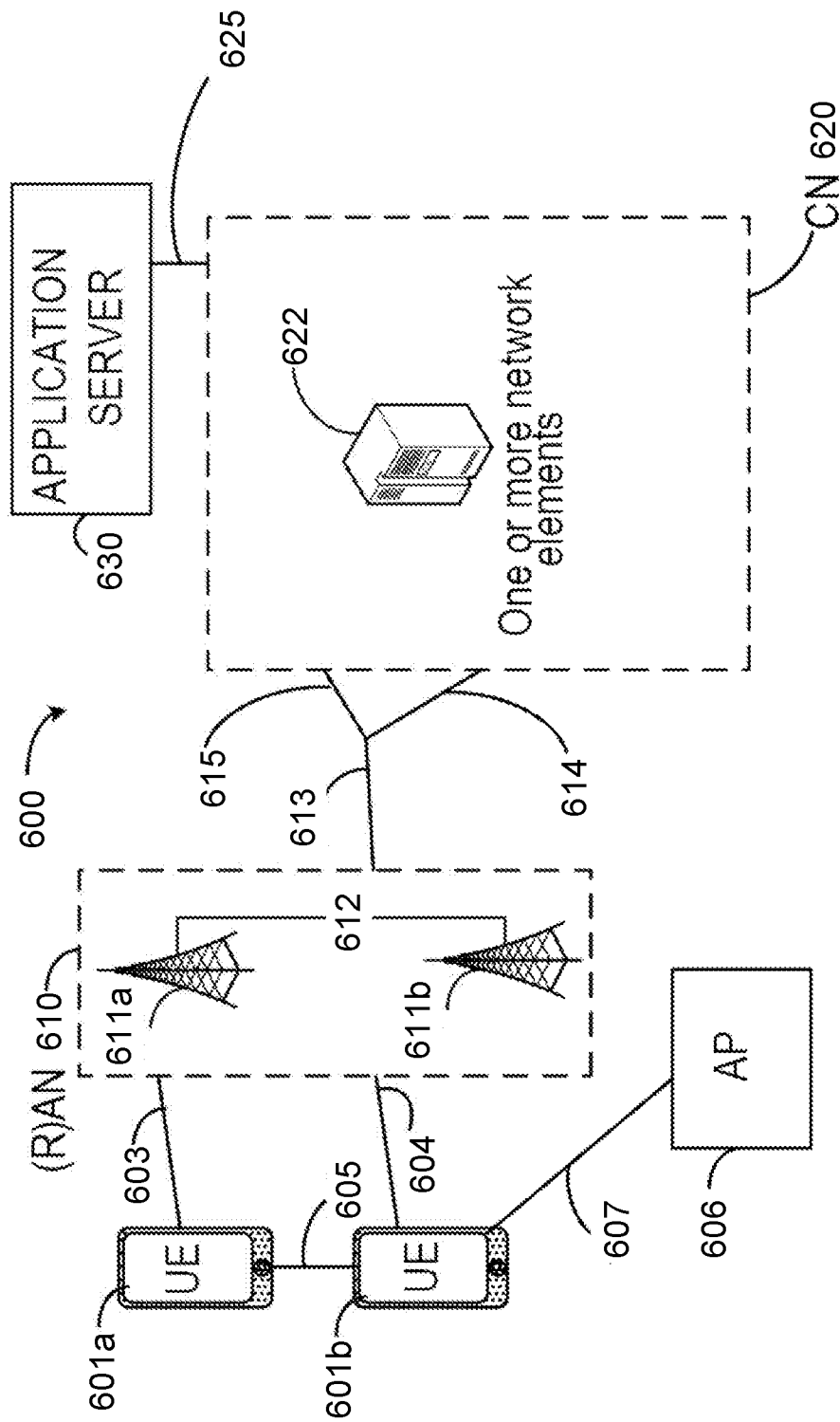


FIG. 6

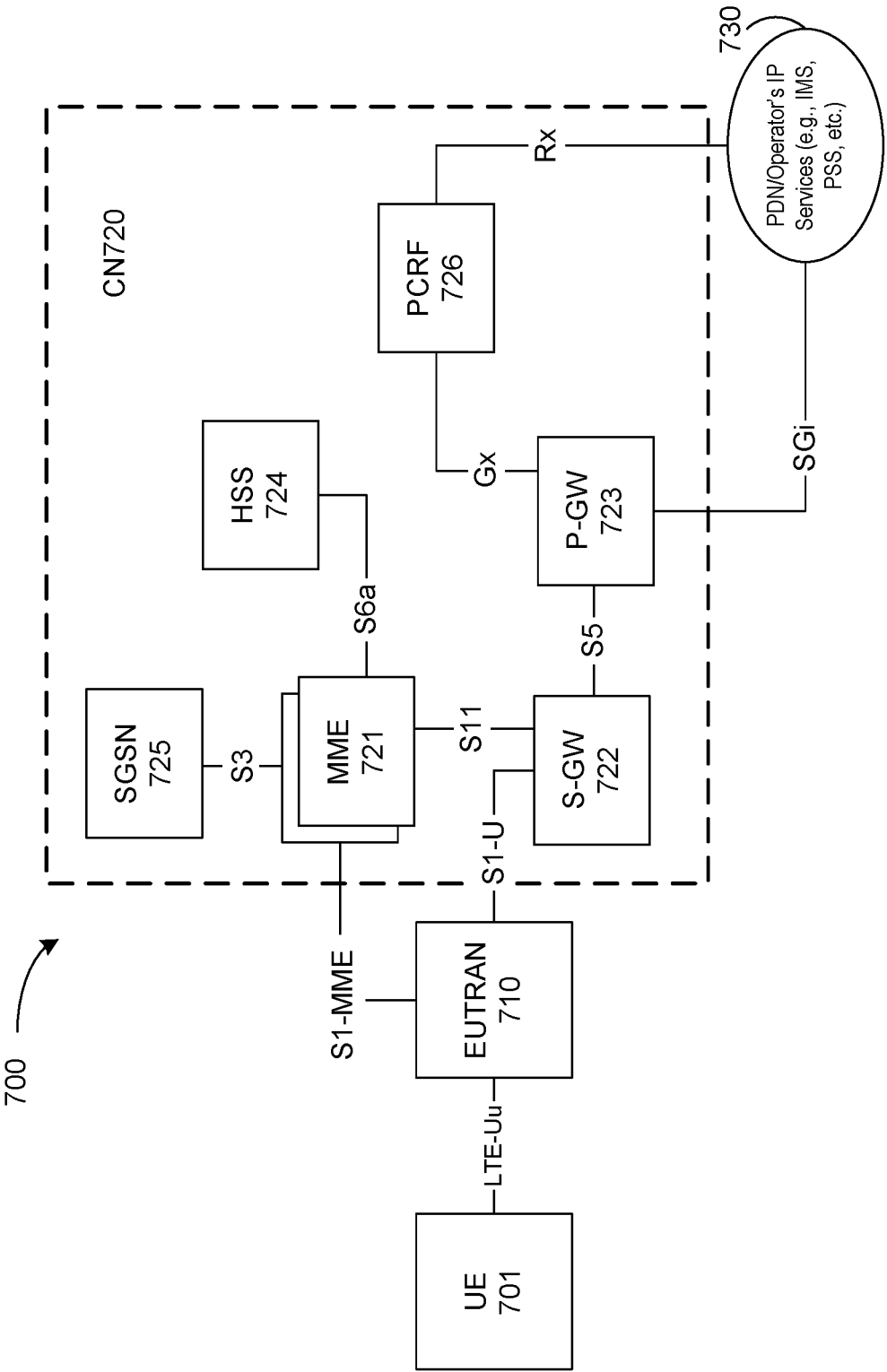


FIG. 7

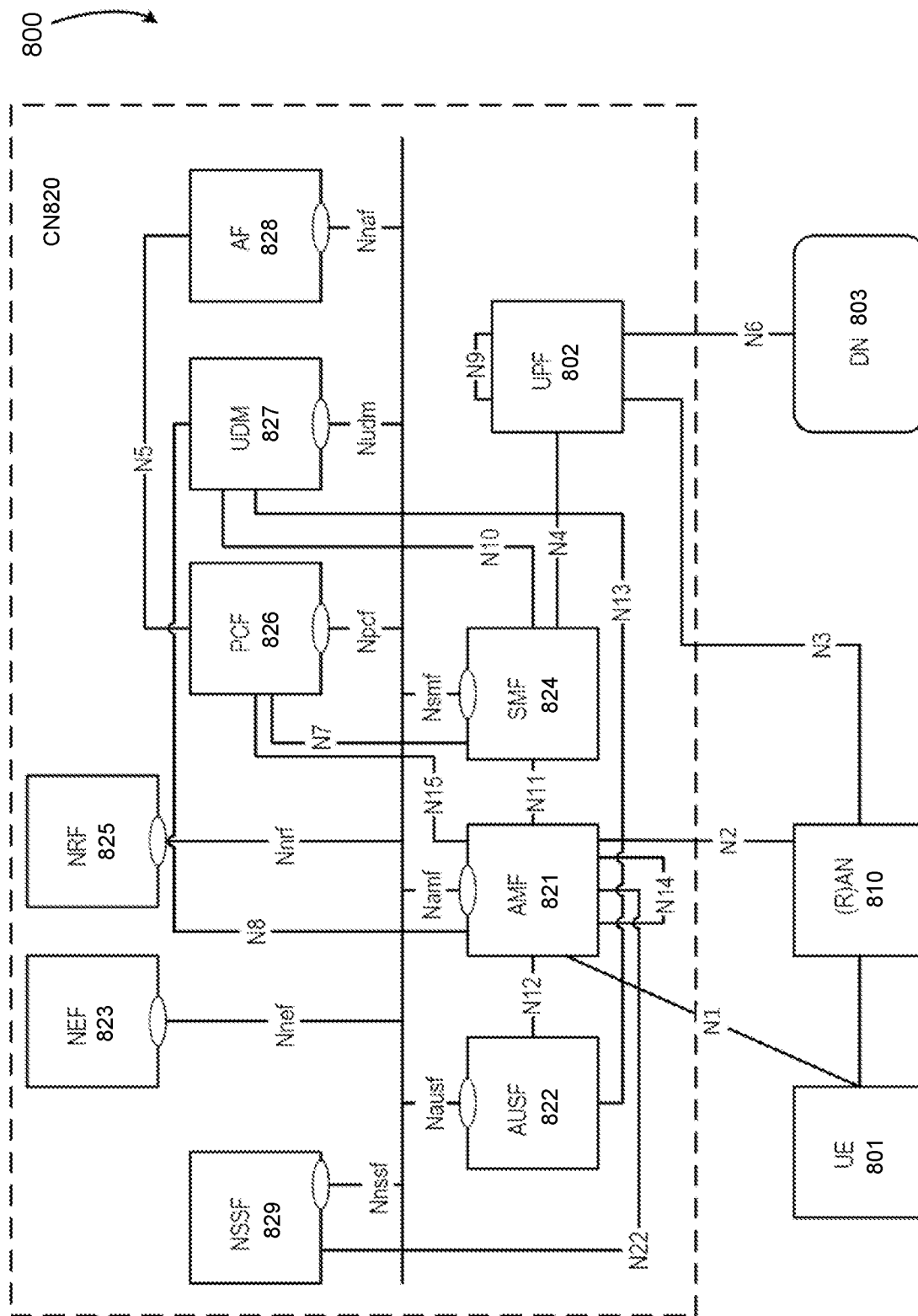


FIG. 8

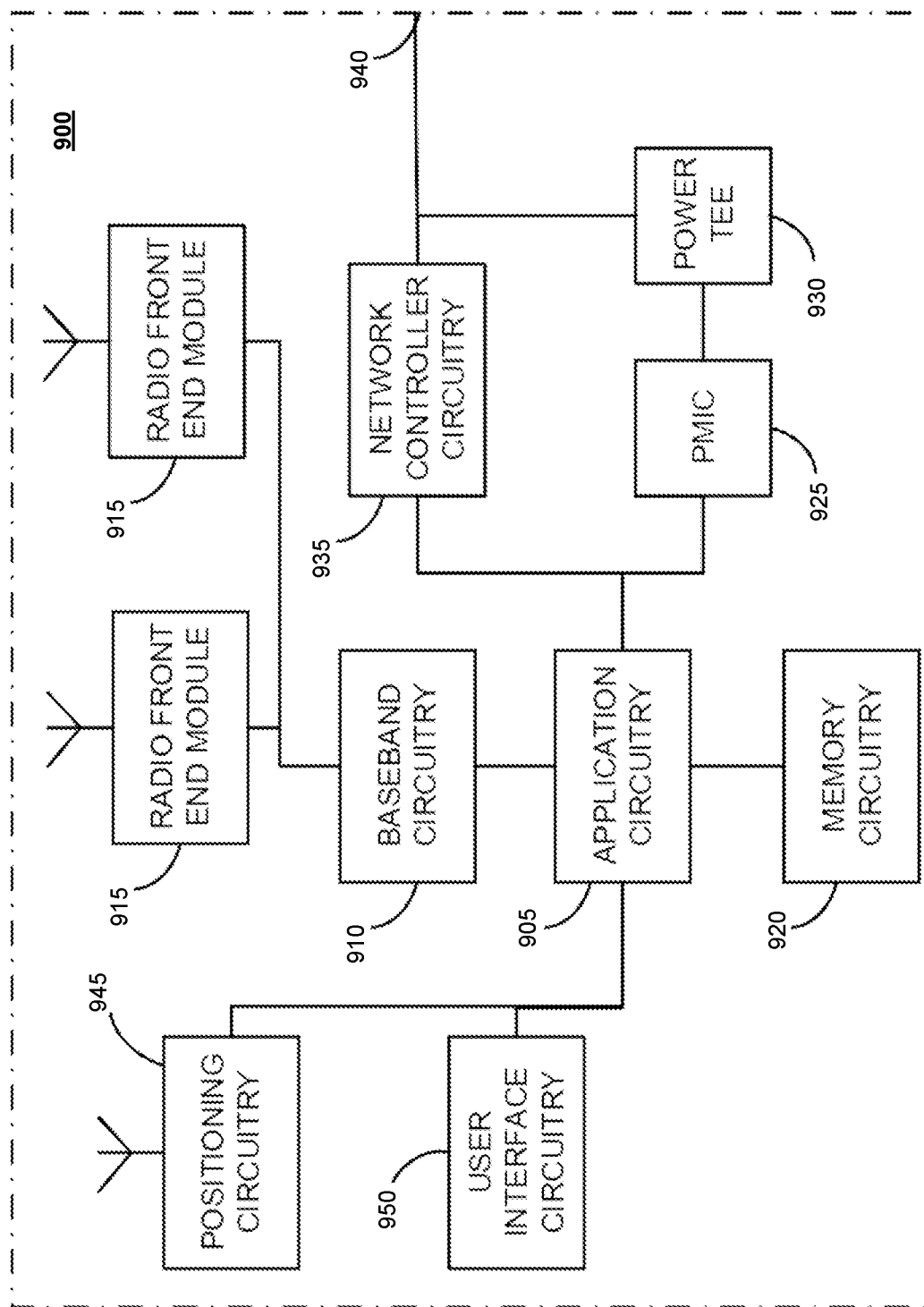


FIG. 9

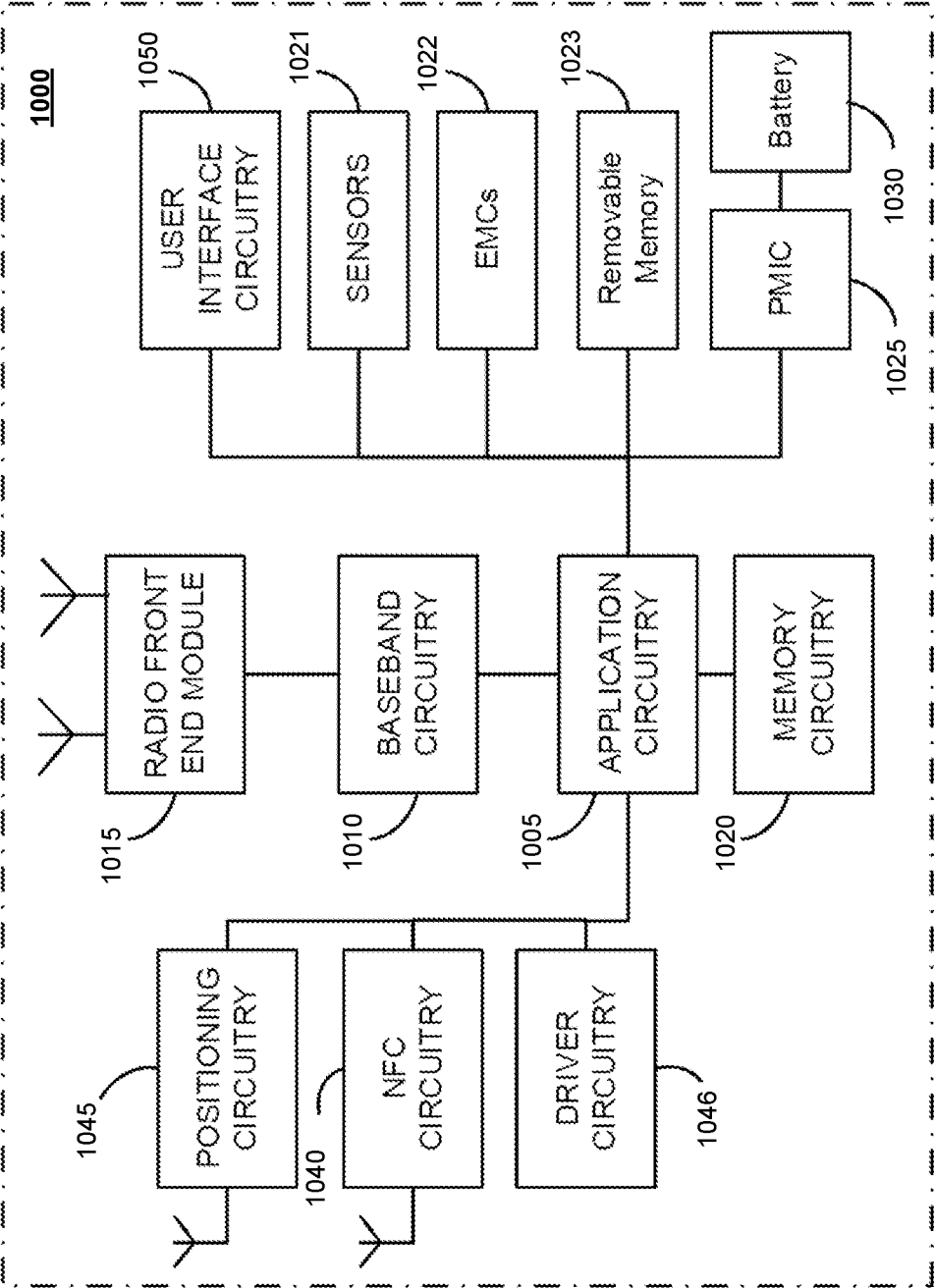


FIG. 10

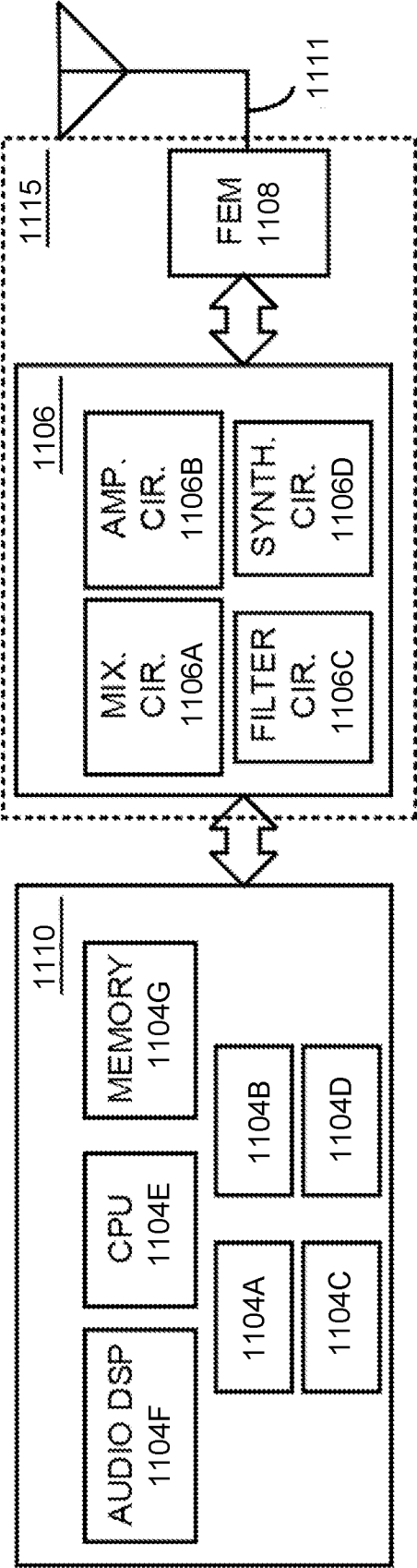


FIG. 11

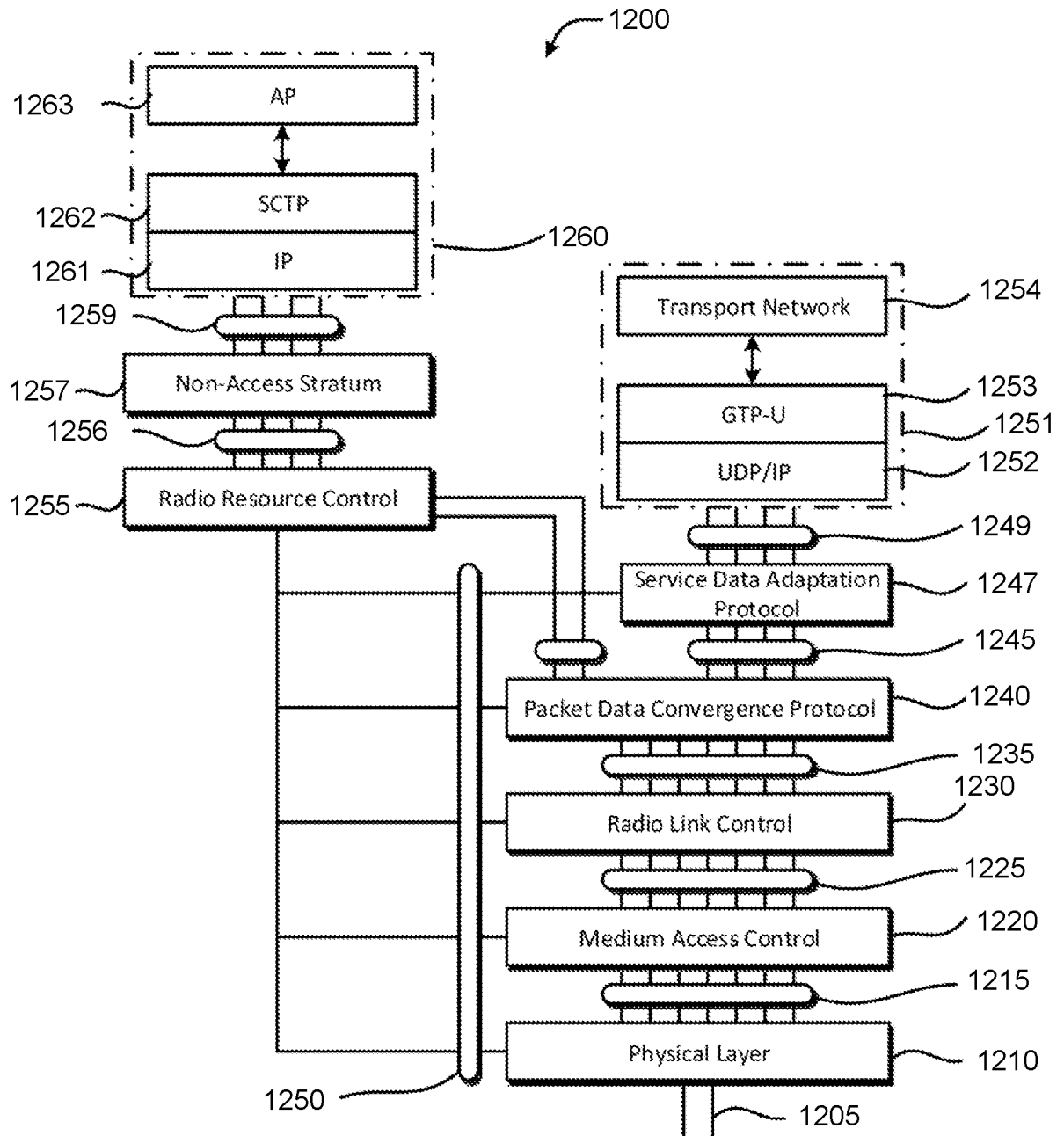


FIG. 12

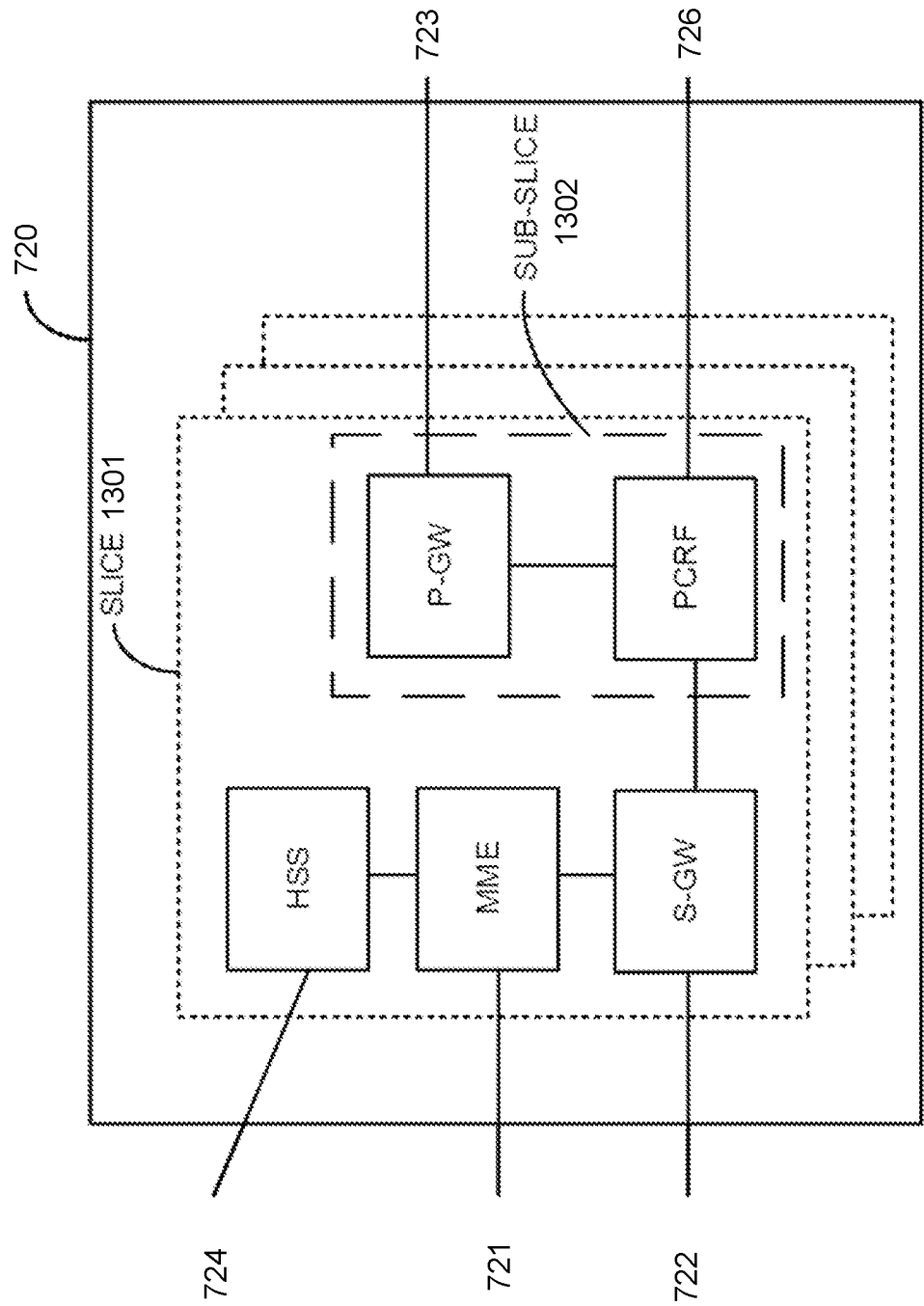


FIG. 13

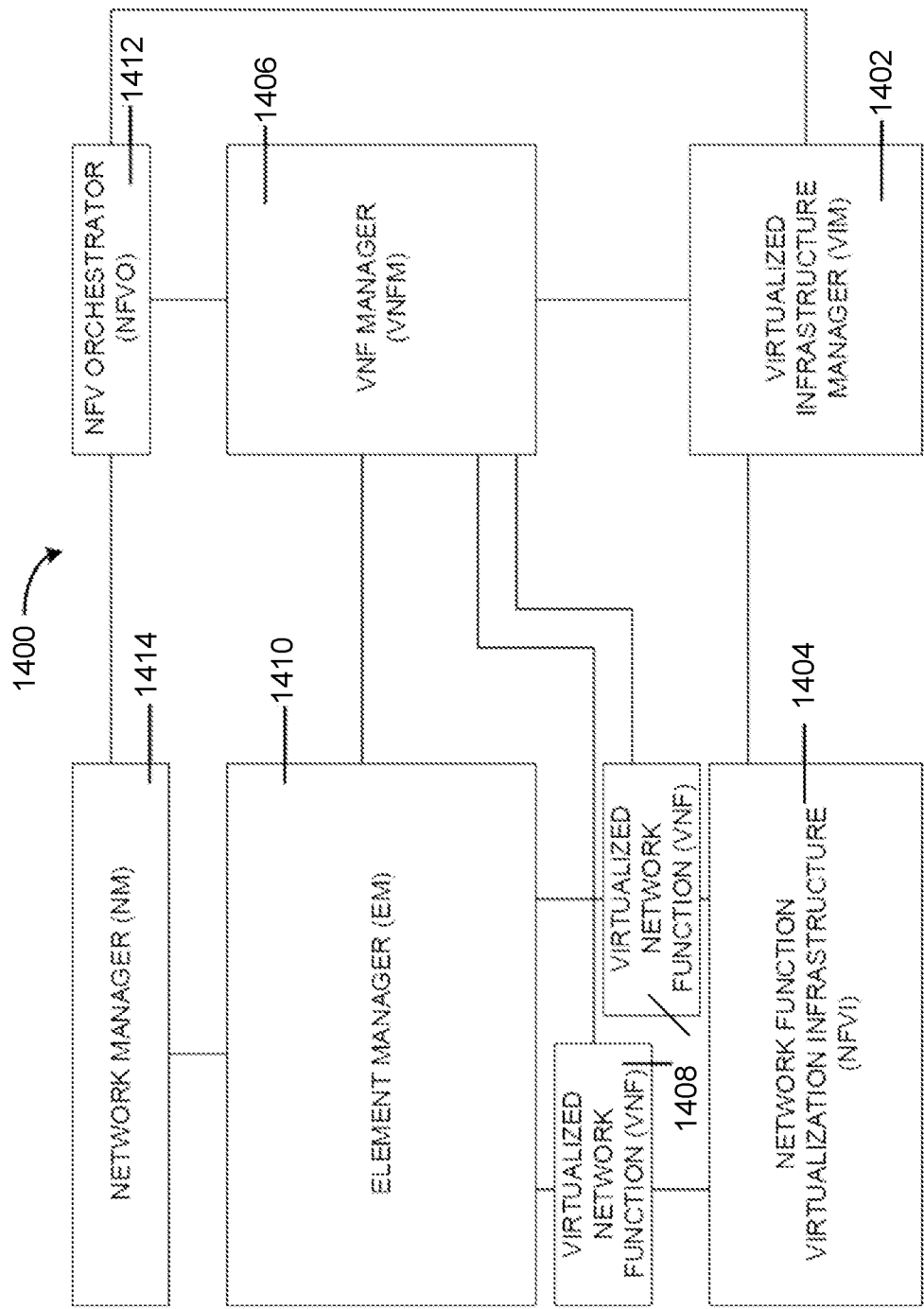


FIG. 14

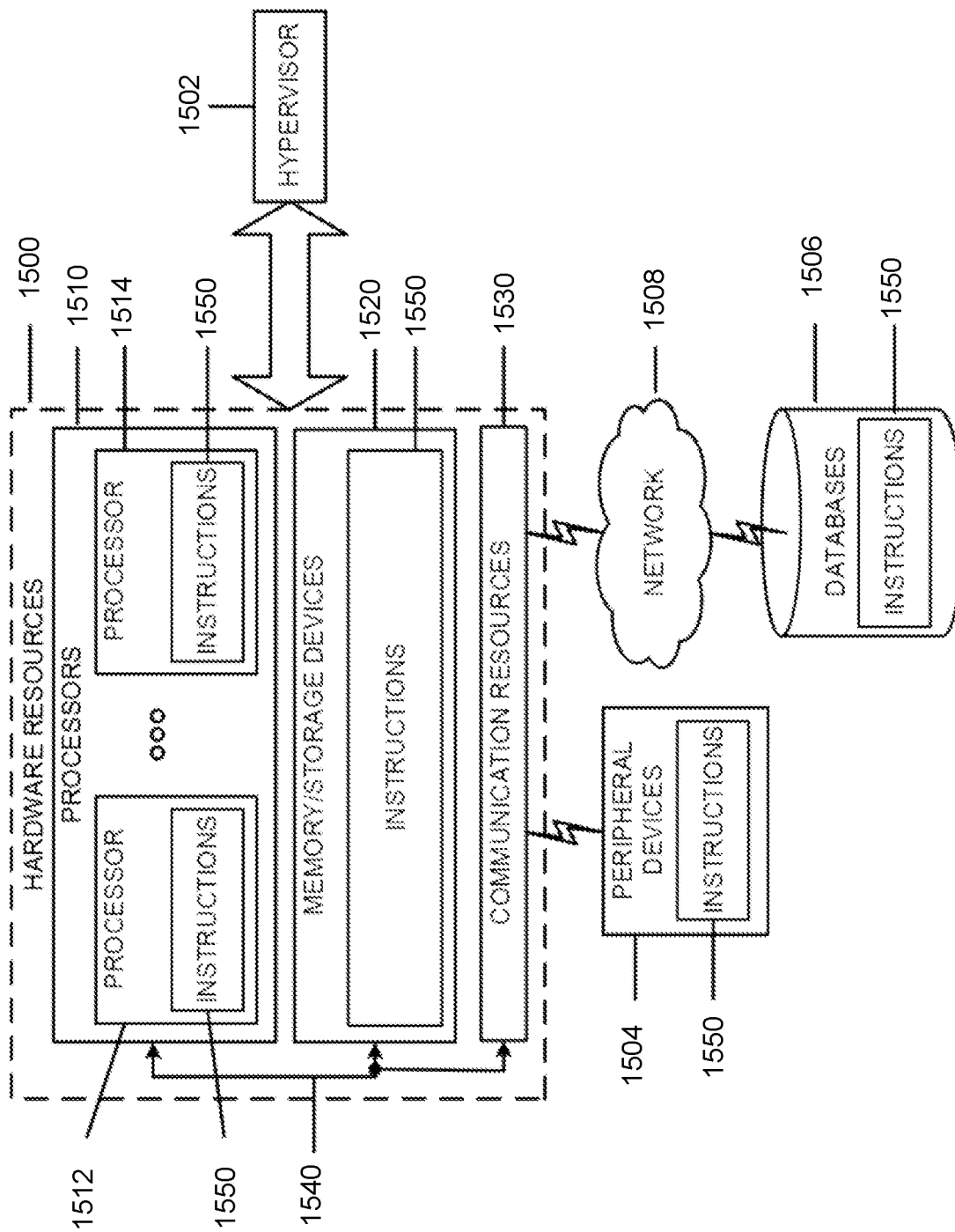


FIG. 15

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2020/012898

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04L1/18
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)
H04L

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.
Y	WO 2016/148622 A1 (ERICSSON TELEFON AB L M [SE]) 22 September 2016 (2016-09-22) abstract figures 9, 11 page 10, lines 4-7 page 11, lines 6-12 page 22, line 24 - page 23, line 23 ----- -/--	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

17 April 2020

Date of mailing of the international search report

28/04/2020

Name and mailing address of the ISA/

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

Authorized officer

Xu, Yuhuan

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2020/012898

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	HUAWEI ET AL: "Remaining issues on CBG-based (re)transmission", 3GPP DRAFT; R1-1801344, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE , vol. RAN WG1, no. Athens, Greece; 20180226 - 20180302 17 February 2018 (2018-02-17), XP051397508, Retrieved from the Internet: URL:http://www.3gpp.org/ftp/tsg%5Fran/WG1%5FRL1/TSGR1%5F92/Docs/ [retrieved on 2018-02-17] figure 1 section 2.1	1-20
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2020/012898

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		WO 2017030417 A1	23-02-2017
