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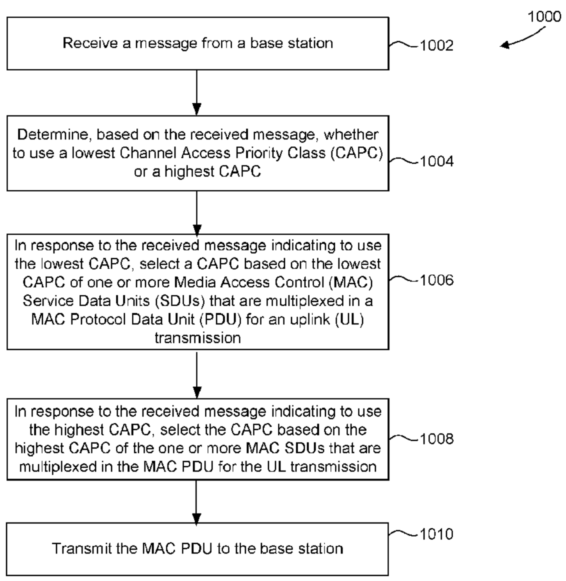

Figure 10

(57) **Abstract:** Some embodiments of this disclosure include systems, apparatuses, methods, and computer-readable media for use in a wireless network for improving configured grant for new radio (NR) unlicensed. For example, some embodiments are directed to an electronic device including radio front end circuitry and processor circuitry. The processor circuitry can be configured to receive, using the radio front end circuitry, a message from a base station and, based on the received message, determine whether to use a lowest Channel Access Priority Class (CAPC) or a highest CAPC of one or more Media Access Control (MAC) Service Data Units (SDUs) that are multiplexed in one or more MAC Protocol Data Units (PDUs) for an uplink (UL) transmission. The processor circuitry transmits, using the radio front end circuitry, the MAC PDU to the base station.

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CONFIGURED GRANT IMPROVEMENT FOR NEW RADIO (NR) UNLICENSED

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application No. 62/841,699, filed May 1, 2019, which is hereby incorporated by reference in its entirety.

BACKGROUND

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

SUMMARY

[0003] Some embodiments of this disclosure include systems, apparatuses, methods, and computer-readable media for use in a wireless network for improving configured grant for new radio (NR) unlicensed.

[0004] Some embodiments are directed to an electronic device. The electronic device includes radio front end circuitry and processor circuitry coupled to the radio front end circuitry. The processor circuitry can be configured to receive, using the radio front end circuitry, a message from a base station and, based on the received message, determine whether to use a lowest Channel Access Priority Class (CAPC) or a highest CAPC. The processor circuitry is further configured to, in response to the received message indicating to use the lowest CAPC, select a CAPC based on the lowest CAPC of one or more Media Access Control (MAC) Service Data Units (SDUs) that are multiplexed in one or more MAC Protocol Data Units (PDUs) for an uplink (UL) transmission. The processor circuitry is further configured to, in response to the received message indicating to use the highest CAPC, select the CAPC based on the highest CAPC of the one or more MAC SDUs that are multiplexed in the MAC PDU for the UL transmission. The processor circuitry also transmits, using the radio front end circuitry, the MAC PDU to the base station.

[0005] In some examples, the message indicates to use the lowest CAPC in response to an access point (AP) associated with a wireless network being detected, wherein the AP is associated with the UE or the base station.

[0006] In some examples, the message indicates to use the highest CAPC in response to an access point (AP) associated with a wireless network not being detected, wherein the AP is associated with the UE or the base station.

[0007] In some examples, the UL transmission correspond to at least one of a configured grant or a dynamic grant.

[0008] In some examples, the MAC PDU includes a first MAC PDU and a second MAC PDU and the processor circuitry is configured to multiplex control signaling into the first MAC PDU, multiplex data signaling into the second MAC PDU, transmit the first MAC PDU using the dynamic grant, and transmit the second MAC PDU sing the configured grant.

[0009] In some examples, the control signaling includes at least one of a MAC control element (CE), a Signaling Radio Bearer (SRB), or a Data Radio Bearer (DRB) with the highest CACP and the data signaling includes a Data Radio Bearer (DRB) not having the highest CACP.

[0010] In some examples, the processor circuitry is configured to start or restart a configured grant timer and a configured grant retransmission timer at a same time.

[0011] In some examples, the processor circuitry is configured to restart the configured grant timer when the configured grant timer expires and run the configured grant retransmission timer for a predefined number of configured grant retransmissions.

[0012] Some embodiments are directed to a method. The method includes receiving, at a user equipment, a message from a base station and based on the received message, determining whether to use a lowest Channel Access Priority Class (CAPC) or a highest CAPC. The method further includes, in response to the received message indicating to use the lowest CAPC, selecting a CAPC based on the lowest CAPC of one or more Media Access Control (MAC) Service Data Units (SDUs) that are multiplexed in one or more MAC Protocol Data Units (PDUs) for an uplink (UL) transmission. The method also includes in response to the received message indicating to use the highest CAPC, selecting the CAPC based on the highest CAPC of the one or more MAC SDUs that are multiplexed in the MAC PDU for the UL transmission. The method also includes transmitting the MAC PDU to the base station.

[0013] Some embodiments are directed to an electronic device. The electronic device includes radio front end circuitry and processor circuitry coupled to the radio front end circuitry. The processor circuitry can be configured to determine whether an access point (AP) associated with a wireless network is detected and generate a message for a user equipment (UE). The message includes a parameter set to a lowest Channel Access Priority Class (CAPC) in response to detecting the AP or is set to a highest CAPC in response to not detecting the AP. The processor circuitry is further configured to transmit, using the radio front end circuitry, the message to the UE.

[0014] In some examples, the processor circuitry is configured to transmit the message using an uplink (UL) grant procedure. In some examples, the message includes an information element included in an *RRCReconfiguraiton* message.

[0015] Some embodiments are directed to a method. The method includes determining whether an access point (AP) associated with a wireless network is detected and generating a message for a user equipment (UE). The message includes a parameter set to a lowest Channel Access Priority Class (CAPC) in response to detecting the AP or is set to a highest CAPC in response to not detecting the AP. The method further includes transmitting the message to the UE.

BRIEF DESCRIPTION OF THE DRAWINGS/FIGURES

[0016] Figure 1 illustrates an exemplary procedure, in accordance with some embodiments.

[0017] Figure 2 depicts an architecture of a system of a network, in accordance with some embodiments.

[0018] Figure 3 depicts an architecture of a system including a first core network, in accordance with some embodiments.

[0019] Figure 4 depicts an architecture of a system including a second core network in accordance with some embodiments.

[0020] Figure 5 depicts an example of infrastructure equipment, in accordance with various embodiments.

[0021] Figure 6 depicts example components of a computer platform, in accordance with various embodiments.

[0022] Figure 7 depicts example components of baseband circuitry and radio frequency circuitry, in accordance with various embodiments.

[0023] Figure 8 is an illustration of various protocol functions that may be used for various protocol stacks, in accordance with various embodiments.

[0024] Figure 9 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.

[0025] Figure 10 depicts an example flowchart for practicing the various embodiments discussed herein, for example, for improving configured grant for new radio (NR) unlicensed.

[0026] Figure 11 depicts another example flowchart for practicing the various embodiments discussed herein, for example, for improving configured grant for new radio (NR) unlicensed.

[0027] The features and advantages of the embodiments will become more apparent from the detailed description set forth below when taken in conjunction with the drawings, in which like reference characters identify corresponding elements throughout. In the drawings, like reference numbers generally indicate identical, functionally similar, and/or structurally similar elements. The drawing in which an element first appears is indicated by the leftmost digit(s) in the corresponding reference number.

DETAILED DESCRIPTION

[0028] 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).

[0029] In current LAA/eLAA (Licensed Assisted Access/enhanced Licensed Assisted Access) systems, a scheduled based uplink (UL) access scheme (e.g., SUL) is used, where UL Physical Uplink Shared Channel (PUSCH) transmission is based on an explicit UL grant transmission via Physical Downlink Control Channel (PDCCH). The UL grant transmission is performed over PDCCH after completing a Listen Before Talk (LBT) procedure at an evolved NodeB (eNB) (e.g., a RAN node 211 of Figure 2) if the PDCCH is sent over an unlicensed carrier. After receiving the UL grant, the scheduled user equipment (UE) (e.g., a UE 201 of Figure 2) is expected to perform a short LBT or category 4 (Cat 4) LBT during the allocated time interval. If the LBT is successful at the scheduled UE, then the UE transmits PUSCH on the resources indicated by the UL grant. When the UE first has UL data to send, the UE may also trigger a Scheduling Request which is sent to the eNB either via dedicated resources (e.g., Physical Uplink Control Channel (PUCCH)) or random access.

[0030] It has been identified that UL throughput performance using the current scheduled based scheme is significantly degraded in an unlicensed environment, or during operation in an unlicensed spectrum. The main cause of this UL degradation is due to the double LBT requirements at both the eNB when sending the UL grant and at the scheduled UEs before transmission. In order to resolve the issues of the scheduled system, an agreement was reached to include Autonomous UL (AUL) access in a work item in release 15 (Rel-15) further enhanced Licensed Assisted Access, further enhanced LAA (FeLAA).

[0031] In release 15 New Radio (NR), configured grant was developed to reduce the number of steps in setting up a UL grant. Not because of LBT, but to reduce the latency of Ultra-Reliable and Low Latency (URLLC) services.

[0032] In Third Generation Partnership Project (3GPP) release 16 (Rel-16), the work on NR-based access to unlicensed spectrum have been started. However, the Rel-15 NR system is designed to operate on licensed spectrum. The NR-unlicensed, a short-hand notation of the NR-based access to unlicensed spectrum, is a technology that enables the operation of NR system on unlicensed spectrum. One goal is to make configured grant works efficiently in an unlicensed environment.

[0033] With respect to the configured UL grant, a first problem is that, in release 15 LAA, the Channel Access Priority Class (CAPC) for a multiplexed Medium Access

Control (MAC) Service Data Unit (SDU) is determined according to the lowest CAPC of the selected logical channels. This enables co-existence with WiFi networks, but delays the delivery of high priority data or Signalling Radio Bearer (SRB) or MAC control element (CE). A second problem with respect to the configured UL grant involves the introduction of auto retransmission using the configured grant. There is a need to control the number of retransmissions. The embodiments herein provide exemplary solutions to the both of the configured UL grant problems.

[0034] An exemplary embodiment provides a solution for the first problem. As mentioned previously, selecting the lowest CAPC from the logical channels of the multiplexed MAC SDU according to release 15 LAA is a reasonable way to allow co-existence with WiFi, but delays the delivery of high priority data or SRB or MAC CE. Another way is to select the highest CAPC from the logical channels within the multiplexed MAC SDU, which allows the high priority data or SRB or MAC CE to access the channel faster due to less stringent LBT criteria, but does not present a fair co-existence to surrounding WiFi systems. In one embodiment, a gNB (Next Generation NodeB) (e.g., a RAN node 211 of Figure 2) dynamically configures the UE (e.g., a UE 201 of Figure 2) to use the lowest/highest CAPC from the multiplexed MAC SDU.

[0035] This embodiment can allow the gNB to dynamically control the UE's selection of CAPC on a multiplexed Protocol Data Unit (PDU). In situations where there are no WiFi access points (APs) (e.g., access points associated with wireless networks operating based on IEEE 802.11 technologies) nearby, the gNB can set the UE to use the highest CAPC for the multiplexed MAC PDU. On the other hand, if there are WiFi APs in a vicinity of the gNB and/or UE, the gNB can set the UE to use a lowest CAPC.

[0036] An exemplary embodiment provides a solution for the first problem, which may be used in cases that require fair-coexistence with a WiFi system. In this embodiment, the logical channel prioritization algorithm is modified to overcome the delay of delivering of high priority data and signaling. Instead of having a single multiplexing scheme for all logical channels, there is one multiplexing scheme for control signaling, such as SRB(s) and MAC CE, and another scheme for all Data Radio Bearer(s) (DRB(s)). Alternatively, one multiplexing scheme may be used for the DRBs and SRB/MAC CE with a highest CAT4 CAPC and another scheme for the remaining DRBs and MAC CEs. Whenever a configured UL grant is available, it will be for the SRB(s) and MAC CE or DRB(s) and SRB(s)/MAC CE with highest CAT4 CAPC.

[0037] In order to overcome the delay of delivery of high priority data and signaling in fair-coexistence with a WiFi system, this embodiment can ensure that the Logical Channel Prioritization (LCP) does not multiplex a highest CAPC priority data/signaling with other CAPC priority data/signaling. This allows the gNB and UE to use their respective computational and signaling resources in a more efficient manner than existing solutions.

[0038] An exemplary embodiment provides a solution for the second problem. In this embodiment, a configured grant timer (e.g., configuredGrantTimer) is used to control the number of restarts of a configured grant retransmission timer (e.g., CGretransmission timer). In this way, this embodiment can control the number of retransmissions on configured grant per Hybrid Automatic Repeat Request (HARQ). Without this, if the channel is busy, it may result in Radio Link Control (RLC) retransmission of the same MAC SDU while the previous MAC SDU is still in the HARQ buffer, which is a waste of computational, storage/memory, and signaling resources.

[0039] This embodiment can limit the number of retransmission on the configured grant and prevent a MAC SDU being stalled at the HARQ entity using configured grant, thereby conserving computational, storage/memory, and signaling resources.

[0040] Figure 1 illustrates an exemplary procedure 100, according to some embodiments. According to some embodiments, the UE 101 goes through a connection setup and transitions from the Radio Resource Control (RRC) idle state 103 to the RRC Connected state 105. According to some examples, UE 101 can send an *RRCSetupRequest* message 107 to network (NW) 109 to establish or re-stablish an RRC connection. Network 109 can include, but is not limited to, a gNB. After receiving the *RRCSetupRequest* message 107 from UE 101, network 109 can send an *RRCSetup* message 111. In response, UE 101 can send *RRCSetupComplete* message 113, which stablishes (or re-stablishes) the RRC connection between UE 101 and network 109.

[0041] In some examples, after stablishing (or re-stablishing) the RRC connection, UE 101 can transition from RRC idle state 103 to RRC connected state 105. According to some examples, network 109 can use *SecurityModeCommand* message 115 to activate security mode(s) at UE 101. UE 101 can use *SecurityModeComplete* message 117 to inform network 109 that the security mode(s) is activated in UE 101. Additionally, or alternatively, network 109 can use *RRCReconfiguration* message 119 to setup or modify the RRC configuration. UE 101 can use *RRCReconfigurationComplete* message 121 to inform network 109 that the reconfiguration has been complete.

[0042] According to some embodiments, either of the RRC messages (e.g., the *RRCSetup* message 113 or the *RRCReconfiguration* message 119) may include a *LogicalChannelConfig* information element (IE), which is used to configure the logical channel parameters including a channel access priority. An example *LogicalChannelConfig* IE is shown below.

***LogicalChannelConfig* information element**

```
-- ASN1START

LogicalChannelConfig ::=            SEQUENCE {
    ul-SpecificParameters               SEQUENCE {
        priority                            INTEGER (1..16),
        prioritisedBitRate                  ENUMERATED {
                                                kBps0, kBps8, kBps16, kBps32, kBps64, kBps128,
                                                kBps256, infinity, kBps512-v1020, kBps1024-v1020,
                                                kBps2048-v1020, spare5, spare4, spare3, spare2,
                                                spare1},
        bucketSizeDuration                  ENUMERATED {
                                                ms50, ms100, ms150, ms300, ms500, ms1000, spare2,
                                                spare1},
        logicalChannelGroup                 INTEGER (0..3)          OPTIONAL            -- Need
OR
    }       OPTIONAL,                                                                   -- Cond
UL
    ...,
    [[  logicalChannelSR-Mask-r9            ENUMERATED {setup}      OPTIONAL        -- Cond
SRmask
    ]],
    [[  logicalChannelSR-Prohibit-r12       BOOLEAN                 OPTIONAL        -- Need ON
    ]],
    [[  laa-UL-Allowed-r14                  BOOLEAN                 OPTIONAL,       -- Need ON
        bitRateQueryProhibitTimer-r14   ENUMERATED {
                                            s0, s0dot4, s0dot8, s1dot6, s3, s6, s12,
                                            s30}                OPTIONAL        --Need OR
    ]],
    [[  allowedTTI-Lengths-r15      CHOICE  {
            release         NULL,
            setup           SEQUENCE {
                shortTTI-r15        BOOLEAN,
                subframeTTI-r15     BOOLEAN
            }
        }                                       OPTIONAL,                               -- Need
ON
        logicalChannelSR-Restriction-r15 CHOICE {
            release         NULL,
            setup           ENUMERATED {spucch, pucch}
        }                                       OPTIONAL,                               -- Need
ON
        channellAccessPriority-r15          CHOICE {
            release                                 NULL,
            setup                                   INTEGER (1..4)
        }                                       OPTIONAL,       -- Need ON
        lch-CellRestriction-r15             BIT STRING (SIZE (maxServCell-r13)) OPTIONAL -- Need
ON
    ]]
}

-- ASN1STOP
```

***LogicalChannelConfig* field descriptions**
allowedTTI-Lengths Indicates the allowed TTI lengths for the logical channel. If not configured, the UE is allowed to transmit the logical channel using any TTI length.
bitRateQueryProhibitTimer The timer is used for bit rate recommendation query in TS 36.321, clause 5.x, in seconds. Value s0 means 0s, s0dot4 means 0.4s and so on.
bucketSizeDuration Bucket Size Duration for logical channel prioritization in TS 36.321. Value in milliseconds. Value ms50 corresponds to 50 ms, ms100 corresponds to 100 ms and so on.
channelAccessPriority Indicates the channel access priority class for the logical channel. UE shall select the lowest channel access priority class (i.e. highest signalled value) of the logical channel with MAC SDU multiplexed into the MAC PDU. MAC CEs except padding BSR apply the highest channel access priority class (i.e. lowest signalled value) , as defined in TS 36.300.
laa-UL-Allowed Indicates whether the data of a logical channel is allowed to be transmitted via UL of LAA SCells. Value *TRUE* indicates that the logical channel is allowed to be sent via UL of LAA SCells. Value *FALSE* indicates that the logical channel is not allowed to be sent via UL of LAA SCells.
lch-CellRestriction Indicates cells which are restricted for the logical channel, The bit is set to 1 if the cell is restricted and to 0 if the cell is not restricted, for each cell. The least significant bit corresponds to the serving cell with index 0, the next bit corresponds to the serving cell with index 1, and so on. If the cell is restricted for the logical channel, then data for the logical channel is not allowed to be sent using that cell. If the field is not included, no cells are restricted. See also TS 36.321, section 5.4.3.1. The restriction is only active when PDCP duplication using CA is activated.

***LogicalChannelConfig* field descriptions**
logicalChannelGroup Mapping of logical channel to logical channel group for BSR reporting in TS 36.321.
logicalChannelSR-Mask Controlling SR triggering on a logical channel basis when an uplink grant is configured. See TS 36.321.
logicalChannelSR-Prohibit Value *TRUE* indicates that the *logicalChannelSR-ProhibitTimer* is enabled for the logical channel. E-UTRAN only (optionally) configures the field (i.e. indicates value *TRUE*) if *logicalChannelSR-ProhibitTimer* is configured. See TS 36.321.
logicalChannelSR-Restriction Defines the restricted SR configuration for the logical channel. Value spucch indicates that the SR cannot be sent on SPUCCH and value pucch indicates that the SR cannot be sent on PUCCH. If not configured, the UE is allowed to transmit the SR on any SR resource.
prioritisedBitRate Prioritized Bit Rate for logical channel prioritization in TS 36.321. Value in kilobytes/second. Value kBps0 corresponds to 0 kB/second, kBps8 corresponds to 8 kB/second, kBps16 corresponds to 16 kB/second and so on. Infinity is the only applicable value for SRB1 and SRB2
priority Logical channel priority in TS 36.321 [6]. Value is an integer.
shortTTI, subframeTTI For short TTIs and subframe TTIs respectively: Value TRUE indicates that the UE is allowed to transmit using this TTI length for the logical channel and the value FALSE indicates that the UE is not allowed to transmit using this TTI length for the logical channel. If not configured for a TTI length, then the UE is allowed to transmit this logical channel using this TTI length.

[0043] In this embodiment, a new IE may be included in the *RRCReconfiguration* message 119 that instructs the UE 101 as to whether the CAPC from lowest/highest

CAPC will be added to the set of parameters. When the IE is set to the lowest CAPC, the UE's MAC entity will select the CAPC based on the lowest CAPC of the MAC SDUs that are multiplexed in a MAC PDU for a UL transmission (e.g., corresponding to a UL configured grant or dynamic grant). If the IE is set to the highest CAPC, the UE's MAC entity will select the CAPC based on the highest CAPC of the MAC SDUs that are multiplexed in a MAC PDU for a UL transmission (corresponding to a UL configured grant or dynamic grant).

[0044] In release 15 NR, the LCP procedure is applied whenever a new transmission is performed, and the logical channels are prioritised in accordance with the following order (highest priority listed first):

- C-RNTI (Cell Radio Network Temporary Identifier (RNTI)) MAC CE or data from UL-CCCH (Common Control Channel);
- Configured Grant Confirmation MAC CE;
- MAC CE for Buffer Status Report (BSR), with exception of BSR included for padding;
- Single Entry PHR MAC CE or Multiple Entry PHR MAC CE;
- data from any Logical Channel, except data from UL-CCCH;
- MAC CE for Recommended bit rate query;
- MAC CE for BSR included for padding

[0045] In one exemplary embodiment, the above priority order is used for both configured grant and dynamic grant. For dynamic grant, CAPC is assigned by gNB through UL grant, where CAPC for configured grant is assigned to each logical channel through RRC as mentioned previously.

[0046] Additionally, or alternatively, the MAC entity separates the multiplexing the control signal, such as the MAC CE and SRB(s) and (DRBs with highest CAPC), into a separate MAC PDU and transmits it through dynamic grant, while configured grant is only used for other CAPC DRB(s).

[0047] In another embodiment, a new transmission on a configured grant is to consider control signalling (e.g., SRB(s) and MAC CE using high priority CAPC) separately to data (e.g., DRBs). Upon configured UL grant for new UL transmission and if data for SRBs is available on the corresponding PDCP/RLC entity and/or high priority CAPC MAC CE is triggered, the configured UL grant will be used solely for multiplexing of the data for SRBs and/or the triggered high priority CAPC MAC CE. If only data for DRBs is available on the corresponding PDCP/RLC entity, the multiplexing of the data for DRBs are based on the logical channel priority. In some embodiments, high priority CAPC DRBs are included to also multiplex with the SRB(s) and MAC CE using high priority CAPC. Whether to multiplex the high priority CAPC DRBs with the control signalling can be configured via the gNB.

[0048] In release 15 NR, the UE starts the *configuredGrantTimer* whenever data is being transmitted using the configured grant resources. When the *configuredGrantTimer* expires, an ACK is assumed and the MAC PDU in the HARQ buffer of the corresponding HARQ process can be overwritten by a new UL transmission corresponding to a configured grant or dynamic grant. In one exemplary embodiment, this is also applied to the configured grant for NR-U (NR-unsilenced) to prevent the MAC PDU corresponding to HARQ process using the configured grant from over-written.

[0049] In release 16 NR-U, a configured grant retransmission timer (*CGretransmission* timer) is added to the configured grant procedure. The *CGretransmission* timer is started whenever data is being transmitted. When the *CGretransmission* timer expires, a NACK is assumed, and retransmission happens automatically. In particular, the *CGretransmission* timer is used for the case of a TB previous being transmitted on a configured grant, where the *CGretransmission* timer is started when the TB is actually transmitted on the configured grant and stopped upon reception of HARQ feedback (DFI) or dynamic grant for the HARQ process.

[0050] According to some embodiments, the two timers are coordinated. In one embodiment, both the *configuredGrantTimer* and *CGretransmission* timer are started/restarted at the same time. In another embodiment, both timers are started at the same time, but only the *CGretransmission* timer is restarted when it expires, and the *configuredGrantTimer* continues to run to allow X number of configured grant retransmissions. When the *configuredGrantTimer* expires, the retransmission of the current HARQ process on the configured grant for NR-U stops and this allows the HARQ process to be used by new transmission.

[0051] In some embodiments, parameters for the *configuredGrantTimer* are conveyed using the *ConfiguredGrantConfig* IE. The *ConfiguredGrantConfig* IE is used to configure uplink transmission without dynamic grant according to two possible schemes. The actual uplink grant may either be configured via RRC (type1) or provided via the PDCCH (addressed to CS-RNTI) (type2). An example of the *ConfiguredGrantConfig* IE is shown below.

ConfiguredGrantConfig information element

```
-- ASN1START
-- TAG-CONFIGUREDGRANTCONFIG-START

ConfiguredGrantConfig ::=       SEQUENCE {
  frequencyHopping          ENUMERATED {intraSlot, interSlot}                   OPTIONAL,  --
Need S,
  cg-DMRS-Configuration         DMRS-UplinkConfig,
  mcs-Table                 ENUMERATED {qam256, qam64LowSE}                 OPTIONAL,  -- Need S
  mcs-TableTransformPrecoder      ENUMERATED {qam256, qam64LowSE}                 OPTIONAL,  -
- Need S
  uci-OnPUSCH               SetupRelease { CG-UCI-OnPUSCH }                 OPTIONAL,  -- Need
M
  resourceAllocation          ENUMERATED { resourceAllocationType0, resourceAllocationType1,
dynamicSwitch },
  rbg-Size                  ENUMERATED {config2}                        OPTIONAL,  -- Need S
  powerControlLoopToUse         ENUMERATED {n0, n1},
  p0-PUSCH-Alpha              P0-PUSCH-AlphaSetId,
  transformPrecoder           ENUMERATED {enabled, disabled}                  OPTIONAL,  --
Need S
  nrofHARQ-Processes          INTEGER(1..16),
  repK                     ENUMERATED {n1, n2, n4, n8},
  repK-RV                   ENUMERATED {s1-0231, s2-0303, s3-0000}              OPTIONAL,  -- Need
R
  periodicity                ENUMERATED {
                        sym2, sym7, sym1x14, sym2x14, sym4x14, sym5x14, sym8x14, sym10x14,
sym16x14, sym20x14,
                        sym32x14, sym40x14, sym64x14, sym80x14, sym128x14, sym160x14, sym256x14,
sym320x14, sym512x14,
                        sym640x14, sym1024x14, sym1280x14, sym2560x14, sym5120x14,
                        sym6, sym1x12, sym2x12, sym4x12, sym5x12, sym8x12, sym10x12, sym16x12,
sym20x12, sym32x12,
                        sym40x12, sym64x12, sym80x12, sym128x12, sym160x12, sym256x12, sym320x12,
sym512x12, sym640x12,
                        sym1280x12, sym2560x12
  },
  configuredGrantTimer          INTEGER (1..64)                           OPTIONAL,  -- Need R
  rrc-ConfiguredUplinkGrant        SEQUENCE {
    timeDomainOffset            INTEGER (0..5119),
    timeDomainAllocation          INTEGER (0..15),
    frequencyDomainAllocation        BIT STRING (SIZE(18)),
    antennaPort               INTEGER (0..31),
    dmrs-SeqInitialization          INTEGER (0..1)                       OPTIONAL,  -- Need R
    precodingAndNumberOfLayers        INTEGER (0..63),
    srs-ResourceIndicator          INTEGER (0..15)                       OPTIONAL,  -- Need R
    mcsAndTBS               INTEGER (0..31),
    frequencyHoppingOffset          INTEGER (1.. maxNrofPhysicalResourceBlocks-1)
OPTIONAL,  -- Need R
    pathlossReferenceIndex          INTEGER (0..maxNrofPUSCH-PathlossReferenceRSs-1),
    ...
  }                                             OPTIONAL,  -- Need R
  ...
}

CG-UCI-OnPUSCH ::= CHOICE {
  dynamic                 SEQUENCE (SIZE (1..4)) OF BetaOffsets,
  semiStatic               BetaOffsets
}

-- TAG-CONFIGUREDGRANTCONFIG-STOP
-- ASN1STOP
```

ConfiguredGrantConfig field descriptions
antennaPort Indicates the antenna port(s) to be used for this configuration, and the maximum bitwidth is 5. See TS 38.214 [19], clause 6.1.2, and TS 38.212 [17], clause 7.3.1.
cg-DMRS-Configuration DMRS configuration (see TS 38.214 [19], clause 6.1.2.3).
configuredGrantTimer Indicates the initial value of the configured grant timer (see TS 38.321 [3]) in multiples of periodicity.
dmrs-SeqInitialization The network configures this field if *transformPrecoder* is disabled. Otherwise the field is absent.
frequencyDomainAllocation Indicates the frequency domain resource allocation, see TS 38.214 [19], clause 6.1.2, and TS 38.212 [17], clause 7.3.1).
frequencyHopping The value *intraSlot* enables 'Intra-slot frequency hopping' and the value *interSlot* enables 'Inter-slot frequency hopping'. If the field is absent, frequency hopping is not configured.
frequencyHoppingOffset Enables intra-slot frequency hopping with the given frequency hopping offset. Frequency hopping offset used when frequency hopping is enabled (see TS 38.214 [19], clause 6.1.2).
mcs-Table Indicates the MCS table the UE shall use for PUSCH without transform precoding. If the field is absent the UE applies the value *qam64*.
mcs-TableTransformPrecoder Indicates the MCS table the UE shall use for PUSCH with transform precoding. If the field is absent the UE applies the value *qam64*.
mcsAndTBS The modulation order, target code rate and TB size (see TS 38.214 [19], clause 6.1.2). The NW does not configure the values 28~31 in this version of the

specification.
nrofHARQ-Processes The number of HARQ processes configured. It applies for both Type 1 and Type 2. See TS 38.321 [3], clause 5.4.1.
p0-PUSCH-Alpha Index of the *P0-PUSCH-AlphaSet* to be used for this configuration.
periodicity Periodicity for UL transmission without UL grant for type 1 and type 2 (see TS 38.321 [3], clause 5.8.2). The following periodicities are supported depending on the configured subcarrier spacing [symbols]: 15 kHz: 2, 7, n*14, where n={1, 2, 4, 5, 8, 10, 16, 20, 32, 40, 64, 80, 128, 160, 320, 640} 30 kHz: 2, 7, n*14, where n={1, 2, 4, 5, 8, 10, 16, 20, 32, 40, 64, 80, 128, 160, 256, 320, 640, 1280} 60 kHz with normal CP: 2, 7, n*14, where n={1, 2, 4, 5, 8, 10, 16, 20, 32, 40, 64, 80, 128, 160, 256, 320, 512, 640, 1280, 2560} 60 kHz with ECP: 2, 6, n*12, where n={1, 2, 4, 5, 8, 10, 16, 20, 32, 40, 64, 80, 128, 160, 256, 320, 512, 640, 1280, 2560} 120 kHz: 2, 7, n*14, where n={1, 2, 4, 5, 8, 10, 16, 20, 32, 40, 64, 80, 128, 160, 256, 320, 512, 640, 1024, 1280, 2560, 5120}
powerControlLoopToUse Closed control loop to apply (see TS 38.213 [13], clause 7.1.1).
rbg-Size Selection between configuration 1 and configuration 2 for RBG size for PUSCH. The UE does not apply this field if resourceAllocation is set to *resourceAllocationType1*. Otherwise, the UE applies the value *config1* when the field is absent. Note: *rbg-Size* is used when the *transformPrecoder* parameter is disabled.
repK-RV The redundancy version (RV) sequence to use. See TS 38.214 [19], clause 6.1.2. The network configures this field if repetitions are used, i.e., if *repK* is set to *n2*, *n4* or *n8*. Otherwise, the field is absent.

repK The number of repetitions of K.
resourceAllocation Configuration of resource allocation type 0 and resource allocation type 1. For Type 1 UL data transmission without grant, "resourceAllocation" should be *resourceAllocationType0* or *resourceAllocationType1*.
rrc-ConfiguredUplinkGrant Configuration for "configured grant" transmission with fully RRC-configured UL grant (Type1). If this field is absent the UE uses UL grant configured by DCI addressed to CS-RNTI (Type2). Type 1 configured grant may be configured for UL or SUL, but not for both simultaneously.
srs-ResourceIndicator Indicates the SRS resource to be used.
timeDomainAllocation Indicates a combination of start symbol and length and PUSCH mapping type, see TS 38.214 [19], clause 6.1.2 and TS 38.212 [17], clause 7.3.1.
timeDomainOffset Offset related to SFN=0, see TS 38.321 [3], clause 5.8.2.
transformPrecoder Enables or disables transform precoding for type1 and type2. If the field is absent, the UE enables or disables transform precoding in accordance with the field *msg3-transformPrecoder* in *RACH-ConfigCommon*, see TS 38.214 [19], clause 6.1.3.
uci-OnPUSCH Selection between and configuration of dynamic and semi-static beta-offset. For Type 1 UL data transmission without grant, *uci-OnPUSCH* should be set to *semiStatic.*

Systems and Implementations

[0052] Figure 2 illustrates an example architecture of a system 200 of a network, in accordance with various embodiments. The following description is provided for an example system 200 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.

[0053] As shown by Figure 2, the system 200 includes UE 201a and UE 201b (collectively referred to as "UEs 201" or "UE 201"). In this example, UEs 201 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.

[0054] In some embodiments, any of the UEs 201 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.

[0055] The UEs 201 may be configured to connect, for example, communicatively couple, with an or RAN 210. In embodiments, the RAN 210 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 210 that operates in an NR or 5G system 200, and the term "E-UTRAN" or the like may refer to a RAN 210 that operates in an LTE or 4G system 200. The UEs 201 utilize connections (or channels) 203 and 204, respectively, each of which comprises a physical communications interface or layer (discussed in further detail below).

[0056] In this example, the connections 203 and 204 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 201 may directly exchange communication data via a ProSe interface 205. The ProSe interface 205 may alternatively be referred to as a SL interface 205 and may comprise one or more logical channels, including but not limited to a PSCCH, a PSSCH, a PSDCH, and a PSBCH.

[0057] The UE 201b is shown to be configured to access an AP 206 (also referred to as “WLAN node 206,” “WLAN 206,” “WLAN Termination 206,” “WT 206” or the like) via connection 207. The connection 207 can comprise a local wireless connection, such as a connection consistent with any IEEE 802.11 protocol, wherein the AP 206 would comprise a wireless fidelity (Wi-Fi®) router. In this example, the AP 206 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 201b, RAN 210, and AP 206 may be configured to utilize LWA operation and/or LWIP operation. The LWA operation may involve the UE 201b in RRC_CONNECTED being configured by a RAN node 211a-b to utilize radio resources of LTE and WLAN. LWIP operation may involve the UE 201b using WLAN radio resources (e.g., connection 207) via IPsec protocol tunneling to authenticate and encrypt packets (e.g., IP packets) sent over the connection 207. 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.

[0058] The RAN 210 can include one or more AN nodes or RAN nodes 211a and 211b (collectively referred to as “RAN nodes 211” or “RAN node 211”) that enable the connections 203 and 204. 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 211 that operates in an NR or 5G system 200 (for example, a gNB), and the term "E-UTRAN node" or the like may refer to a RAN node 211 that operates in an LTE or 4G system 200 (e.g., an eNB). According to various embodiments, the RAN nodes 211 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.

[0059] In some embodiments, all or parts of the RAN nodes 211 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 211; 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 211; 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 211. This virtualized framework allows the freed-up processor cores of the RAN nodes 211 to perform other virtualized applications. In some implementations, an individual RAN node 211 may represent individual gNB-DUs that are connected to a gNB-CU via individual F1 interfaces (not shown by Figure 2). In these implementations, the gNB-DUs may include one or more remote radio heads or RFEMs (see, e.g., Figure 5), and the gNB-CU may be operated by a server that is located in the RAN 210 (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 211 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 201, and are connected to a 5GC (e.g., CN 420 of Figure 4) via an NG interface (discussed infra).

[0060] In V2X scenarios one or more of the RAN nodes 211 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 201 (vUEs 201). 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.

[0061] Any of the RAN nodes 211 can terminate the air interface protocol and can be the first point of contact for the UEs 201. In some embodiments, any of the RAN nodes 211 can fulfill various logical functions for the RAN 210 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.

[0062] In embodiments, the UEs 201 can be configured to communicate using OFDM communication signals with each other or with any of the RAN nodes 211 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.

[0063] In some embodiments, a downlink resource grid can be used for downlink transmissions from any of the RAN nodes 211 to the UEs 201, 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.

[0064] The PDSCH carries user data and higher-layer signaling to the UEs 201. 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 201 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 201b within a cell) may be performed at any of the RAN nodes 211 based on channel quality information fed back from any of the UEs 201. The downlink resource assignment information may be sent on the PDCCH used for (e.g., assigned to) each of the UEs 201.

[0065] 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).

[0066] 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.

[0067] According to various embodiments, the UEs 201 and the RAN nodes 211 communicate data (e.g., 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.

[0068] To operate in the unlicensed spectrum, the UEs 201 and the RAN nodes 211 may operate using LAA, eLAA, and/or feLAA mechanisms. LAA/eLAA/feLAA involves carrier aggregation with at least one SCell operating in the unlicensed spectrum. In LAA/eLAA/feLAA, the configured set of serving cells for the UE 201 includes at least one SCell operating in the unlicensed spectrum according to Frame structure Type 3, also referred to as an "LAA SCell." In most embodiments, LAA SCells act as regular Scells.

[0069] In these implementations, the UEs 201 and the RAN nodes 211 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 LBT protocol. LBT is a mechanism whereby equipment (e.g., UEs 201, RAN nodes 211, etc.) senses a medium (e.g., 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). If the channel is determined to be free, the transmitter may perform the transmission on the LAA SCell; otherwise, the transmitter does not perform the transmission.

[0070] 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.

[0071] 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. When a WLAN node (e.g., an MS such as UE 201, AP 206, or the like) intends to transmit, the WLAN node may first perform CCA before transmission. Additionally, a backoff mechanism is used to avoid collisions in situations where more than one WLAN node senses the channel as idle and transmits at the same time. The backoff mechanism may be a counter that is drawn randomly within the CWS, which is increased exponentially upon the occurrence of collision and reset to a minimum value when the transmission succeeds. The LBT mechanism designed for LAA is somewhat similar to the CSMA/CA of WLAN. In some implementations, the LBT procedure for DL or UL transmission bursts including PDSCH or PUSCH transmissions, respectively, may have an LAA contention window that is variable in length between X and Y ECCA slots, where X and Y are minimum and maximum values for the CWSs for LAA. In one example, the minimum CWS for an LAA transmission may be 9 microseconds (μs); however, the size of the CWS and a MCOT (for example, a transmission burst) may be based on governmental regulatory requirements.

[0072] 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. 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 201 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.

[0073] In embodiments, the particular LBT type (e.g., type 1 or type 2 uplink channel access) that the UE 201 applies is signalled via uplink grant for uplink PUSCH transmission on LAA SCells, except for AUL transmissions. For type 1 UL channel access on AUL, the RAN 210 signals the CAPC for each logical channel and the UE 201 selects the lowest CAPC (e.g., with a higher number in table CAPC-1) of the logical channel(s) with MAC SDU multiplexed into the MAC PDU. The MAC CEs except padding BSR use the highest CAPC (e.g., the lowest number in table CAPC-1). For type 2 uplink channel access on AUL, the UE 201 may select logical channels corresponding to any CAPC for UL transmission in the subframes signalled by the RAN 210 in common DL control signalling. For uplink LAA operation, the RAN node 211 does not schedule the UE 201 more subframes than the minimum necessary to transmit all the traffic corresponding to the selected CAPC or lower (e.g., with a lower number in table CAPC-1), than the CAPC signaled in UL grant based on the latest BSR and received uplink traffic from the UE 201 if type 1 uplink channel access procedure (see e.g., clause 15.2.1.1 of 3GPP TS 36.213) is signalled to the UE 201, and/or the CAPC used by the RAN node 211 based on the DL traffic, the latest BSR and received UL traffic from the UE if type 2 UL channel access procedure (see e.g., clause 15.2.1.2 of 3GPP TS 36.213) is signalled to the UE 201. Four CAPCs are defined (see e.g., 3GPP TS 36.213), which can be used when performing uplink and downlink transmissions in LAA carriers. Table CAPC-1 shows which CAPC should be used by traffic belonging to the different standardized QCIs (or non-standardized QCIs). For uplink, the RAN node 211 selects the CAPC by taking into account the lowest priority QCI in a Logical Channel Group.

Table CAPC-1: Mapping between CAPC and QCI

CAPC (p)	QCI
1	1, 3, 5, 65, 66, 69, 70
2	2, 7

3	4, 6, 8, 9
4	-

[0074] If a DL transmission burst with PDSCH is transmitted, for which channel access has been obtained using CAPC P (1...4), the RAN 210 is to ensure the following conditions, wherein a DL Tx burst refers to the continuous transmission by E-UTRAN after a successful LBT: the Tx duration of the DL transmission burst shall not exceed the minimum duration needed to transmit all available buffered traffic corresponding to Channel Access Priority Class(es) ≤ P; the Tx duration of the DL Tx burst shall not exceed the Maximum Channel Occupancy Time ($T_{m\cot,p}$ as defined in table 15.1.1-1 of 3GPP TS 36.213) for CAPC P; and additional traffic corresponding to CAPC(s) > P may only be included in the DL TX burst once no more data corresponding to CAPC ≤ P is available for transmission. In such cases, the RAN 210 should maximise occupancy of the remaining Tx resources in the DL Tx burst with this additional traffic. For uplink PUSCH Tx, there is no additional restriction at the UE 201, other than the multiplexing rules defined in clause 5.4.3 of 3GPP TS 36.321, on the type of the traffic that can be carried in the scheduled subframes

[0075] The RAN nodes 211 may be configured to communicate with one another via interface 212. In embodiments where the system 200 is an LTE system (e.g., when CN 220 is an EPC 320 as in Figure 3), the interface 212 may be an X2 interface 212. The X2 interface may be defined between two or more RAN nodes 211 (e.g., two or more eNBs and the like) that connect to EPC 220, and/or between two eNBs connecting to EPC 220. 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 201 from an SeNB for user data; information of PDCP PDUs that were not delivered to a UE 201; 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.

[0076] In embodiments where the system 200 is a 5G or NR system (e.g., when CN 220 is an 5GC 420 as in Figure 4), the interface 212 may be an Xn interface 212. The Xn interface is defined between two or more RAN nodes 211 (e.g., two or more gNBs and the like) that connect to 5GC 220, between a RAN node 211 (e.g., a gNB) connecting to 5GC 220 and an eNB, and/or between two eNBs connecting to 5GC 220. 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 201 in a connected mode (e.g., CM-CONNECTED) including functionality to manage the UE mobility for connected mode between one or more RAN nodes 211. The mobility support may include context transfer from an old (source) serving RAN node 211 to new (target) serving RAN node 211; and control of user plane tunnels between old (source) serving RAN node 211 to new (target) serving RAN node 211. 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.

[0077] The RAN 210 is shown to be communicatively coupled to a core network—in this embodiment, core network (CN) 220. The CN 220 may comprise a plurality of network elements 222, which are configured to offer various data and telecommunications services to customers/subscribers (e.g., users of UEs 201) who are connected to the CN 220 via the RAN 210. The components of the CN 220 may be implemented in one physical node or separate physical nodes including components to read and execute instructions from a machine-readable or computer-readable medium (e.g., a non-transitory machine-readable storage medium). In 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 220 may be referred to as a network slice, and a logical instantiation of a portion of the CN 220 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.

[0078] Generally, the application server 230 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 230 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 201 via the EPC 220.

[0079] In embodiments, the CN 220 may be a 5GC (referred to as "5GC 220" or the like), and the RAN 210 may be connected with the CN 220 via an NG interface 213. In embodiments, the NG interface 213 may be split into two parts, an NG user plane (NG-U) interface 214, which carries traffic data between the RAN nodes 211 and a UPF, and the S1 control plane (NG-C) interface 215, which is a signaling interface between the RAN nodes 211 and AMFs. Embodiments where the CN 220 is a 5GC 220 are discussed in more detail with regard to Figure 4.

[0080] In embodiments, the CN 220 may be a 5G CN (referred to as "5GC 220" or the like), while in other embodiments, the CN 220 may be an EPC). Where CN 220 is an EPC (referred to as "EPC 220" or the like), the RAN 210 may be connected with the CN 220 via an S1 interface 213. In embodiments, the S1 interface 213 may be split into two parts, an S1 user plane (S1-U) interface 214, which carries traffic data between the RAN nodes 211 and the S-GW, and the S1-MME interface 215, which is a signaling interface between the RAN nodes 211 and MMEs.

[0081] Figure 3 illustrates an example architecture of a system 300 including a first CN 320, in accordance with various embodiments. In this example, system 300 may implement the LTE standard wherein the CN 320 is an EPC 320 that corresponds with CN 220 of Figure 2. Additionally, the UE 301 may be the same or similar as the UEs 201 of Figure 2, and the E-UTRAN 310 may be a RAN that is the same or similar to the RAN 210 of Figure 2, and which may include RAN nodes 211 discussed previously. The CN 320 may comprise MMEs 321, an S-GW 322, a P-GW 323, a HSS 324, and a SGSN 325.

[0082] The MMEs 321 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 301. The MMEs 321 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 301, provide user identity confidentiality, and/or perform other like services to users/subscribers. Each UE 301 and the MME 321 may include an MM or EMM sublayer, and an MM context may be established in the UE 301 and the MME 321 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 301. The MMEs 321 may be coupled with the HSS 324 via an S6a reference point, coupled with the SGSN 325 via an S3 reference point, and coupled with the S-GW 322 via an S11 reference point.

[0083] The SGSN 325 may be a node that serves the UE 301 by tracking the location of an individual UE 301 and performing security functions. In addition, the SGSN 325 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 321; handling of UE 301 time zone functions as specified by the MMEs 321; and MME selection for handovers to E-UTRAN 3GPP access network. The S3 reference point between the MMEs 321 and the SGSN 325 may enable user and bearer information exchange for inter-3GPP access network mobility in idle and/or active states.

[0084] The HSS 324 may comprise a database for network users, including subscription-related information to support the network entities' handling of communication sessions. The EPC 320 may comprise one or several HSSs 324, depending on the number of mobile subscribers, on the capacity of the equipment, on the organization of the network, etc. For example, the HSS 324 can provide support for routing/roaming, authentication, authorization, naming/addressing resolution, location dependencies, etc. An S6a reference point between the HSS 324 and the MMEs 321 may enable transfer of subscription and authentication data for authenticating/authorizing user access to the EPC 320 between HSS 324 and the MMEs 321.

[0085] The S-GW 322 may terminate the S1 interface 213 (“S1-U” in Figure 3) toward the RAN 310, and routes data packets between the RAN 310 and the EPC 320. In addition, the S-GW 322 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 322 and the MMEs 321 may provide a control plane between the MMEs 321 and the S-GW 322. The S-GW 322 may be coupled with the P-GW 323 via an S5 reference point.

[0086] The P-GW 323 may terminate an SGi interface toward a PDN 330. The P-GW 323 may route data packets between the EPC 320 and external networks such as a network including the application server 230 (alternatively referred to as an “AF”) via an IP interface 225 (see e.g., Figure 2). In embodiments, the P-GW 323 may be communicatively coupled to an application server (application server 230 of Figure 2 or PDN 330 in Figure 3) via an IP communications interface 225 (see, e.g., Figure 2). The S5 reference point between the P-GW 323 and the S-GW 322 may provide user plane tunneling and tunnel management between the P-GW 323 and the S-GW 322. The S5 reference point may also be used for S-GW 322 relocation due to UE 301 mobility and if the S-GW 322 needs to connect to a non-collocated P-GW 323 for the required PDN connectivity. The P-GW 323 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 323 and the packet data network (PDN) 330 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 323 may be coupled with a PCRF 326 via a Gx reference point.

[0087] PCRF 326 is the policy and charging control element of the EPC 320. In a non-roaming scenario, there may be a single PCRF 326 in the Home Public Land Mobile Network (HPLMN) associated with a UE 301’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 301’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 326 may be communicatively coupled to the application server 330 via the P-GW 323. The application server 330 may signal the PCRF 326 to indicate a new service flow and select the appropriate QoS and charging parameters. The PCRF 326 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 330. The Gx reference point between the PCRF 326 and the P-GW 323 may allow for the transfer of QoS policy and charging rules from the PCRF 326 to PCEF in the P-GW 323. An Rx reference point may reside between the PDN 330 (or "AF 330") and the PCRF 326.

[0088] Figure 4 illustrates an architecture of a system 400 including a second CN 420 in accordance with various embodiments. The system 400 is shown to include a UE 401, which may be the same or similar to the UEs 201 and UE 301 discussed previously; a (R)AN 410, which may be the same or similar to the RAN 210 and RAN 310 discussed previously, and which may include RAN nodes 211 discussed previously; and a DN 403, which may be, for example, operator services, Internet access or 3rd party services; and a 5GC 420. The 5GC 420 may include an AUSF 422; an AMF 421; a SMF 424; a NEF 423; a PCF 426; a NRF 425; a UDM 427; an AF 428; a UPF 402; and a NSSF 429.

[0089] The UPF 402 may act as an anchor point for intra-RAT and inter-RAT mobility, an external PDU session point of interconnect to DN 403, and a branching point to support multi-homed PDU session. The UPF 402 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 402 may include an uplink classifier to support routing traffic flows to a data network. The DN 403 may represent various network operator services, Internet access, or third party services. DN 403 may include, or be similar to, application server 230 discussed previously. The UPF 402 may interact with the SMF 424 via an N4 reference point between the SMF 424 and the UPF 402.

[0090] The AUSF 422 may store data for authentication of UE 401 and handle authentication-related functionality. The AUSF 422 may facilitate a common authentication framework for various access types. The AUSF 422 may communicate with the AMF 421 via an N12 reference point between the AMF 421 and the AUSF 422;

and may communicate with the UDM 427 via an N13 reference point between the UDM 427 and the AUSF 422. Additionally, the AUSF 422 may exhibit an Nausf service-based interface.

[0091] The AMF 421 may be responsible for registration management (e.g., for registering UE 401, etc.), connection management, reachability management, mobility management, and lawful interception of AMF-related events, and access authentication and authorization. The AMF 421 may be a termination point for the an N11 reference point between the AMF 421 and the SMF 424. The AMF 421 may provide transport for SM messages between the UE 401 and the SMF 424, and act as a transparent proxy for routing SM messages. AMF 421 may also provide transport for SMS messages between UE 401 and an SMSF (not shown by Figure 4). AMF 421 may act as SEAF, which may include interaction with the AUSF 422 and the UE 401, receipt of an intermediate key that was established as a result of the UE 401 authentication process. Where USIM based authentication is used, the AMF 421 may retrieve the security material from the AUSF 422. AMF 421 may also include a SCM function, which receives a key from the SEA that it uses to derive access-network specific keys. Furthermore, AMF 421 may be a termination point of a RAN CP interface, which may include or be an N2 reference point between the (R)AN 410 and the AMF 421; and the AMF 421 may be a termination point of NAS (N1) signalling, and perform NAS ciphering and integrity protection.

[0092] AMF 421 may also support NAS signalling with a UE 401 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 410 and the AMF 421 for the control plane, and may be a termination point for the N3 reference point between the (R)AN 410 and the UPF 402 for the user plane. As such, the AMF 421 may handle N2 signalling from the SMF 424 and the AMF 421 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 401 and AMF 421 via an N1 reference point between the UE 401 and the AMF 421, and relay uplink and downlink user-plane packets between the UE 401 and UPF 402. The N3IWF also provides mechanisms for IPsec tunnel establishment with the UE 401. The AMF 421 may exhibit an Namf service-based interface, and may be a termination point for an N14 reference point between two AMFs 421 and an N17 reference point between the AMF 421 and a 5G-EIR (not shown by Figure 4).

[0093] The UE 401 may need to register with the AMF 421 in order to receive network services. RM is used to register or deregister the UE 401 with the network (e.g., AMF 421), and establish a UE context in the network (e.g., AMF 421). The UE 401 may operate in an RM-REGISTERED state or an RM-DEREGISTERED state. In the RM-DEREGISTERED state, the UE 401 is not registered with the network, and the UE context in AMF 421 holds no valid location or routing information for the UE 401 so the UE 401 is not reachable by the AMF 421. In the RM-REGISTERED state, the UE 401 is registered with the network, and the UE context in AMF 421 may hold a valid location or routing information for the UE 401 so the UE 401 is reachable by the AMF 421. In the RM-REGISTERED state, the UE 401 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 401 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.

[0094] The AMF 421 may store one or more RM contexts for the UE 401, 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 421 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 421 may store a CE mode B Restriction parameter of the UE 401 in an associated MM context or RM context. The AMF 421 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).

[0095] CM may be used to establish and release a signaling connection between the UE 401 and the AMF 421 over the N1 interface. The signaling connection is used to enable NAS signaling exchange between the UE 401 and the CN 420, 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 401 between the AN (e.g., RAN 410) and the AMF 421. The UE 401 may operate in one of two CM states, CM-IDLE mode or CM-CONNECTED mode. When the UE 401 is operating in the CM-IDLE state/mode, the UE 401 may have no NAS signaling connection established with the AMF 421 over the N1 interface, and there may be (R)AN 410 signaling connection (e.g., N2 and/or N3 connections) for the UE 401. When the UE 401 is operating in the CM-CONNECTED state/mode, the UE 401 may have an established NAS signaling connection with the AMF 421 over the N1 interface, and there may be a (R)AN 410 signaling connection (e.g., N2 and/or N3 connections) for the UE 401. Establishment of an N2 connection between the (R)AN 410 and the AMF 421 may cause the UE 401 to transition from CM-IDLE mode to CM-CONNECTED mode, and the UE 401 may transition from the CM-CONNECTED mode to the CM-IDLE mode when N2 signaling between the (R)AN 410 and the AMF 421 is released.

[0096] The SMF 424 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 401 and a data network (DN) 403 identified by a Data Network Name (DNN). PDU sessions may be established upon UE 401 request, modified upon UE 401 and 5GC 420 request, and released upon UE 401 and 5GC 420 request using NAS SM signaling exchanged over the N1 reference point between the UE 401 and the SMF 424. Upon request from an application server, the 5GC 420 may trigger a specific application in the UE 401. In response to receipt of the trigger message, the UE 401 may pass the trigger message (or relevant parts/information of the trigger message) to one or more identified applications in the UE 401. The identified application(s) in the UE 401 may establish a PDU session to a specific DNN. The SMF 424 may check whether the UE 401 requests are compliant with user subscription information associated with the UE 401. In this regard, the SMF 424 may retrieve and/or request to receive update notifications on SMF 424 level subscription data from the UDM 427.

[0097] The SMF 424 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 424 may be included in the system 400, which may be between another SMF 424 in a visited network and the SMF 424 in the home network in roaming scenarios. Additionally, the SMF 424 may exhibit the Nsmf service-based interface.

[0098] The NEF 423 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 428), edge computing or fog computing systems, etc. In such embodiments, the NEF 423 may authenticate, authorize, and/or throttle the AFs. NEF 423 may also translate information exchanged with the AF 428 and information exchanged with internal network functions. For example, the NEF 423 may translate between an AF-Service-Identifier and an internal 5GC information. NEF 423 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 423 as structured data, or at a data storage NF using standardized interfaces. The stored information can then be re-exposed by the NEF 423 to other NFs and AFs, and/or used for other purposes such as analytics. Additionally, the NEF 423 may exhibit an Nnef service-based interface.

[0099] The NRF 425 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 425 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 425 may exhibit the Nnrf service-based interface.

[0100] The PCF 426 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 426 may also implement an FE to access subscription information relevant for policy decisions in a UDR of the UDM 427. The PCF 426 may communicate with the AMF 421 via an N15 reference point between the PCF 426 and the AMF 421, which may include a PCF 426 in a visited network and the AMF 421 in case of roaming scenarios. The PCF 426 may communicate with the AF 428 via an N5 reference point between the PCF 426 and the AF 428; and with the SMF 424 via an N7 reference point between the PCF 426 and the SMF 424. The system 400 and/or CN 420 may also include an N24 reference point between the PCF 426 (in the home network) and a PCF 426 in a visited network. Additionally, the PCF 426 may exhibit an Npcf service-based interface.

[0101] The UDM 427 may handle subscription-related information to support the network entities' handling of communication sessions, and may store subscription data of UE 401. For example, subscription data may be communicated between the UDM 427 and the AMF 421 via an N8 reference point between the UDM 427 and the AMF. The UDM 427 may include two parts, an application FE and a UDR (the FE and UDR are not shown by Figure 4). The UDR may store subscription data and policy data for the UDM 427 and the PCF 426, and/or structured data for exposure and application data (including PFDs for application detection, application request information for multiple UEs 401) for the NEF 423. The Nudr service-based interface may be exhibited by the UDR 221 to allow the UDM 427, PCF 426, and NEF 423 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 424 via an N10 reference point between the UDM 427 and the SMF 424. UDM 427 may also support SMS management, wherein an SMS-FE implements the similar application logic as discussed previously. Additionally, the UDM 427 may exhibit the Nudm service-based interface.

[0102] The AF 428 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 420 and AF 428 to provide information to each other via NEF 423, 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 401 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 402 close to the UE 401 and execute traffic steering from the UPF 402 to DN 403 via the N6 interface. This may be based on the UE subscription data, UE location, and information provided by the AF 428. In this way, the AF 428 may influence UPF (re)selection and traffic routing. Based on operator deployment, when AF 428 is considered to be a trusted entity, the network operator may permit AF 428 to interact directly with relevant NFs. Additionally, the AF 428 may exhibit an Naf service-based interface.

[0103] The NSSF 429 may select a set of network slice instances serving the UE 401. The NSSF 429 may also determine allowed NSSAI and the mapping to the subscribed S-NSSAIs, if needed. The NSSF 429 may also determine the AMF set to be used to serve the UE 401, or a list of candidate AMF(s) 421 based on a suitable configuration and possibly by querying the NRF 425. The selection of a set of network slice instances for the UE 401 may be triggered by the AMF 421 with which the UE 401 is registered by interacting with the NSSF 429, which may lead to a change of AMF 421. The NSSF 429 may interact with the AMF 421 via an N22 reference point between AMF 421 and NSSF 429; and may communicate with another NSSF 429 in a visited network via an N31 reference point (not shown by Figure 4). Additionally, the NSSF 429 may exhibit an Nnssf service-based interface.

[0104] As discussed previously, the CN 420 may include an SMSF, which may be responsible for SMS subscription checking and verification, and relaying SM messages to/from the UE 401 to/from other entities, such as an SMS-GMSC/IWMSC/SMS-router. The SMS may also interact with AMF 421 and UDM 427 for a notification procedure that the UE 401 is available for SMS transfer (e.g., set a UE not reachable flag, and notifying UDM 427 when UE 401 is available for SMS).

[0105] The CN 120 may also include other elements that are not shown by Figure 4, 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 4). 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 4). 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.

[0106] 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 4 for clarity. In one example, the CN 420 may include an Nx interface, which is an inter-CN interface between the MME (e.g., MME 321) and the AMF 421 in order to enable interworking between CN 420 and CN 320. 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.

[0107] Figure 5 illustrates an example of infrastructure equipment 500 in accordance with various embodiments. The infrastructure equipment 500 (or "system 500") may be implemented as a base station, radio head, RAN node such as the RAN nodes 211 and/or AP 206 shown and described previously, application server(s) 230, and/or any other element/device discussed herein. In other examples, the system 500 could be implemented in or by a UE.

[0108] The system 500 includes application circuitry 505, baseband circuitry 510, one or more radio front end modules (RFEMs) 515, memory circuitry 520, power management integrated circuitry (PMIC) 525, power tee circuitry 530, network controller circuitry 535, network interface connector 540, satellite positioning circuitry 545, and user interface 550. In some embodiments, the device 500 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.

[0109] Application circuitry 505 includes circuitry such as, but not limited to one or more processors (or processor cores), cache memory, and one or more of low drop-out voltage regulators (LDOs), interrupt controllers, serial interfaces such as SPI, I^2C or universal programmable serial interface module, real time clock (RTC), timer-counters including interval and watchdog timers, general purpose input/output (I/O or IO), memory card controllers such as Secure Digital (SD) MultiMediaCard (MMC) or similar, Universal Serial Bus (USB) interfaces, Mobile Industry Processor Interface (MIPI) interfaces and

Joint Test Access Group (JTAG) test access ports. The processors (or cores) of the application circuitry 505 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 500. 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.

[0110] The processor(s) of application circuitry 505 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 505 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 505 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 500 may not utilize application circuitry 505, and instead may include a special-purpose processor/controller to process IP data received from an EPC or 5GC, for example.

[0111] In some implementations, the application circuitry 505 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 505 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 505 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.

[0112] The baseband circuitry 510 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 510 are discussed infra with regard to Figure 7.

[0113] User interface circuitry 550 may include one or more user interfaces designed to enable user interaction with the system 500 or peripheral component interfaces designed to enable peripheral component interaction with the system 500. 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.

[0114] The radio front end modules (RFEMs) 515 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 711 of Figure 7 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 515, which incorporates both mmWave antennas and sub-mmWave.

[0115] The memory circuitry 520 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 520 may be implemented as one or more of solder down packaged integrated circuits, socketed memory modules and plug-in memory cards.

[0116] The PMIC 525 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 530 may provide for electrical power drawn from a network cable to provide both power supply and data connectivity to the infrastructure equipment 500 using a single cable.

[0117] The network controller circuitry 535 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 500 via network interface connector 540 using a physical connection, which may be electrical (commonly referred to as a “copper interconnect”), optical, or wireless. The network controller circuitry 535 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 535 may include multiple controllers to provide connectivity to other networks using the same or different protocols.

[0118] The positioning circuitry 545 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 545 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 545 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 545 may also be part of, or interact with, the baseband circuitry 510 and/or RFEMs 515 to communicate with the nodes and components of the positioning network. The positioning circuitry 545 may also provide position data and/or time data to the application circuitry 505, which may use the data to synchronize operations with various infrastructure (e.g., RAN nodes 211, etc.), or the like.

[0119] The components shown by Figure 5 may communicate with one another using interface circuitry, which may include any number of bus and/or interconnect (IX) technologies such as industry standard architecture (ISA), extended ISA (EISA), peripheral component interconnect (PCI), peripheral component interconnect extended (PCIx), PCI express (PCIe), or any number of other technologies. The bus/IX may be a proprietary bus, for example, used in a SoC based system. Other bus/IX systems may be included, such as an I^2C interface, an SPI interface, point to point interfaces, and a power bus, among others.

[0120] Figure 6 illustrates an example of a platform 600 (or “device 600”) in accordance with various embodiments. In embodiments, the computer platform 600 may be suitable for use as UEs 201, 301, 401, application servers 230, and/or any other element/device discussed herein. The platform 600 may include any combinations of the components shown in the example. The components of platform 600 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 600, or as components otherwise incorporated within a chassis of a larger system. The block diagram of Figure 6 is intended to show a high level view of components of the computer platform 600. 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.

[0121] Application circuitry 605 includes circuitry such as, but not limited to one or more processors (or processor cores), cache memory, and one or more of LDOs, interrupt controllers, serial interfaces such as SPI, I^2C or universal programmable serial interface module, RTC, timer-counters including interval and watchdog timers, general purpose I/O, memory card controllers such as SD MMC or similar, USB interfaces, MIPI interfaces, and JTAG test access ports. The processors (or cores) of the application circuitry 605 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 600. 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.

[0122] The processor(s) of application circuitry 505 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 505 may comprise, or may be, a special-purpose processor/controller to operate according to the various embodiments herein.

[0123] As examples, the processor(s) of application circuitry 605 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 605 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 605 may be a part of a system on a chip (SoC) in which the application circuitry 605 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.

[0124] Additionally or alternatively, application circuitry 605 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 605 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 605 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.

[0125] The baseband circuitry 610 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 610 are discussed infra with regard to Figure 7.

[0126] The RFEMs 615 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 711 of Figure 7 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 615, which incorporates both mmWave antennas and sub-mmWave.

[0127] The memory circuitry 620 may include any number and type of memory devices used to provide for a given amount of system memory. As examples, the memory circuitry 620 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 620 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 620 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 620 may be on-die memory or registers associated with the application circuitry 605. To provide for persistent storage of information such as data, applications, operating systems and so forth, memory circuitry 620 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 600 may incorporate the three-dimensional (3D) cross-point (XPOINT) memories from Intel® and Micron®.

[0128] Removable memory circuitry 623 may include devices, circuitry, enclosures/housings, ports or receptacles, etc. used to couple portable data storage devices with the platform 600. 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.

[0129] The platform 600 may also include interface circuitry (not shown) that is used to connect external devices with the platform 600. The external devices connected to the platform 600 via the interface circuitry include sensor circuitry 621 and electro-mechanical components (EMCs) 622, as well as removable memory devices coupled to removable memory circuitry 623.

[0130] The sensor circuitry 621 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.

[0131] EMCs 622 include devices, modules, or subsystems whose purpose is to enable platform 600 to change its state, position, and/or orientation, or move or control a mechanism or (sub)system. Additionally, EMCs 622 may be configured to generate and send messages/signalling to other components of the platform 600 to indicate a current state of the EMCs 622. Examples of the EMCs 622 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 600 is configured to operate one or more EMCs 622 based on one or more captured events and/or instructions or control signals received from a service provider and/or various clients.

[0132] In some implementations, the interface circuitry may connect the platform 600 with positioning circuitry 645. The positioning circuitry 645 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 645 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 645 may include a Micro-PNT IC that uses a master timing clock to perform position tracking/estimation without GNSS assistance. The positioning circuitry 645 may also be part of, or interact with, the baseband circuitry 510 and/or RFEMs 615 to communicate with the nodes and components of the positioning network. The positioning circuitry 645 may also provide position data and/or time data to the application circuitry 605, 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

[0133] In some implementations, the interface circuitry may connect the platform 600 with Near-Field Communication (NFC) circuitry 640. NFC circuitry 640 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 640 and NFC-enabled devices external to the platform 600 (e.g., an “NFC touchpoint”). NFC circuitry 640 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 640 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 640, or initiate data transfer between the NFC circuitry 640 and another active NFC device (e.g., a smartphone or an NFC-enabled POS terminal) that is proximate to the platform 600.

[0134] The driver circuitry 646 may include software and hardware elements that operate to control particular devices that are embedded in the platform 600, attached to the platform 600, or otherwise communicatively coupled with the platform 600. The driver circuitry 646 may include individual drivers allowing other components of the platform 600 to interact with or control various input/output (I/O) devices that may be present within, or connected to, the platform 600. For example, driver circuitry 646 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 600, sensor drivers to obtain sensor readings of sensor circuitry 621 and control and allow access to sensor circuitry 621, EMC drivers to obtain actuator positions of the EMCs 622 and/or control and allow access to the EMCs 622, 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.

[0135] The power management integrated circuitry (PMIC) 625 (also referred to as "power management circuitry 625") may manage power provided to various components of the platform 600. In particular, with respect to the baseband circuitry 610, the PMIC 625 may control power-source selection, voltage scaling, battery charging, or DC-to-DC conversion. The PMIC 625 may often be included when the platform 600 is capable of being powered by a battery 630, for example, when the device is included in a UE 201, 301, 401.

[0136] In some embodiments, the PMIC 625 may control, or otherwise be part of, various power saving mechanisms of the platform 600. For example, if the platform 600 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 600 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 600 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 600 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 600 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.

[0137] A battery 630 may power the platform 600, although in some examples the platform 600 may be mounted deployed in a fixed location, and may have a power supply coupled to an electrical grid. The battery 630 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 630 may be a typical lead-acid automotive battery.

[0138] In some implementations, the battery 630 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 600 to track the state of charge (SoCh) of the battery 630. The BMS may be used to monitor other parameters of the battery 630 to provide failure predictions, such as the state of health (SoH) and the state of function (SoF) of the battery 630. The BMS may communicate the information of the battery 630 to the application circuitry 605 or other components of the platform 600. The BMS may also include an analog-to-digital (ADC) convertor that allows the application circuitry 605 to directly monitor the voltage of the battery 630 or the current flow from the battery 630. The battery parameters may be used to determine actions that the platform 600 may perform, such as transmission frequency, network operation, sensing frequency, and the like.

[0139] A power block, or other power supply coupled to an electrical grid may be coupled with the BMS to charge the battery 630. In some examples, the power block 630 may be replaced with a wireless power receiver to obtain the power wirelessly, for example, through a loop antenna in the computer platform 600. 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 630, 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.

[0140] User interface circuitry 650 includes various input/output (I/O) devices present within, or connected to, the platform 600, and includes one or more user interfaces designed to enable user interaction with the platform 600 and/or peripheral component interfaces designed to enable peripheral component interaction with the platform 600. The user interface circuitry 650 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 600. 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 621 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.

[0141] Although not shown, the components of platform 600 may communicate with one another using a suitable bus or interconnect (IX) technology, which may include any number of technologies, including ISA, EISA, PCI, PCIx, PCIe, a Time-Trigger Protocol (TTP) system, a FlexRay system, or any number of other technologies. The bus/IX may be a proprietary bus/IX, for example, used in a SoC based system. Other bus/IX systems may be included, such as an I^2C interface, an SPI interface, point-to-point interfaces, and a power bus, among others.

[0142] Figure 7 illustrates example components of baseband circuitry 710 and radio front end modules (RFEM) 715 in accordance with various embodiments. The baseband circuitry 710 corresponds to the baseband circuitry 510 and 610 of Figures 5 and 6, respectively. The RFEM 715 corresponds to the RFEM 515 and 615 of Figures 5 and 6, respectively. As shown, the RFEMs 715 may include Radio Frequency (RF) circuitry 706, front-end module (FEM) circuitry 708, antenna array 711 coupled together at least as shown.

[0143] The baseband circuitry 710 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 706. 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 710 may include Fast-Fourier Transform (FFT), precoding, or constellation mapping/demapping functionality. In some embodiments, encoding/decoding circuitry of the baseband circuitry 710 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 710 is configured to process baseband signals received from a receive signal path of the RF circuitry 706 and to generate baseband signals for a transmit signal path of the RF circuitry 706. The baseband circuitry 710 is configured to interface with application circuitry 505/605 (see Figures 5 and 6) for generation and processing of the baseband signals and for controlling operations of the RF circuitry 706. The baseband circuitry 710 may handle various radio control functions.

[0144] The aforementioned circuitry and/or control logic of the baseband circuitry 710 may include one or more single or multi-core processors. For example, the one or more processors may include a 3G baseband processor 704A, a 4G/LTE baseband processor 704B, a 5G/NR baseband processor 704C, or some other baseband processor(s) 704D 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 704A-D may be included in modules stored in the memory 704G and executed via a Central Processing Unit (CPU) 704E. In other embodiments, some or all of the functionality of baseband processors 704A-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 704G may store program code of a real-time OS (RTOS), which when executed by the CPU 704E (or other baseband processor), is to cause the CPU 704E (or other baseband processor) to manage resources of the baseband circuitry 710, 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 710 includes one or more audio digital signal processor(s) (DSP) 704F. The audio DSP(s) 704F include elements for compression/decompression and echo cancellation and may include other suitable processing elements in other embodiments.

[0145] In some embodiments, each of the processors 704A-704E include respective memory interfaces to send/receive data to/from the memory 704G. The baseband circuitry 710 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 710; an application circuitry interface to send/receive data to/from the application circuitry 505/605 of FIGS. 5-7); an RF circuitry interface to send/receive data to/from RF circuitry 706 of Figure 7; 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 625.

[0146] In alternate embodiments (which may be combined with the above described embodiments), baseband circuitry 710 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 710 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 715).

[0147] Although not shown by Figure 7, in some embodiments, the baseband circuitry 710 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 710 and/or RF circuitry 706 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 710 and/or RF circuitry 706 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., 704G) 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 710 may also support radio communications for more than one wireless protocol.

[0148] The various hardware elements of the baseband circuitry 710 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 710 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 710 and RF circuitry 706 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 710 may be implemented as a separate SoC that is communicatively coupled with and RF circuitry 706 (or multiple instances of RF circuitry 706). In yet another example, some or all of the constituent components of the baseband circuitry 710 and the application circuitry 505/605 may be implemented together as individual SoCs mounted to a same circuit board (e.g., a “multi-chip package”).

[0149] In some embodiments, the baseband circuitry 710 may provide for communication compatible with one or more radio technologies. For example, in some embodiments, the baseband circuitry 710 may support communication with an E-UTRAN or other WMAN, a WLAN, a WPAN. Embodiments in which the baseband circuitry 710 is configured to support radio communications of more than one wireless protocol may be referred to as multi-mode baseband circuitry.

[0150] RF circuitry 706 may enable communication with wireless networks using modulated electromagnetic radiation through a non-solid medium. In various embodiments, the RF circuitry 706 may include switches, filters, amplifiers, etc. to facilitate the communication with the wireless network. RF circuitry 706 may include a receive signal path, which may include circuitry to down-convert RF signals received from the FEM circuitry 708 and provide baseband signals to the baseband circuitry 710. RF circuitry 706 may also include a transmit signal path, which may include circuitry to up-convert baseband signals provided by the baseband circuitry 710 and provide RF output signals to the FEM circuitry 708 for transmission.

[0151] In some embodiments, the receive signal path of the RF circuitry 706 may include mixer circuitry 706a, amplifier circuitry 706b and filter circuitry 706c. In some embodiments, the transmit signal path of the RF circuitry 706 may include filter circuitry 706c and mixer circuitry 706a. RF circuitry 706 may also include synthesizer circuitry 706d for synthesizing a frequency for use by the mixer circuitry 706a of the receive signal path and the transmit signal path. In some embodiments, the mixer circuitry 706a of the receive signal path may be configured to down-convert RF signals received from the FEM circuitry 708 based on the synthesized frequency provided by synthesizer circuitry 706d. The amplifier circuitry 706b may be configured to amplify the down-converted signals and the filter circuitry 706c 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 710 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 706a of the receive signal path may comprise passive mixers, although the scope of the embodiments is not limited in this respect.

[0152] In some embodiments, the mixer circuitry 706a of the transmit signal path may be configured to up-convert input baseband signals based on the synthesized frequency provided by the synthesizer circuitry 706d to generate RF output signals for the FEM circuitry 708. The baseband signals may be provided by the baseband circuitry 710 and may be filtered by filter circuitry 706c.

[0153] In some embodiments, the mixer circuitry 706a of the receive signal path and the mixer circuitry 706a 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 706a of the receive signal path and the mixer circuitry 706a 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 706a of the receive signal path and the mixer circuitry 706a of the transmit signal path may be arranged for direct downconversion and direct upconversion, respectively. In some embodiments, the mixer circuitry 706a of the receive signal path and the mixer circuitry 706a of the transmit signal path may be configured for super-heterodyne operation.

[0154] 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 706 may include analog-to-digital converter (ADC) and digital-to-analog converter (DAC) circuitry and the baseband circuitry 710 may include a digital baseband interface to communicate with the RF circuitry 706.

[0155] 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.

[0156] In some embodiments, the synthesizer circuitry 706d 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 706d may be a delta-sigma synthesizer, a frequency multiplier, or a synthesizer comprising a phase-locked loop with a frequency divider.

[0157] The synthesizer circuitry 706d may be configured to synthesize an output frequency for use by the mixer circuitry 706a of the RF circuitry 706 based on a frequency input and a divider control input. In some embodiments, the synthesizer circuitry 706d may be a fractional N/N+1 synthesizer.

[0158] 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 710 or the application circuitry 505/605 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 505/605.

[0159] Synthesizer circuitry 706d of the RF circuitry 706 may include a divider, a delay-locked loop (DLL), a multiplexer and a phase accumulator. In some embodiments, the divider may be a dual modulus divider (DMD) and the phase accumulator may be a digital phase accumulator (DPA). In some embodiments, the DMD may be configured to divide the input signal by either N or N+1 (e.g., based on a carry out) to provide a fractional division ratio. In some example embodiments, the DLL may include a set of cascaded, tunable, delay elements, a phase detector, a charge pump and a D-type flip-flop. In these embodiments, the delay elements may be configured to break a VCO period up into Nd equal packets of phase, where Nd is the number of delay elements in the delay line. In this way, the DLL provides negative feedback to help ensure that the total delay through the delay line is one VCO cycle.

[0160] In some embodiments, synthesizer circuitry 706d 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 706 may include an IQ/polar converter.

[0161] FEM circuitry 708 may include a receive signal path, which may include circuitry configured to operate on RF signals received from antenna array 711, amplify the received signals and provide the amplified versions of the received signals to the RF circuitry 706 for further processing. FEM circuitry 708 may also include a transmit signal path, which may include circuitry configured to amplify signals for transmission provided by the RF circuitry 706 for transmission by one or more of antenna elements of antenna array 711. In various embodiments, the amplification through the transmit or receive signal paths may be done solely in the RF circuitry 706, solely in the FEM circuitry 708, or in both the RF circuitry 706 and the FEM circuitry 708.

[0162] In some embodiments, the FEM circuitry 708 may include a TX/RX switch to switch between transmit mode and receive mode operation. The FEM circuitry 708 may include a receive signal path and a transmit signal path. The receive signal path of the FEM circuitry 708 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 706). The transmit signal path of the FEM circuitry 708 may include a power amplifier (PA) to amplify input RF signals (e.g., provided by RF circuitry 706), and one or more filters to generate RF signals for subsequent transmission by one or more antenna elements of the antenna array 711.

[0163] The antenna array 711 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 710 is converted into analog RF signals (e.g., modulated waveform) that will be amplified and transmitted via the antenna elements of the antenna array 711 including one or more antenna elements (not shown). The antenna elements may be omnidirectional, direction, or a combination thereof. The antenna elements may be formed in a multitude of arranges as are known and/or discussed herein. The antenna array 711 may comprise microstrip antennas or printed antennas that are fabricated on the surface of one or more printed circuit boards. The antenna array 711 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 706 and/or FEM circuitry 708 using metal transmission lines or the like.

[0164] Processors of the application circuitry 505/605 and processors of the baseband circuitry 710 may be used to execute elements of one or more instances of a protocol stack. For example, processors of the baseband circuitry 710, alone or in combination, may be used execute Layer 3, Layer 2, or Layer 1 functionality, while processors of the application circuitry 505/605 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.

[0165] Figure 8 illustrates various protocol functions that may be implemented in a wireless communication device according to various embodiments. In particular, Figure 8 includes an arrangement 800 showing interconnections between various protocol layers/entities. The following description of Figure 8 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 8 may be applicable to other wireless communication network systems as well.

[0166] The protocol layers of arrangement 800 may include one or more of PHY 810, MAC 820, RLC 830, PDCP 840, SDAP 847, RRC 855, and NAS layer 857, in addition to other higher layer functions not illustrated. The protocol layers may include one or more service access points (e.g., items 859, 856, 850, 849, 845, 835, 825, and 815 in Figure 8) that may provide communication between two or more protocol layers.

[0167] The PHY 810 may transmit and receive physical layer signals 805 that may be received from or transmitted to one or more other communication devices. The physical layer signals 805 may comprise one or more physical channels, such as those discussed herein. The PHY 810 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 855. The PHY 810 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 810 may process requests from and provide indications to an instance of MAC 820 via one or more PHY-SAP 815. According to some embodiments, requests and indications communicated via PHY-SAP 815 may comprise one or more transport channels.

[0168] Instance(s) of MAC 820 may process requests from, and provide indications to, an instance of RLC 830 via one or more MAC-SAPs 825. These requests and indications communicated via the MAC-SAP 825 may comprise one or more logical channels. The MAC 820 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 810 via the transport channels, de-multiplexing MAC SDUs to one or more logical channels from TBs delivered from the PHY 810 via transport channels, multiplexing MAC SDUs onto TBs, scheduling information reporting, error correction through HARQ, and logical channel prioritization.

[0169] Instance(s) of MAC 820 are also responsible for UL-SCH data transfer. A UL grant is either received dynamically on the PDCCH, in a Random Access Response, or configured semi-persistently by RRC 855. The MAC 820 entity may have an uplink grant to transmit on the UL-SCH. To perform the requested transmissions, the MAC 820 receives HARQ information from lower layers. If the MAC 820 entity has a C-RNTI, a Temporary C-RNTI, or CS-RNTI, the MAC 820 entity, for each PDCCH occasion, and for each Serving Cell belonging to a TAG that has a running *timeAlignmentTimer*, and for each grant received for this PDCCH occasion:

[0170] If an uplink grant for this Serving Cell has been received on the PDCCH for the MAC entity's C-RNTI or Temporary C-RNTI, or if an uplink grant has been received in a Random Access Response, then the MAC 820 considers the NDI to have been toggled for the corresponding HARQ process regardless of the value of the NDI if the uplink grant is for MAC entity's C-RNTI and if the previous uplink grant delivered to the HARQ entity for the same HARQ process was either an uplink grant received for the MAC entity's CS-RNTI or a configured uplink grant; starts or restarts the *configuredGrantTimer* for the correponding HARQ process, if configured if the uplink grant is for MAC 820 entity's C-RNTI, and the identified HARQ process is configured for a configured uplink grant; and/or delivers the UL grant and the associated HARQ information to the HARQ entity of the MAC 820. Otherwise, if a UL grant for this PDCCH occasion has been received for this Serving Cell on the PDCCH for the MAC entity's CS-RNTI, and if the NDI in the received HARQ information is 1, the MAC 820 considers the NDI for the corresponding HARQ process not to have been toggled; starts or restarts the *configuredGrantTimer* for the corresponding HARQ process, if configured; and/or delivers the UL grant and the associated HARQ information to the HARQ entity. Otherwise, if the NDI in the received HARQ information is 0, and if PDCCH contents indicate configured grant Type 2 deactivation, the MAC 820 triggers configured uplink grant confirmation. Otherwise, if the PDCCH contents indicate configured grant Type 2 activation, the MAC 820 triggers configured uplink grant confirmation; stores the uplink grant for this Serving Cell and the associated HARQ information as configured uplink grant; initialises or re-initialises the configured uplink grant for this Serving Cell to start in the associated PUSCH duration and to recur according to rules in subclause 5.8.2 of 3GPP TS 38.321; and/or stops the *configuredGrantTimer* for the corresponding HARQ process, if running.

[0171] For each Serving Cell and each configured UL grant, if configured and activated, the MAC 820 entity, if the PUSCH duration of the configured UL grant does not overlap with the PUSCH duration of a UL grant received on the PDCCH or in a Random Access

Response for this Serving Cell, sets the HARQ Process ID to the HARQ Process ID associated with this PUSCH duration; if the *configuredGrantTimer* for the corresponding HARQ process is not running, the MAC 820 considers the NDI bit for the corresponding HARQ process to have been toggled; and/or delivers the configured UL grant and the associated HARQ information to the HARQ entity.

[0172] For configured uplink grants, the HARQ Process ID associated with the first symbol of a UL transmission is derived from the following equation:

[0173] HARQ Process ID = [floor(CURRENT_symbol/*periodicity*)] modulo *nrofHARQ-Processes* where CURRENT_symbol = (SFN × *numberOfSlotsPerFrame* × *numberOfSymbolsPerSlot* + slot number in the frame × *numberOfSymbolsPerSlot* + symbol number in the slot), and *numberOfSlotsPerFrame* and *numberOfSymbolsPerSlot* refer to the number of consecutive slots per frame and the number of consecutive symbols per slot, respectively as specified in 3GPP TS 38.211. The CURRENT_symbol refers to the symbol index of the first transmission occasion of a repetition bundle that takes place. A HARQ process is configured for a configured UL grant if the configured uplink grant is activated and the associated HARQ process ID is less than *nrofHARQ-Processes*. If the MAC 820 entity receives both a grant in a Random Access Response and an overlapping grant for its C-RNTI or CS-RNTI, requiring concurrent transmissions on the SpCell, the MAC 820 entity may choose to continue with either the grant for its RA-RNTI or the grant for its C-RNTI or CS-RNTI.

[0174] As alluded to previously, the MAC 820 entity includes a HARQ entity for each Serving Cell with configured UL (including the case when it is configured with *supplementaryUplink*), which maintains a number of parallel HARQ processes. The number of parallel UL HARQ processes per HARQ entity is specified in 3GPP TS 38.214. Each HARQ process supports one TB. Each HARQ process is associated with a HARQ process identifier. For UL transmission with UL grant in RA Response, HARQ process identifier 0 is used.

[0175] When the MAC 820 entity is configured with *pusch-AggregationFactor* > 1, the parameter *pusch-AggregationFactor* provides the number of transmissions of a TB within a bundle of the dynamic grant. After the initial transmission, *pusch-AggregationFactor* – 1 HARQ retransmissions follow within a bundle. When the MAC 820 entity is configured with *repK* > 1, the parameter *repK* provides the number of transmissions of a TB within a bundle of the configured uplink grant. After the initial transmission, HARQ retransmissions follow within a bundle. For both dynamic grant and configured uplink grant, bundling operation relies on the HARQ entity for invoking the same HARQ process for each transmission that is part of the same bundle. Within a bundle, HARQ retransmissions are triggered without waiting for feedback from previous transmission according to *pusch-AggregationFactor* for a dynamic grant and *repK* for a configured uplink grant, respectively. Each transmission within a bundle is a separate uplink grant after the initial uplink grant within a bundle is delivered to the HARQ entity. For each transmission within a bundle of the dynamic grant, the sequence of redundancy versions is determined according to subclause 6.1.2.1 of 3GPP TS 38.214. For each transmission within a bundle of the configured uplink grant, the sequence of redundancy versions is determined according to subclause 6.1.2.3 of 3GPP TS 38.214.

[0176] The MAC 820 entity also applies an LCP procedure whenever a new transmission is performed. The RRC entity (e.g., RRC 855 of Figure 8) controls the scheduling of uplink data by signalling for each logical channel per MAC entity (e.g., MAC 820 of Figure 8) according to: *priority* where an increasing priority value indicates a lower priority level; *prioritisedBitRate* which sets the Prioritized Bit Rate (PBR); and *bucketSizeDuration* which sets the Bucket Size Duration (BSD).

[0177] The RRC entity additionally controls the LCP procedure by configuring mapping restrictions for each logical channel according to: *allowedSCS-List* which sets the allowed Subcarrier Spacing(s) for transmission; *maxPUSCH-Duration* which sets the maximum PUSCH duration allowed for transmission; *configuredGrantType1Allowed* which sets whether a configured grant Type 1 can be used for transmission; and *allowedServingCells* which sets the allowed cell(s) for transmission.

[0178] The following UE variable is used for the Logical channel prioritization procedure: *Bj* which is maintained for each logical channel *j*. The MAC 820 entity initializes *Bj* of the logical channel to zero when the logical channel is established. For each logical channel *j*, the MAC 820 entity, increments *Bj* by the product PBR × T before every instance of the LCP procedure, where T is the time elapsed since *Bj* was last incremented; and sets *Bj* to the bucket size if the value of *Bj* is greater than the bucket size (e.g., PBR × BSD). The exact moment(s) when the UE 201/2201 updates *Bj* between LCP procedures is up to UE implementation, as long as *Bj* is up to date at the time when a grant is processed by LCP.

[0179] When a new transmission is performed, the MAC 820 entity selects the logical channels for each UL grant that satisfy all the following conditions: the set of allowed Subcarrier Spacing index values in *allowedSCS-List*, if configured, includes the Subcarrier Spacing index associated to the UL grant; and *maxPUSCH-Duration*, if configured, is larger than or equal to the PUSCH transmission duration associated to the UL grant; and *configuredGrantType1Allowed*, if configured, is set to *true* in case the UL grant is a Configured Grant Type 1; and *allowedServingCells*, if configured, includes the Cell information associated to the UL grant. Does not apply to logical channels associated with a DRB configured with PDCP duplication within the same MAC entity (e.g., CA duplication) for which PDCP duplication is deactivated. The Subcarrier Spacing index, PUSCH transmission duration and Cell information are included in Uplink transmission information received from lower layers for the corresponding scheduled uplink transmission.

[0180] When a new transmission is performed, the MAC 820 entity allocates resources to the logical channels as follows: selected logical channels for the UL grant with $Bj > 0$ are allocated resources in a decreasing priority order. If the PBR of a logical channel is set to *infinity*, the MAC 820 entity allocates resources for all the data that is available for transmission on the logical channel before meeting the PBR of the lower priority logical channel(s); decrement Bj by the total size of MAC SDUs served to logical channel j above; and if any resources remain, all the logical channels selected in subclause 5.4.3.1.2 are served in a strict decreasing priority order (regardless of the value of Bj) until either the data for that logical channel or the UL grant is exhausted, whichever comes first. Logical channels configured with equal priority should be served equally. The value of Bj can be negative.

[0181] If the MAC 820 entity is requested to simultaneously transmit multiple MAC PDUs, or if the MAC 820 entity receives the multiple UL grants within one or more coinciding PDCCH occasions (e.g., on different Serving Cells), it is up to UE implementation in which order the grants are processed. The UE 201/401 also follows the rules below during the scheduling procedures: the UE 201/401 should not segment an RLC SDU (or partially transmitted SDU or retransmitted RLC PDU) if the whole SDU (or partially transmitted SDU or retransmitted RLC PDU) fits into the remaining resources of the associated MAC 820 entity; if the UE 201/401 segments an RLC SDU from the logical channel, the MAC 820 maximizes the size of the segment to fill the grant of the associated MAC 820 entity as much as possible; the UE 201/401 should maximise the transmission of data; if the MAC 820 entity is given a UL grant size that is equal to or larger than 8 bytes while having data available and allowed for transmission, the MAC 820 entity does not transmit only padding BSR and/or padding. The MAC 820 entity does not generate a MAC PDU for the HARQ entity if the following conditions are satisfied: the MAC 820 entity is configured with *skipUplinkTxDynamic* with value *true* and the grant indicated to the HARQ entity was addressed to a C-RNTI, or the grant indicated to the HARQ entity is a configured uplink grant; and there is no aperiodic CSI requested for this PUSCH transmission as specified in 3GPP TS 38.212; and the MAC PDU includes zero MAC SDUs; and the MAC PDU includes only the periodic BSR and there is no data available for any LCG, or the MAC PDU includes only the padding BSR. Logical channels are prioritised according to the following order (highest priority listed first): C-RNTI MAC CE or data from UL-CCCH; Configured Grant Confirmation MAC CE; MAC CE for BSR, with exception of BSR included for padding; single Entry PHR MAC CE or Multiple Entry PHR MAC CE; data from any Logical Channel, except data from UL-CCCH; MAC CE for Recommended bit rate query; and/or MAC CE for BSR included for padding.

[0182] Instance(s) of RLC 830 may process requests from and provide indications to an instance of PDCP 840 via one or more radio link control service access points (RLC-SAP) 835. These requests and indications communicated via RLC-SAP 835 may comprise one or more RLC channels. The RLC 830 may operate in a plurality of modes of operation, including: Transparent Mode (TM), Unacknowledged Mode (UM), and Acknowledged Mode (AM). The RLC 830 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 830 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.

[0183] Instance(s) of PDCP 840 may process requests from and provide indications to instance(s) of RRC 855 and/or instance(s) of SDAP 847 via one or more packet data convergence protocol service access points (PDCP-SAP) 845. These requests and indications communicated via PDCP-SAP 845 may comprise one or more radio bearers.

The PDCP 840 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.).

[0184] Instance(s) of SDAP 847 may process requests from and provide indications to one or more higher layer protocol entities via one or more SDAP-SAP 849. These requests and indications communicated via SDAP-SAP 849 may comprise one or more QoS flows. The SDAP 847 may map QoS flows to DRBs, and vice versa, and may also mark QFIs in DL and UL packets. A single SDAP entity 847 may be configured for an individual PDU session. In the UL direction, the NG-RAN 210 may control the mapping of QoS Flows to DRB(s) in two different ways, reflective mapping or explicit mapping. For reflective mapping, the SDAP 847 of a UE 201 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 847 of the UE 201 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 410 may mark DL packets over the Uu interface with a QoS flow ID. The explicit mapping may involve the RRC 855 configuring the SDAP 847 with an explicit QoS flow to DRB mapping rule, which may be stored and followed by the SDAP 847. In embodiments, the SDAP 847 may only be used in NR implementations and may not be used in LTE implementations.

[0185] The RRC 855 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 810, MAC 820, RLC 830, PDCP 840 and SDAP 847. In embodiments, an instance of RRC 855 may process requests from and provide indications to one or more NAS entities 857 via one or more RRC-SAPs 856. The main services and functions of the RRC 855 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 201 and RAN 210 (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.

[0186] For example, an RRC connection establishment procedure involves the establishment of SRB1. The NW completes RRC connection establishment prior to completing the establishment of an NG connection, for example, prior to receiving the UE context information from the 5GC 220/420. Consequently, AS security is not activated during the initial phase of the RRC connection. During this initial phase of the RRC connection, the NW may configure the UE 201/401 to perform measurement reporting, but the UE 201/401 only sends the corresponding measurement reports after successful AS security activation. However, the UE only accepts a re-configuration with sync message when AS security has been activated.

[0187] Upon receiving the UE context from the 5GC 220/420, the RAN 210/410 activates AS security (both ciphering and integrity protection) using the initial AS security activation procedure. The RRC messages to activate AS security (command and successful response) are integrity protected, while ciphering is started only after completion of the procedure. That is, the response to the message used to activate AS security is not ciphered, while the subsequent messages (e.g. used to establish SRB2 and DRBs) are both integrity protected and ciphered. After having initiated the initial AS security activation procedure, the network may initiate the establishment of SRB2 and DRBs, for example, the NW may do this prior to receiving the confirmation of the initial AS security activation from the UE 201/401. In any case, the network will apply both ciphering and integrity protection for the RRC reconfiguration messages used to establish SRB2 and DRBs. The network should release the RRC connection if the initial AS security activation and/ or the radio bearer establishment fails.

[0188] The release of the RRC connection normally is initiated by the NW. This procedure may be used to re-direct the UE to an NR frequency or an E-UTRA carrier frequency.

[0189] The suspension of the RRC connection is initiated by the NW. When the RRC connection is suspended, the UE 201/401 stores the UE Inactive AS context and any configuration received from the network, and transits to RRC_INACTIVE state. The RRC message to suspend the RRC connection is integrity protected and ciphered.

[0190] The resumption of a suspended RRC connection is initiated by upper layers when the UE 201/401 needs to transit from RRC_INACTIVE state to RRC_CONNECTED state or by RRC layer to perform an RNA update or by RAN paging from NG-RAN 410. When the RRC connection is resumed, network configures the UE 201/401 according to the RRC connection resume procedure based on the stored UE Inactive AS context and any RRC configuration received from the network. The RRC connection resume procedure re-activates AS security and re-establishes SRB(s) and DRB(s).

[0191] In response to a request to resume the RRC connection, the NW may resume the suspended RRC connection and send the UE 201/401 to RRC_CONNECTED, or reject the request to resume and send the UE 201/401to RRC_INACTIVE (with a wait timer), or directly re-suspend the RRC connection and send the UE 201/401 to RRC_INACTIVE, or directly release the RRC connection and send the UE 201/401 to RRC_IDLE, or instruct the UE 201/401 to initiate NAS level recovery (in this case the NW sends an RRC setup message).

[0192] The NAS 857 may form the highest stratum of the control plane between the UE 201 and the AMF 421. The NAS 857 may support the mobility of the UEs 201 and the session management procedures to establish and maintain IP connectivity between the UE 201 and a P-GW in LTE systems.

[0193] According to various embodiments, one or more protocol entities of arrangement 800 may be implemented in UEs 201, RAN nodes 211, AMF 421 in NR implementations or MME 321 in LTE implementations, UPF 402 in NR implementations or S-GW 322 and P-GW 323 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 201, gNB 211, AMF 421, 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 211 may host the RRC 855, SDAP 847, and PDCP 840 of the gNB that controls the operation of one or more gNB-DUs, and the gNB-DUs of the gNB 211 may each host the RLC 830, MAC 820, and PHY 810 of the gNB 211.

[0194] In a first example, a control plane protocol stack may comprise, in order from highest layer to lowest layer, NAS 857, RRC 855, PDCP 840, RLC 830, MAC 820, and PHY 810. In this example, upper layers 860 may be built on top of the NAS 857, which includes an IP layer 861, an SCTP 862, and an application layer signaling protocol (AP) 863.

[0195] In NR implementations, the AP 863 may be an NG application protocol layer (NGAP or NG-AP) 863 for the NG interface 213 defined between the NG-RAN node 211 and the AMF 421, or the AP 863 may be an Xn application protocol layer (XnAP or Xn-AP) 863 for the Xn interface 212 that is defined between two or more RAN nodes 211.

[0196] The NG-AP 863 may support the functions of the NG interface 213 and may comprise Elementary Procedures (EPs). An NG-AP EP may be a unit of interaction between the NG-RAN node 211 and the AMF 421. The NG-AP 863 services may comprise two groups: UE-associated services (e.g., services related to a UE 201) and non-UE-associated services (e.g., services related to the whole NG interface instance between the NG-RAN node 211 and AMF 421). These services may include functions including, but not limited to: a paging function for the sending of paging requests to NG-RAN nodes 211 involved in a particular paging area; a UE context management function for allowing the AMF 421 to establish, modify, and/or release a UE context in the AMF 421 and the NG-RAN node 211; a mobility function for UEs 201 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 201 and AMF 421; a NAS node selection function for determining an association between the AMF 421 and the UE 201; 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 211 via CN 220; and/or other like functions.

[0197] The XnAP 863 may support the functions of the Xn interface 212 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 211 (or E-UTRAN 310), 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 201, such as Xn interface setup and reset procedures, NG-RAN update procedures, cell activation procedures, and the like.

[0198] In LTE implementations, the AP 863 may be an S1 Application Protocol layer (S1-AP) 863 for the S1 interface 213 defined between an E-UTRAN node 211 and an MME, or the AP 863 may be an X2 application protocol layer (X2AP or X2-AP) 863 for the X2 interface 212 that is defined between two or more E-UTRAN nodes 211.

[0199] The S1 Application Protocol layer (S1-AP) 863 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 211 and an MME 321within an LTE CN 220. The S1-AP 863 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.

[0200] The X2AP 863 may support the functions of the X2 interface 212 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 220, 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 201, such as X2 interface setup and reset procedures, load indication procedures, error indication procedures, cell activation procedures, and the like.

[0201] The SCTP layer (alternatively referred to as the SCTP/IP layer) 862 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 862 may ensure reliable delivery of signaling messages between the RAN node 211 and the AMF 421/MME 321 based, in part, on the IP protocol, supported by the IP 861. The Internet Protocol layer (IP) 861 may be used to perform packet addressing and routing functionality. In some implementations the IP layer 861 may use point-to-point transmission to deliver and convey PDUs. In this regard, the RAN node 211 may comprise L2 and L1 layer communication links (e.g., wired or wireless) with the MME/AMF to exchange information.

[0202] In a second example, a user plane protocol stack may comprise, in order from highest layer to lowest layer, SDAP 847, PDCP 840, RLC 830, MAC 820, and PHY 810. The user plane protocol stack may be used for communication between the UE 201, the RAN node 211, and UPF 402 in NR implementations or an S-GW 322 and P-GW 323 in LTE implementations. In this example, upper layers 851 may be built on top of the SDAP 847, and may include a user datagram protocol (UDP) and IP security layer (UDP/IP) 852, a General Packet Radio Service (GPRS) Tunneling Protocol for the user plane layer (GTP-U) 853, and a User Plane PDU layer (UP PDU) 863.

[0203] The transport network layer 854 (also referred to as a “transport layer”) may be built on IP transport, and the GTP-U 853 may be used on top of the UDP/IP layer 852 (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.

[0204] The GTP-U 853 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 852 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 211 and the S-GW 322 may utilize an S1-U interface to exchange user plane data via a protocol stack comprising an L1 layer (e.g., PHY 810), an L2 layer (e.g., MAC 820, RLC 830, PDCP 840, and/or SDAP 847), the UDP/IP layer 852, and the GTP-U 853. The S-GW 322 and the P-GW 323 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 852, and the GTP-U 853. As discussed previously, NAS protocols may support the mobility of the UE 201 and the session management procedures to establish and maintain IP connectivity between the UE 201 and the P-GW 323.

[0205] Moreover, although not shown by Figure 8, an application layer may be present above the AP 863 and/or the transport network layer 854. The application layer may be a layer in which a user of the UE 201, RAN node 211, or other network element interacts with software applications being executed, for example, by application circuitry 505 or application circuitry 605, respectively. The application layer may also provide one or more interfaces for software applications to interact with communications systems of the

UE 201 or RAN node 211, such as the baseband circuitry 710. 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).

[0206] Figure 9 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 9 shows a diagrammatic representation of hardware resources 900 including one or more processors (or processor cores) 910, one or more memory/storage devices 920, and one or more communication resources 930, each of which may be communicatively coupled via a bus 940. For embodiments where node virtualization (e.g., NFV) is utilized, a hypervisor 902 may be executed to provide an execution environment for one or more network slices/sub-slices to utilize the hardware resources 900.

[0207] The processors 910 may include, for example, a processor 912 and a processor 914. The processor(s) 910 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.

[0208] The memory/storage devices 920 may include main memory, disk storage, or any suitable combination thereof. The memory/storage devices 920 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.

[0209] The communication resources 930 may include interconnection or network interface components or other suitable devices to communicate with one or more peripheral devices 904 or one or more databases 906 via a network 908. For example, the communication resources 930 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..

[0210] Instructions 950 may comprise software, a program, an application, an applet, an app, or other executable code for causing at least any of the processors 910 to perform any one or more of the methodologies discussed herein. The instructions 950 may reside, completely or partially, within at least one of the processors 910 (e.g., within the processor's cache memory), the memory/storage devices 920, or any suitable combination thereof. Furthermore, any portion of the instructions 950 may be transferred to the hardware resources 900 from any combination of the peripheral devices 904 or the databases 906. Accordingly, the memory of processors 910, the memory/storage devices 920, the peripheral devices 904, and the databases 906 are examples of computer-readable and machine-readable media.

[0211] In some embodiments, the electronic device(s), network(s), system(s), chip(s) or component(s), or portions or implementations thereof, of Figures 1-9, or some other figure herein, may be configured to perform one or more processes, techniques, or methods as described herein, or portions thereof. One such process is depicted in Figure 10. Figure 10 illustrates a flowchart 1000 that describes an electronic device, for use in a wireless network for improving configured grant for new radio (NR) unlicensed. According to some embodiments, the electronic device can include a UE 201, 301, 401, 600. In some embodiments, the flowchart 1000 can be performed or controlled by a processor or processor circuitry described in the various embodiments herein, including the processor shown in Figure 9, and/or the application circuitry 505 or 605, and/or baseband circuitry 510 or 610 shown in Figures 5-6.

[0212] At 1002, a message from a base station is received. For example the UE receives the message from the base station (e.g., a gNB). At 1004, based on the received message, it is determined whether to use a lowest Channel Access Priority Class (CAPC) or a highest CAPC. For example, the message indicates to the UE to use the lowest CAPC in response to an access point (AP) associated with a wireless network is detected. In some examples, the AP is associated with the UE. Additionally, or alternatively, the AP is associated with the base station. In other words, if the base station has determined that the AP is in the vicinity of the base station and/or the UE, the message indicates to use the lowest CAPC. In some examples, the message indicates to the UE to use the highest CAPC in response to the AP associated with the wireless network is not detected.

[0213] Although some embodiments are discussed with respect to the UE using the lowest CAPC or the highest CAPC, the embodiments of this disclosure are not limited to using the lowest CAPC or the highest CAPC. In some examples, the message can indicate to the UE to use a CAPC between the lowest CAPC and the highest CAPC but closer to the lowest CAPC in response to the AP being detected. For example, the CAPCs can be divided into one or more groups and the message can indicate to the UE to use a CAPC in the lowest group in response to the AP being detected. In some examples, the message can indicate to the UE to use a CAPC between the lowest CAPC and the highest CAPC but closer to the highest CAPC in response to the AP not being detected. For example, the CAPCs can be divided into one or more groups and the message can indicate to the UE to use a CAPC in the highest group in response to the AP not being detected.

[0214] At 1006, in response to the received message indicating to the UE to use the lowest CAPC, the UE selects a CAPC based on the lowest CAPC of one or more Media Access Control (MAC) Service Data Units (SDUs) that are multiplexed in one or more MAC Protocol Data Units (PDUs) for an uplink (UL) transmission. In some examples, the UL transmission corresponds to at least one of a configured grant or a dynamic grant. Alternatively, the UE can select a CAPC based on a CAPC in the lowest CAPC group of one or more MAC SDUs in one or more MAC PDUs for UL transmission.

[0215] Alternatively, at 1008, in response to the received message indicating to the UE to use the highest CAPC, th UE selects the CAPC based on the highest CAPC of the one or more MAC SDUs that are multiplexed in the one or more MAC PDUs for the UL transmission. In some examples, the UL transmission corresponds to at least one of a configured grant or a dynamic grant. Alternatively, the UE can select a CAPC based on a CAPC in the highest CAPC group of one or more MAC SDUs in one or more MAC PDUs for UL transmission.

[0216] At 1010, the UE can transmit the MAC PDU to the base station.

[0217] According to some examples, the MAC PDU can include a first MAC PDU and a second MAC PDU and method 1000 can also include multiplexing control signaling into the first MAC PDU, multiplexing data signaling into the second MAC PDU, transmitting the first MAC PDU using the dynamic grant, and transmitting the second MAC PDU using the configured grant.

[0218] According to some examples, the control signaling includes at least one of a MAC control element (CE), a Signaling Radio Bearer (SRB), or a Data Radio Bearer (DRB) with the highest CACP and the data signaling includes a Data Radio Bearer (DRB) not having the highest CACP.

[0219] According to some examples, method 1000 can include starting or restarting a configured grant timer and a configured grant retransmission timer at a same time. Additionally, or alternatively, method 1000 can include restarting the configured grant timer when the configured grant timer expires and running the configured grant retransmission timer for a predefined number of configured grant retransmissions.

[0220] In some embodiments, the electronic device(s), network(s), system(s), chip(s) or component(s), or portions or implementations thereof, of Figures 1-9, or some other figure herein, may be configured to perform one or more processes, techniques, or methods as described herein, or portions thereof. One such process is depicted in Figure 11. Figure 11 illustrates a flowchart 1100 that describes an electronic device, for use in a wireless network for improving configured grant for new radio (NR) unlicensed. According to some embodiments, the electronic device can include a base station, such as RAN node 211, AP 206, E-UTRAN 310, RAN 410, infrastructure equipment 500. In some embodiments, the flowchart 1100 can be performed or controlled by a processor or processor circuitry described in the various embodiments herein, including the processor shown in Figure 9, and/or the application circuitry 505 or 605, and/or baseband circuitry 510 or 610 shown in Figures 5-6.

[0221] At 1102, the base station determines whether an access point (AP) associated with a wireless network is detected. In some examples, the AP is associated with a UE that is served by the base station. Additionally, or alternatively, the AP is associated with the base station. In other words, if the base station determines whether the AP is in the vicinity of the base station and/or is in the vicinity of the UE.

[0222] At 1104, the base station generates a message for the UE. The message includes a parameter set to a lowest Channel Access Priority Class (CAPC) in response to detecting the AP or is set to a highest CAPC in response to not detecting the AP.

[0223] At 1006, the base station transmit the message to the UE. According to some examples, the base station transmits the message using an uplink (UL) grant procedure. Additionally, or alternatively, the message includes an information element included in an *RRCReconfiguraiton* message.

[0224] According to some examples, method 1100 can include receiving a MAC PDU from the UE. In some embodiments, the MAC PDU can include a first MAC PDU including control signaling and a second MAC PDU including data signaling. According to some examples, the control signaling includes at least one of a MAC control element (CE), a Signaling Radio Bearer (SRB), or a Data Radio Bearer (DRB) with the highest CACP and the data signaling includes a Data Radio Bearer (DRB) not having the highest CACP.

[0225] 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

[0226] Example A01 includes a method of configuring a channel access priority class (CAPC).

[0227] Example A02 includes the method of example A01 and/or some other example(s) herein, wherein the CAPC is to be used for a multiplexed MAC SDU and is controlled by an IE from RRC configuration.

[0228] Example A03 includes the method of example A02 and/or some other example(s) herein, wherein the CAPC to use can be the highest priority or the lowest priority depends on the RRC configuration.

[0229] Example A04 may include the method of example A03 and/or some other example(s) herein, wherein configured grant timer continue after restarting of configured grant retransmission timer

[0230] Example A05 includes a method of separating control signaling (e.g., SRB and/or MAC CE) into a different MAC SDU than data from DRB(s).

[0231] Example A06 includes the method of example A05 and/or some other example(s) herein, wherein the MAC SDU that carries the control signal use a different CAPC than the one use for the MAC SDU that encapsulate the data from the DRB(s).

[0232] Example A07 includes an interworking method of configured grant timer (configuredGrantTimer) and configured grant retransmission timer (CGretransmission).

[0233] Example A08 includes the method of example A07 and/or some other example(s) herein, wherein the configured grant timer and configured grant retransmission timer starts at the same time.

[0234] Example A09 includes the method of example A08 and/or some other example(s) herein, wherein, when configured grant timer expires, the configured grant retransmission HARQ process stop.

[0235] Example B01 includes a method comprising: determining or causing to determine whether to use a highest or lowest Channel Access Priority Class (CAPC) based on a received configuration; selecting or causing to select, when the configuration indicates to use the lowest CAPC, a CAPC based on a lowest CAPC of one or more Media Access Control (MAC) Service Data Units (SDUs) that are multiplexed in a MAC Protocol Data Unit (PDU) for an uplink (UL) transmission (Tx); and selecting or causing to select, when the configuration indicates to use the highest CAPC, a CAPC highest CAPC of the MAC SDUs that are multiplexed in a MAC PDU for the UL Tx.

[0236] Example B02 includes the method of example B01 and/or some other examples herein, wherein the UL Tx corresponds to a configured grant and a dynamic grant.

[0237] Example B03 includes the method of example B02 and/or some other examples herein, further comprising: performing or causing to perform a Logical Channel Prioritization (LCP) procedure according to a predefined prioritization for both the configured grant and the dynamic grant.

[0238] Example B04 includes the method of example B03 and/or some other examples herein, wherein the predefined prioritization includes, in order from a highest priority to a lowest priority, C-RNTI MAC CE or data from UL-CCCH; Configured Grant Confirmation MAC CE; MAC CE for BSR, with exception of BSR included for padding; Single Entry PHR MAC CE or Multiple Entry PHR MAC CE; data from any Logical Channel, except data from UL-CCCH; MAC CE for Recommended bit rate query; and MAC CE for BSR included for padding.

[0239] Example B05 includes the method of examples B03-B04 and/or some other examples herein, wherein a CAPC for the dynamic grant is assigned via the configured grant, wherein a CAPC for configured grant is assigned to each logical channel via the received configuration.

[0240] Example B06 includes the method of examples B03-B04 and/or some other examples herein, further comprising: multiplexing or causing to multiplex, by a MAC entity, control signalling into a first MAC PDU; multiplexing or causing to multiplex, by the MAC entity, data signalling into a second MAC PDU; transmitting or causing to transmit the first MAC PDU using the dynamic grant; and transmitting or causing to transmit the second MAC PDU using the configured grant.

[0241] Example B07 includes the method of example B06 and/or some other examples herein, wherein the control signalling includes one or more MAC CEs, one or more SRBs, and/or DRBs with a highest CAPC; and the data signalling includes one or more DRBs not having a highest CAPC.

[0242] Example B08 includes the method of examples B03-B04 and/or some other examples herein, further comprising: multiplexing or causing to multiplex, by a MAC entity, one or more SRBs and/or one or more MAC CEs into a MAC PDU when SRB and/or MAC CE data is available at a corresponding PDCP entity or corresponding RLC entity and/or when a high priority CAPC MAC CE is triggered; and transmitting or causing to transmit the MAC PDU using the configured grant.

[0243] Example B09 includes the method of example B08 and/or some other examples herein, further comprising: multiplexing or causing to multiplex, by the MAC entity, data signaling DRBs into another MAC PDU according to a logical channel priority when the data signaling DRBs are available on the corresponding PDCP entity or the corresponding RLC entity and SRB or MAC CE data is not available; and transmitting or causing to transmit the other MAC PDU using the configured grant.

[0244] Example B10 includes the method of examples B02-B09 and/or some other examples herein, further comprising: starting or causing to start a configured grant timer (*configuredGrantTimer*) when data is transmitted using resource of the configured grant; and overwritting or causing to overwrite a MAC PDU in a HARQ buffer of a corresponding HARQ process with a new UL Tx corresponding to the configured grant or the dynamic grant when the *configuredGrantTimer* expires.

[0245] Example B11 includes the method of examples B02-B10 and/or some other examples herein, further comprising: starting or causing to start a configured grant retransmission timer (*CGretransmission* timer) when data is transmitted; and retransmitting or causing to retransmit the data upon expiration of the *CGretransmission* timer.

[0246] Example B12 includes the method of examples B10-B11 and/or some other examples herein, further comprising: starting or causing to start the *configuredGrantTimer* and the *CGretransmission* timer at a same time.

[0247] Example B13 includes the method of example B12 and/or some other examples herein, further comprising: restarting or causing to restart the *configuredGrantTimer* and the *CGretransmission* timer at a same time.

[0248] Example B14 includes the method of example B12 and/or some other examples herein, further comprising: only restarting or only causing to restart the *CGretransmission* timer when the *CGretransmission* timer expires; allowing or causing to allow the *configuredGrantTimer* to continue to run to allow X number of configured grant retransmissions; and when the *configuredGrantTimer* expires, stopping or causing to stop retransmission of a current HARQ process on the configured grant to allows the current HARQ process to be used for a new transmission.

[0249] Example B15 includes the method of examples B01-B14 and/or some other examples herein, wherein the method is to be performed by a user equipment (UE).

[0250] 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 A01-A09, B01-B15, or any other method or process described herein.

[0251] 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 A01-A09, B01-B15, or any other method or process described herein.

[0252] 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 A01-A09, B01-B15, or any other method or process described herein.

[0253] Example Z04 may include a method, technique, or process as described in or related to any of examples A01-A09, B01-B15, or portions or parts thereof.

[0254] 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 A01-A09, B01-B15, or portions thereof.

[0255] Example Z06 may include a signal as described in or related to any of examples A01-A09, B01-B15, or portions or parts thereof.

[0256] Example Z07 may include a datagram, packet, frame, segment, protocol data unit (PDU), or message as described in or related to any of examples A01-A09, B01-B15, or portions or parts thereof, or otherwise described in the present disclosure.

[0257] Example Z08 may include a signal encoded with data as described in or related to any of examples A01-A09, B01-B15, or portions or parts thereof, or otherwise described in the present disclosure.

[0258] Example Z09 may include a signal encoded with a datagram, packet, frame, segment, protocol data unit (PDU), or message as described in or related to any of examples A01-A09, B01-B15, or portions or parts thereof, or otherwise described in the present disclosure.

[0259] Example Z10 may include an electromagnetic signal carrying computer-readable instructions, wherein execution of the computer-readable instructions by one or more processors is to cause the one or more processors to perform the method, techniques, or process as described in or related to any of examples A01-A09, B01-B15, or portions thereof.

[0260] Example Z11 may include a computer program comprising instructions, wherein execution of the program by a processing element is to cause the processing element to carry out the method, techniques, or process as described in or related to any of examples A01-A09, B01-B15, or portions thereof.

[0261] Example Z12 may include a signal in a wireless network as shown and described herein.

[0262] Example Z13 may include a method of communicating in a wireless network as shown and described herein.

[0263] Example Z14 may include a system for providing wireless communication as shown and described herein.

[0264] Example Z15 may include a device for providing wireless communication as shown and described herein.

[0265] 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

[0266] For the purposes of the present document, the following abbreviations may apply to the examples and embodiments discussed herein, but are not meant to be limiting.

[0267]	3GPP	Third Generation Partnership Project
[0268]	4G	Fourth Generation
[0269]	5G	Fifth Generation
[0270]	5GC	5G Core network
[0271]	ACK	Acknowledgement
[0272]	AF	Application Function
[0273]	AM	Acknowledged Mode
[0274]	AMBR	Aggregate Maximum Bit Rate
[0275]	AMF	Access and Mobility Management Function
[0276]	AN	Access Network
[0277]	ANR	Automatic Neighbour Relation
[0278]	AP	Application Protocol, Antenna Port, Access Point
[0279]	API	Application Programming Interface
[0280]	APN	Access Point Name
[0281]	ARP	Allocation and Retention Priority
[0282]	ARQ	Automatic Repeat Request
[0283]	AS	Access Stratum
[0284]	ASN.1	Abstract Syntax Notation One
[0285]	AUL	Autonomous UL
[0286]	AUSF	Authentication Server Function
[0287]	AWGN	Additive White Gaussian Noise
[0288]	BCH	Broadcast Channel
[0289]	BER	Bit Error Ratio
[0290]	BFD	Beam Failure Detection
[0291]	BLER	Block Error Rate
[0292]	BPSK	Binary Phase Shift Keying
[0293]	BRAS	Broadband Remote Access Server

[0294]	BSS	Business Support System
[0295]	BS	Base Station
[0296]	BSR	Buffer Status Report
[0297]	BW	Bandwidth
[0298]	BWP	Bandwidth Part
[0299]	C-RNTI	Cell Radio Network Temporary Identity
[0300]	CA	Carrier Aggregation, Certification Authority
[0301]	CAPC	Channel Access Priority Class
[0302]	CAPEX	CAPital EXpenditure
[0303]	CBRA	Contention Based Random Access
[0304]	CC	Component Carrier, Country Code, Cryptographic Checksum
[0305]	CCA	Clear Channel Assessment
[0306]	CCE	Control Channel Element
[0307]	CCCH	Common Control Channel
[0308]	CE	Coverage Enhancement
[0309]	CDM	Content Delivery Network
[0310]	CDMA	Code-Division Multiple Access
[0311]	CFRA	Contention Free Random Access
[0312]	CG	Cell Group
[0313]	CI	Cell Identity
[0314]	CID	Cell-ID (e.g., positioning method)
[0315]	CIM	Common Information Model
[0316]	CIR	Carrier to Interference Ratio
[0317]	CK	Cipher Key
[0318]	CM	Connection Management, Conditional Mandatory
[0319]	CMAS	Commercial Mobile Alert Service
[0320]	CMD	Command
[0321]	CMS	Cloud Management System
[0322]	CO	Conditional Optional
[0323]	CoMP	Coordinated Multi-Point
[0324]	CORESET	Control Resource Set
[0325]	COTS	Commercial Off-The-Shelf
[0326]	CP	Control Plane, Cyclic Prefix, Connection Point

[0327]	CPD	Connection Point Descriptor
[0328]	CPE	Customer Premise Equipment
[0329]	CPICH	Common Pilot Channel
[0330]	CQI	Channel Quality Indicator
[0331]	CPU	CSI processing unit, Central Processing Unit
[0332]	C/R	Command/Response field bit
[0333]	CRAN	Cloud Radio Access Network, Cloud RAN
[0334]	CRB	Common Resource Block
[0335]	CRC	Cyclic Redundancy Check
[0336]	CRI	Channel-State Information Resource Indicator, CSI-RS Resource Indicator
[0337]	C-RNTI	Cell RNTI
[0338]	CS	Circuit Switched
[0339]	CSAR	Cloud Service Archive
[0340]	CSI	Channel-State Information
[0341]	CSI-IM	CSI Interference Measurement
[0342]	CSI-RS	CSI Reference Signal
[0343]	CSI-RSRP	CSI reference signal received power
[0344]	CSI-RSRQ	CSI reference signal received quality
[0345]	CSI-SINR	CSI signal-to-noise and interference ratio
[0346]	CSMA	Carrier Sense Multiple Access
[0347]	CSMA/CA	CSMA with collision avoidance
[0348]	CSS	Common Search Space, Cell-specific Search Space
[0349]	CTS	Clear-to-Send
[0350]	CW	Codeword
[0351]	CWS	Contention Window Size
[0352]	D2D	Device-to-Device
[0353]	DC	Dual Connectivity, Direct Current
[0354]	DCI	Downlink Control Information
[0355]	DF	Deployment Flavour
[0356]	DL	Downlink
[0357]	DMTF	Distributed Management Task Force
[0358]	DPDK	Data Plane Development Kit

[0359]	DM-RS, DMRS	Demodulation Reference Signal
[0360]	DN	Data network
[0361]	DRB	Data Radio Bearer
[0362]	DRS	Discovery Reference Signal
[0363]	DRX	Discontinuous Reception
[0364]	DSL	Domain Specific Language. Digital Subscriber Line
[0365]	DSLAM	DSL Access Multiplexer
[0366]	DwPTS	Downlink Pilot Time Slot
[0367]	E-LAN	Ethernet Local Area Network
[0368]	E2E	End-to-End
[0369]	ECCA	extended clear channel assessment, extended CCA
[0370]	ECCE	Enhanced Control Channel Element, Enhanced CCE
[0371]	ED	Energy Detection
[0372]	EDGE	Enhanced Datarates for GSM Evolution (GSM Evolution)
[0373]	EGMF	Exposure Governance Management Function
[0374]	EGPRS	Enhanced GPRS
[0375]	EIR	Equipment Identity Register
[0376]	eLAA	enhanced Licensed Assisted Access, enhanced LAA
[0377]	EM	Element Manager
[0378]	eMBB	Enhanced Mobile Broadband
[0379]	EMS	Element Management System
[0380]	eNB	evolved NodeB, E-UTRAN Node B
[0381]	EN-DC	E-UTRA-NR Dual Connectivity
[0382]	EPC	Evolved Packet Core
[0383]	EPDCCH	enhanced PDCCH, enhanced Physical Downlink Control Cannel
[0384]	EPRE	Energy per resource element
[0385]	EPS	Evolved Packet System
[0386]	EREG	enhanced REG, enhanced resource element groups
[0387]	ETSI	European Telecommunications Standards Institute
[0388]	ETWS	Earthquake and Tsunami Warning System
[0389]	eUICC	embedded UICC, embedded Universal Integrated Circuit Card
[0390]	E-UTRA	Evolved UTRA

[0391]	E-UTRAN	Evolved UTRAN
[0392]	EV2X	Enhanced V2X
[0393]	F1AP	F1 Application Protocol
[0394]	F1-C	F1 Control plane interface
[0395]	F1-U	F1 User plane interface
[0396]	FACCH	Fast Associated Control CHannel
[0397]	FACCH/F	Fast Associated Control Channel/Full rate
[0398]	FACCH/H	Fast Associated Control Channel/Half rate
[0399]	FACH	Forward Access Channel
[0400]	FAUSCH	Fast Uplink Signalling Channel
[0401]	FB	Functional Block
[0402]	FBI	Feedback Information
[0403]	FCC	Federal Communications Commission
[0404]	FCCH	Frequency Correction CHannel
[0405]	FDD	Frequency Division Duplex
[0406]	FDM	Frequency Division Multiplex
[0407]	FDMA	Frequency Division Multiple Access
[0408]	FE	Front End
[0409]	FEC	Forward Error Correction
[0410]	FFS	For Further Study
[0411]	FFT	Fast Fourier Transformation
[0412]	feLAA	further enhanced Licensed Assisted Access, further enhanced LAA
[0413]	FN	Frame Number
[0414]	FPGA	Field-Programmable Gate Array
[0415]	FR	Frequency Range
[0416]	G-RNTI	GERAN Radio Network Temporary Identity
[0417]	GERAN	GSM EDGE RAN, GSM EDGE Radio Access Network
[0418]	GGSN	Gateway GPRS Support Node
[0419]	GLONASS	GLObal'naya NAvigatsionnaya Sputnikovaya Sistema (Engl.: Global Navigation Satellite System)
[0420]	gNB	Next Generation NodeB
[0421]	gNB-CU	gNB-centralized unit, Next Generation NodeB centralized unit

[0422]	gNB-DU	gNB-distributed unit, Next Generation NodeB distributed unit
[0423]	GNSS	Global Navigation Satellite System
[0424]	GPRS	General Packet Radio Service
[0425]	GSM	Global System for Mobile Communications, Groupe Spécial Mobile
[0426]	GTP	GPRS Tunneling Protocol
[0427]	GTP-U	GPRS Tunnelling Protocol for User Plane
[0428]	GTS	Go To Sleep Signal (related to WUS)
[0429]	GUMMEI	Globally Unique MME Identifier
[0430]	GUTI	Globally Unique Temporary UE Identity
[0431]	HARQ	Hybrid ARQ, Hybrid Automatic Repeat Request
[0432]	HANDO, HO	Handover
[0433]	HFN	HyperFrame Number
[0434]	HHO	Hard Handover
[0435]	HLR	Home Location Register
[0436]	HN	Home Network
[0437]	HO	Handover
[0438]	HPLMN	Home Public Land Mobile Network
[0439]	HSDPA	High Speed Downlink Packet Access
[0440]	HSN	Hopping Sequence Number
[0441]	HSPA	High Speed Packet Access
[0442]	HSS	Home Subscriber Server
[0443]	HSUPA	High Speed Uplink Packet Access
[0444]	HTTP	Hyper Text Transfer Protocol
[0445]	HTTPS	Hyper Text Transfer Protocol Secure (https is http/1.1 over SSL, i.e. port 443)
[0446]	I-Block	Information Block
[0447]	ICCID	Integrated Circuit Card Identification
[0448]	ICIC	Inter-Cell Interference Coordination
[0449]	ID	Identity, identifier
[0450]	IDFT	Inverse Discrete Fourier Transform
[0451]	IE	Information element
[0452]	IBE	In-Band Emission

[0453]	IEEE	Institute of Electrical and Electronics Engineers
[0454]	IEI	Information Element Identifier
[0455]	IEIDL	Information Element Identifier Data Length
[0456]	IETF	Internet Engineering Task Force
[0457]	IF	Infrastructure
[0458]	IM	Interference Measurement, Intermodulation, IP Multimedia
[0459]	IMC	IMS Credentials
[0460]	IMEI	International Mobile Equipment Identity
[0461]	IMGI	International mobile group identity
[0462]	IMPI	IP Multimedia Private Identity
[0463]	IMPU	IP Multimedia PUblic identity
[0464]	IMS	IP Multimedia Subsystem
[0465]	IMSI	International Mobile Subscriber Identity
[0466]	IoT	Internet of Things
[0467]	IP	Internet Protocol
[0468]	Ipsec	IP Security, Internet Protocol Security
[0469]	IP-CAN	IP-Connectivity Access Network
[0470]	IP-M	IP Multicast
[0471]	IPv4	Internet Protocol Version 4
[0472]	IPv6	Internet Protocol Version 6
[0473]	IR	Infrared
[0474]	IS	In Sync
[0475]	IRP	Integration Reference Point
[0476]	ISDN	Integrated Services Digital Network
[0477]	ISIM	IM Services Identity Module
[0478]	ISO	International Organisation for Standardisation
[0479]	ISP	Internet Service Provider
[0480]	IWF	Interworking-Function
[0481]	I-WLAN	Interworking WLAN
[0482]	K	Constraint length of the convolutional code, USIM Individual key
[0483]	kB	Kilobyte (1000 bytes)
[0484]	kbps	kilo-bits per second

[0485]	Kc	Ciphering key
[0486]	Ki	Individual subscriber authentication key
[0487]	KPI	Key Performance Indicator
[0488]	KQI	Key Quality Indicator
[0489]	KSI	Key Set Identifier
[0490]	ksps	kilo-symbols per second
[0491]	KVM	Kernel Virtual Machine
[0492]	L1	Layer 1 (physical layer)
[0493]	L1-RSRP	Layer 1 reference signal received power
[0494]	L2	Layer 2 (data link layer)
[0495]	L3	Layer 3 (network layer)
[0496]	LAA	Licensed Assisted Access
[0497]	LAN	Local Area Network
[0498]	LBT	Listen Before Talk
[0499]	LCM	LifeCycle Management
[0500]	LCP	Logical Channel Prioritization
[0501]	LCR	Low Chip Rate
[0502]	LCS	Location Services
[0503]	LCID	Logical Channel ID
[0504]	LI	Layer Indicator
[0505]	LLC	Logical Link Control, Low Layer Compatibility
[0506]	LPLMN	Local PLMN
[0507]	LPP	LTE Positioning Protocol
[0508]	LSB	Least Significant Bit
[0509]	LTE	Long Term Evolution
[0510]	LWA	LTE-WLAN aggregation
[0511]	LWIP	LTE/WLAN Radio Level Integration with IPsec Tunnel
[0512]	LTE	Long Term Evolution
[0513]	M2M	Machine-to-Machine
[0514]	MAC	Medium Access Control (protocol layering context)
[0515]	MAC	Message authentication code (security/encryption context)
[0516]	MAC-A	MAC used for authentication and key agreement (TSG T WG3 context)

[0517] MAC-I MAC used for data integrity of signalling messages (TSG T WG3 context)

[0518] MANO Management and Orchestration

[0519] MBMS Multimedia Broadcast and Multicast Service

[0520] MBSFN Multimedia Broadcast multicast service Single Frequency Network

[0521] MCC Mobile Country Code

[0522] MCG Master Cell Group

[0523] MCOT Maximum Channel Occupancy Time

[0524] MCS Modulation and coding scheme

[0525] MDAF Management Data Analytics Function

[0526] MDAS Management Data Analytics Service

[0527] MDT Minimization of Drive Tests

[0528] ME Mobile Equipment

[0529] MeNB master eNB

[0530] MER Message Error Ratio

[0531] MGL Measurement Gap Length

[0532] MGRP Measurement Gap Repetition Period

[0533] MIB Master Information Block, Management Information Base

[0534] MIMO Multiple Input Multiple Output

[0535] MLC Mobile Location Centre

[0536] MM Mobility Management

[0537] MME Mobility Management Entity

[0538] MN Master Node

[0539] MO Measurement Object, Mobile Originated

[0540] MPBCH MTC Physical Broadcast CHannel

[0541] MPDCCH MTC Physical Downlink Control CHannel

[0542] MPDSCH MTC Physical Downlink Shared CHannel

[0543] MPRACH MTC Physical Random Access CHannel

[0544] MPUSCH MTC Physical Uplink Shared Channel

[0545] MPLS MultiProtocol Label Switching

[0546] MS Mobile Station

[0547] MSB Most Significant Bit

[0548] MSC Mobile Switching Centre

[0549] MSI Minimum System Information, MCH Scheduling Information

[0550] MSID Mobile Station Identifier

[0551] MSIN Mobile Station Identification Number

[0552] MSISDN Mobile Subscriber ISDN Number

[0553] MT Mobile Terminated, Mobile Termination

[0554] MTC Machine-Type Communications

[0555] mMTC massive MTC, massive Machine-Type Communications

[0556] MU-MIMO Multi User MIMO

[0557] MWUS MTC wake-up signal, MTC WUS

[0558] NACK Negative Acknowledgement

[0559] NAI Network Access Identifier

[0560] NAS Non-Access Stratum, Non-Access Stratum layer

[0561] NCT Network Connectivity Topology

[0562] NEC Network Capability Exposure

[0563] NE-DC NR-E-UTRA Dual Connectivity

[0564] NEF Network Exposure Function

[0565] NF Network Function

[0566] NFP Network Forwarding Path

[0567] NFPD Network Forwarding Path Descriptor

[0568] NFV Network Functions Virtualization

[0569] NFVI NFV Infrastructure

[0570] NFVO NFV Orchestrator

[0571] NG Next Generation, Next Gen

[0572] NGEN-DC NG-RAN E-UTRA-NR Dual Connectivity

[0573] NM Network Manager

[0574] NMS Network Management System

[0575] N-PoP Network Point of Presence

[0576] NMIB, N-MIB Narrowband MIB

[0577] NPBCH Narrowband Physical Broadcast CHannel

[0578] NPDCCH Narrowband Physical Downlink Control CHannel

[0579] NPDSCH Narrowband Physical Downlink Shared CHannel

[0580] NPRACH Narrowband Physical Random Access CHannel

[0581]	NPUSCH	Narrowband Physical Uplink Shared CHannel
[0582]	NPSS	Narrowband Primary Synchronization Signal
[0583]	NSSS	Narrowband Secondary Synchronization Signal
[0584]	NR	New Radio, Neighbour Relation
[0585]	NRF	NF Repository Function
[0586]	NRS	Narrowband Reference Signal
[0587]	NS	Network Service
[0588]	NSA	Non-Standalone operation mode
[0589]	NSD	Network Service Descriptor
[0590]	NSR	Network Service Record
[0591]	NSSAI	`Network Slice Selection Assistance Information
[0592]	S-NNSAI	Single-NSSAI
[0593]	NSSF	Network Slice Selection Function
[0594]	NW	Network
[0595]	NWUS	Narrowband wake-up signal, Narrowband WUS
[0596]	NZP	Non-Zero Power
[0597]	O&M	Operation and Maintenance
[0598]	ODU2	Optical channel Data Unit - type 2
[0599]	OFDM	Orthogonal Frequency Division Multiplexing
[0600]	OFDMA	Orthogonal Frequency Division Multiple Access
[0601]	OOB	Out-of-band
[0602]	OOS	Out of Sync
[0603]	OPEX	OPerating EXpense
[0604]	OSI	Other System Information
[0605]	OSS	Operations Support System
[0606]	OTA	over-the-air
[0607]	PAPR	Peak-to-Average Power Ratio
[0608]	PAR	Peak to Average Ratio
[0609]	PBCH	Physical Broadcast Channel
[0610]	PC	Power Control, Personal Computer
[0611]	PCC	Primary Component Carrier, Primary CC
[0612]	PCell	Primary Cell
[0613]	PCI	Physical Cell ID, Physical Cell Identity

[0614]	PCEF	Policy and Charging Enforcement Function
[0615]	PCF	Policy Control Function
[0616]	PCRF	Policy Control and Charging Rules Function
[0617]	PDCP	Packet Data Convergence Protocol, Packet Data Convergence Protocol layer
[0618]	PDCCH	Physical Downlink Control Channel
[0619]	PDCP	Packet Data Convergence Protocol
[0620]	PDN	Packet Data Network, Public Data Network
[0621]	PDSCH	Physical Downlink Shared Channel
[0622]	PDU	Protocol Data Unit
[0623]	PEI	Permanent Equipment Identifiers
[0624]	PFD	Packet Flow Description
[0625]	P-GW	PDN Gateway
[0626]	PHICH	Physical hybrid-ARQ indicator channel
[0627]	PHY	Physical layer
[0628]	PLMN	Public Land Mobile Network
[0629]	PIN	Personal Identification Number
[0630]	PM	Performance Measurement
[0631]	PMI	Precoding Matrix Indicator
[0632]	PNF	Physical Network Function
[0633]	PNFD	Physical Network Function Descriptor
[0634]	PNFR	Physical Network Function Record
[0635]	POC	PTT over Cellular
[0636]	PP, PTP	Point-to-Point
[0637]	PPP	Point-to-Point Protocol
[0638]	PRACH	Physical RACH
[0639]	PRB	Physical resource block
[0640]	PRG	Physical resource block group
[0641]	ProSe	Proximity Services, Proximity-Based Service
[0642]	PRS	Positioning Reference Signal
[0643]	PRR	Packet Reception Radio
[0644]	PS	Packet Services
[0645]	PSBCH	Physical Sidelink Broadcast Channel

[0646]	PSDCH	Physical Sidelink Downlink Channel
[0647]	PSCCH	Physical Sidelink Control Channel
[0648]	PSSCH	Physical Sidelink Shared Channel
[0649]	PSCell	Primary SCell
[0650]	PSS	Primary Synchronization Signal
[0651]	PSTN	Public Switched Telephone Network
[0652]	PT-RS	Phase-tracking reference signal
[0653]	PTT	Push-to-Talk
[0654]	PUCCH	Physical Uplink Control Channel
[0655]	PUSCH	Physical Uplink Shared Channel
[0656]	QAM	Quadrature Amplitude Modulation
[0657]	QCI	QoS class of identifier
[0658]	QCL	Quasi co-location
[0659]	QFI	QoS Flow ID, QoS Flow Identifier
[0660]	QoS	Quality of Service
[0661]	QPSK	Quadrature (Quaternary) Phase Shift Keying
[0662]	QZSS	Quasi-Zenith Satellite System
[0663]	RA-RNTI	Random Access RNTI
[0664]	RAB	Radio Access Bearer, Random Access Burst
[0665]	RACH	Random Access Channel
[0666]	RADIUS	Remote Authentication Dial In User Service
[0667]	RAN	Radio Access Network
[0668]	RAND	RANDom number (used for authentication)
[0669]	RAR	Random Access Response
[0670]	RAT	Radio Access Technology
[0671]	RAU	Routing Area Update
[0672]	RB	Resource block, Radio Bearer
[0673]	RBG	Resource block group
[0674]	REG	Resource Element Group
[0675]	Rel	Release
[0676]	REQ	REQuest
[0677]	RF	Radio Frequency
[0678]	RI	Rank Indicator

[0679]	RIV	Resource indicator value
[0680]	RL	Radio Link
[0681]	RLC	Radio Link Control, Radio Link Control layer
[0682]	RLC AM	RLC Acknowledged Mode
[0683]	RLC UM	RLC Unacknowledged Mode
[0684]	RLF	Radio Link Failure
[0685]	RLM	Radio Link Monitoring
[0686]	RLM-RS	Reference Signal for RLM
[0687]	RM	Registration Management
[0688]	RMC	Reference Measurement Channel
[0689]	RMSI	Remaining MSI, Remaining Minimum System Information
[0690]	RN	Relay Node
[0691]	RNC	Radio Network Controller
[0692]	RNL	Radio Network Layer
[0693]	RNTI	Radio Network Temporary Identifier
[0694]	ROHC	RObust Header Compression
[0695]	RRC	Radio Resource Control, Radio Resource Control layer
[0696]	RRM	Radio Resource Management
[0697]	RS	Reference Signal
[0698]	RSRP	Reference Signal Received Power
[0699]	RSRQ	Reference Signal Received Quality
[0700]	RSSI	Received Signal Strength Indicator
[0701]	RSU	Road Side Unit
[0702]	RSTD	Reference Signal Time difference
[0703]	RTP	Real Time Protocol
[0704]	RTS	Ready-To-Send
[0705]	RTT	Round Trip Time
[0706]	Rx	Reception, Receiving, Receiver
[0707]	S1AP	S1 Application Protocol
[0708]	S1-MME	S1 for the control plane
[0709]	S1-U	S1 for the user plane
[0710]	S-GW	Serving Gateway
[0711]	S-RNTI	SRNC Radio Network Temporary Identity

[0712]	S-TMSI	SAE Temporary Mobile Station Identifier
[0713]	SA	Standalone operation mode
[0714]	SAE	System Architecture Evolution
[0715]	SAP	Service Access Point
[0716]	SAPD	Service Access Point Descriptor
[0717]	SAPI	Service Access Point Identifier
[0718]	SCC	Secondary Component Carrier, Secondary CC
[0719]	SCell	Secondary Cell
[0720]	SC-FDMA	Single Carrier Frequency Division Multiple Access
[0721]	SCG	Secondary Cell Group
[0722]	SCM	Security Context Management
[0723]	SCS	Subcarrier Spacing
[0724]	SCTP	Stream Control Transmission Protocol
[0725]	SDAP	Service Data Adaptation Protocol, Service Data Adaptation Protocol layer
[0726]	SDL	Supplementary Downlink
[0727]	SDNF	Structured Data Storage Network Function
[0728]	SDP	Session Description Protocol
[0729]	SDSF	Structured Data Storage Function
[0730]	SDU	Service Data Unit
[0731]	SEAF	Security Anchor Function
[0732]	SeNB	secondary eNB
[0733]	SEPP	Security Edge Protection Proxy
[0734]	SFI	Slot format indication
[0735]	SFTD	Space-Frequency Time Diversity, SFN and frame timing difference
[0736]	SFN	System Frame Number
[0737]	SgNB	Secondary gNB
[0738]	SGSN	Serving GPRS Support Node
[0739]	S-GW	Serving Gateway
[0740]	SI	System Information
[0741]	SI-RNTI	System Information RNTI
[0742]	SIB	System Information Block

[0743]	SIM	Subscriber Identity Module
[0744]	SIP	Session Initiated Protocol
[0745]	SiP	System in Package
[0746]	SL	Sidelink
[0747]	SLA	Service Level Agreement
[0748]	SM	Session Management
[0749]	SMF	Session Management Function
[0750]	SMS	Short Message Service
[0751]	SMSF	SMS Function
[0752]	SMTC	SSB-based Measurement Timing Configuration
[0753]	SN	Secondary Node, Sequence Number
[0754]	SoC	System on Chip
[0755]	SON	Self-Organizing Network
[0756]	SpCell	Special Cell
[0757]	SP-CSI-RNTI	Semi-Persistent CSI RNTI
[0758]	SPS	Semi-Persistent Scheduling
[0759]	SQN	Sequence number
[0760]	SR	Scheduling Request
[0761]	SRB	Signalling Radio Bearer
[0762]	SRS	Sounding Reference Signal
[0763]	SS	Synchronization Signal
[0764]	SSB	Synchronization Signal Block, SS/PBCH Block
[0765]	SSBRI	SS/PBCH Block Resource Indicator, Synchronization Signal Block Resource Indicator
[0766]	SSC	Session and Service Continuity
[0767]	SS-RSRP	Synchronization Signal based Reference Signal Received Power
[0768]	SS-RSRQ	Synchronization Signal based Reference Signal Received Quality
[0769]	SS-SINR	Synchronization Signal based Signal to Noise and Interference Ratio
[0770]	SSS	Secondary Synchronization Signal
[0771]	SSSG	Search Space Set Group

[0772]	SSSIF	Search Space Set Indicator
[0773]	SST	Slice/Service Types
[0774]	SU-MIMO	Single User MIMO
[0775]	SUL	Supplementary Uplink
[0776]	TA	Timing Advance, Tracking Area
[0777]	TAC	Tracking Area Code
[0778]	TAG	Timing Advance Group
[0779]	TAU	Tracking Area Update
[0780]	TB	Transport Block
[0781]	TBS	Transport Block Size
[0782]	TBD	To Be Defined
[0783]	TCI	Transmission Configuration Indicator
[0784]	TCP	Transmission Communication Protocol
[0785]	TDD	Time Division Duplex
[0786]	TDM	Time Division Multiplexing
[0787]	TDMA	Time Division Multiple Access
[0788]	TE	Terminal Equipment
[0789]	TEID	Tunnel End Point Identifier
[0790]	TFT	Traffic Flow Template
[0791]	TMSI	Temporary Mobile Subscriber Identity
[0792]	TNL	Transport Network Layer
[0793]	TPC	Transmit Power Control
[0794]	TPMI	Transmitted Precoding Matrix Indicator
[0795]	TR	Technical Report
[0796]	TRP, TRxP	Transmission Reception Point
[0797]	TRS	Tracking Reference Signal
[0798]	TRx	Transceiver
[0799]	TS	Technical Specifications, Technical Standard
[0800]	TTI	Transmission Time Interval
[0801]	Tx	Transmission, Transmitting, Transmitter
[0802]	U-RNTI	UTRAN Radio Network Temporary Identity
[0803]	UART	Universal Asynchronous Receiver and Transmitter
[0804]	UCI	Uplink Control Information

[0805]	UE	User Equipment
[0806]	UDM	Unified Data Management
[0807]	UDP	User Datagram Protocol
[0808]	UDSF	Unstructured Data Storage Network Function
[0809]	UICC	Universal Integrated Circuit Card
[0810]	UL	Uplink
[0811]	UM	Unacknowledged Mode
[0812]	UML	Unified Modelling Language
[0813]	UMTS	Universal Mobile Telecommunications System
[0814]	UP	User Plane
[0815]	UPF	User Plane Function
[0816]	URI	Uniform Resource Identifier
[0817]	URL	Uniform Resource Locator
[0818]	URLLC	Ultra-Reliable and Low Latency
[0819]	USB	Universal Serial Bus
[0820]	USIM	Universal Subscriber Identity Module
[0821]	USS	UE-specific search space
[0822]	UTRA	UMTS Terrestrial Radio Access
[0823]	UTRAN	Universal Terrestrial Radio Access Network
[0824]	UwPTS	Uplink Pilot Time Slot
[0825]	V2I	Vehicle-to-Infrastruction
[0826]	V2P	Vehicle-to-Pedestrian
[0827]	V2V	Vehicle-to-Vehicle
[0828]	V2X	Vehicle-to-everything
[0829]	VIM	Virtualized Infrastructure Manager
[0830]	VL	Virtual Link,
[0831]	VLAN	Virtual LAN, Virtual Local Area Network
[0832]	VM	Virtual Machine
[0833]	VNF	Virtualized Network Function
[0834]	VNFFG	VNF Forwarding Graph
[0835]	VNFFGD	VNF Forwarding Graph Descriptor
[0836]	VNFM	VNF Manager
[0837]	VoIP	Voice-over-IP, Voice-over-Internet Protocol

[0838]	VPLMN	Visited Public Land Mobile Network
[0839]	VPN	Virtual Private Network
[0840]	VRB	Virtual Resource Block
[0841]	WiMAX	Worldwide Interoperability for Microwave Access
[0842]	WLAN	Wireless Local Area Network
[0843]	WMAN	Wireless Metropolitan Area Network
[0844]	WPAN	Wireless Personal Area Network
[0845]	X2-C	X2-Control plane
[0846]	X2-U	X2-User plane
[0847]	XML	eXtensible Markup Language
[0848]	XRES	EXpected user RESponse
[0849]	XOR	eXclusive OR
[0850]	ZC	Zadoff-Chu
[0851]	ZP	Zero Power

Terminology

[0852] For the purposes of the present document, the following terms and definitions are applicable to the examples and embodiments discussed herein, but are not meant to be limiting.

[0853] The term "circuitry" refers to a circuit or system of multiple circuits configured to perform a particular function in an electronic device. The circuit or system of circuits may be part of, or include one or more hardware components, such as 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 gate array (FPGA), programmable logic device (PLD), complex PLD (CPLD), high-capacity PLD (HCPLD), System-on-Chip (SoC), System-in-Package (SiP), Multi-Chip Package (MCP), digital signal processor (DSP), etc., that are configured to provide the described functionality. In addition, the term "circuitry" may also refer to a combination of one or more hardware elements with the program code used to carry out the functionality of that program code. Some types of circuitry may execute one or more software or firmware programs to provide at least some of the described functionality. Such a combination of hardware elements and program code may be referred to as a particular type of circuitry.

[0854] 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."

[0855] The term "memory" and/or "memory circuitry" as used herein refers to one or more hardware devices for storing data, including random access memory (RAM), magnetoresistive RAM (MRAM), phase change random access memory (PRAM), dynamic random access memory (DRAM) and/or synchronous dynamic random access memory (SDRAM), core memory, read only memory (ROM), magnetic disk storage mediums, optical storage mediums, flash memory devices or other machine readable mediums for storing data. The term "computer-readable medium" may include, but is not limited to, memory, portable or fixed storage devices, optical storage devices, and various other mediums capable of storing, containing or carrying instructions or data.

[0856] 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.

[0857] 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.

[0858] 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.

[0859] 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.

[0860] 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.

[0861] The term “element” refers to a unit that is indivisible at a given level of abstraction and has a clearly defined boundary, wherein an element may be any type of entity including, for example, one or more devices, systems, controllers, network elements, modules, etc., or combinations thereof.

[0862] The term “device” refers to a physical entity embedded inside, or attached to, another physical entity in its vicinity, with capabilities to convey digital information from or to that physical entity.

[0863] The term “entity” refers to a distinct component of an architecture or device, or information transferred as a payload.

[0864] The term “controller” refers to an element or entity that has the capability to affect a physical entity, such as by changing its state or causing the physical entity to move.

[0865] 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.

[0866] 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.

[0867] As used herein, the term “communication protocol” (either wired or wireless) refers to a set of standardized rules or instructions implemented by a communication device and/or system to communicate with other devices and/or systems, including instructions for packetizing/depacketizing data, modulating/demodulating signals, implementation of protocols stacks, and/or the like.

[0868] 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.

[0869] The terms “coupled,” “communicatively coupled,” along with derivatives thereof are used herein. The term “coupled” may mean two or more elements are in direct physical or electrical contact with one another, may mean that two or more elements indirectly contact each other but still cooperate or interact with each other, and/or may mean that one or more other elements are coupled or connected between the elements that are said to be coupled with each other. The term “directly coupled” may mean that two or more elements are in direct contact with one another. The term “communicatively coupled” may mean that two or more elements may be in contact with one another by a means of communication including through a wire or other interconnect connection, through a wireless communication channel or ink, and/or the like.

[0870] 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.

[0871] The term “admission control” refers to a validation process in communication systems where a check is performed before a connection is established to see if current resources are sufficient for the proposed connection.

[0872] The term “SMTC” refers to an SSB-based measurement timing configuration configured by *SSB-MeasurementTimingConfiguration*.

[0873] The term “SSB” refers to an SS/PBCH block.

[0874] 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.

[0875] 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.

[0876] The term “Secondary Cell” refers to a cell providing additional radio resources on top of a Special Cell for a UE configured with CA.

[0877] 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.

[0878] 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.

[0879] 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/.

[0880] 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.

[0881] As described above, aspects of the present technology may include the gathering and use of data available from various sources, e.g., to improve or enhance functionality. The present disclosure contemplates that in some instances, this gathered data may include personal information data that uniquely identifies or can be used to contact or locate a specific person. Such personal information data can include demographic data, location-based data, telephone numbers, email addresses, Twitter ID's, home addresses, data or records relating to a user’s health or level of fitness (e.g., vital signs measurements, medication information, exercise information), date of birth, or any other identifying or personal information. The present disclosure recognizes that the use of such personal information data, in the present technology, may be used to the benefit of users.

[0882] The present disclosure contemplates that the entities responsible for the collection, analysis, disclosure, transfer, storage, or other use of such personal information data will comply with well-established privacy policies and/or privacy practices. In particular, such entities should implement and consistently use privacy policies and practices that are generally recognized as meeting or exceeding industry or governmental requirements for maintaining personal information data private and secure. Such policies should be easily accessible by users, and should be updated as the collection and/or use of data changes. Personal information from users should be collected for legitimate and reasonable uses of the entity and not shared or sold outside of those legitimate uses. Further, such collection/sharing should only occur after receiving the informed consent of the users. Additionally, such entities should consider taking any needed steps for safeguarding and securing access to such personal information data and ensuring that others with access to the personal information data adhere to their privacy policies and procedures. Further, such entities can subject themselves to evaluation by third parties to certify their adherence to widely accepted privacy policies and practices. In addition, policies and practices should be adapted for the particular types of personal information data being collected and/or accessed and adapted to applicable laws and standards, including jurisdiction-specific considerations. For instance, in the US, collection of, or access to, certain health data may be governed by federal and/or state laws, such as the Health Insurance Portability and Accountability Act (HIPAA); whereas health data in other countries may be subject to other regulations and policies and should be handled accordingly. Hence different privacy practices should be maintained for different personal data types in each country.

[0883] Despite the foregoing, the present disclosure also contemplates embodiments in which users selectively block the use of, or access to, personal information data. That is, the present disclosure contemplates that hardware and/or software elements can be provided to prevent or block access to such personal information data. For example, the present technology may be configurable to allow users to selectively "opt in" or "opt out" of participation in the collection of personal information data, e.g., during registration for services or anytime thereafter. In addition to providing “opt in” and “opt out” options, the present disclosure contemplates providing notifications relating to the access or use of personal information. For instance, a user may be notified upon downloading an app that their personal information data will be accessed and then reminded again just before personal information data is accessed by the app.

[0884] Moreover, it is the intent of the present disclosure that personal information data should be managed and handled in a way to minimize risks of unintentional or unauthorized access or use. Risk can be minimized by limiting the collection of data and deleting data once it is no longer needed. In addition, and when applicable, including in certain health related applications, data de-identification can be used to protect a user’s privacy. De-identification may be facilitated, when appropriate, by removing specific identifiers (e.g., date of birth, etc.), controlling the amount or specificity of data stored (e.g., collecting location data a city level rather than at an address level), controlling how data is stored (e.g., aggregating data across users), and/or other methods.

[0885] Therefore, although the present disclosure may broadly cover use of personal information data to implement one or more various disclosed embodiments, the present disclosure also contemplates that the various embodiments can also be implemented without the need for accessing such personal information data. That is, the various embodiments of the present technology are not rendered inoperable due to the lack of all or a portion of such personal information data.

WHAT IS CLAIMED IS:

1. A user equipment (UE), comprising:

radio front end circuitry; and

processor circuitry, coupled to the radio front end circuitry, and configured to:

receive, using the radio front end circuitry, a message from a base station;

based on the received message, determine whether to use a lowest Channel Access Priority Class (CAPC) or a highest CAPC;

in response to the received message indicating to use the lowest CAPC, select a CAPC based on the lowest CAPC of one or more Media Access Control (MAC) Service Data Units (SDUs) that are multiplexed in one or more MAC Protocol Data Units (PDUs) for an uplink (UL) transmission;

in response to the received message indicating to use the highest CAPC, select the CAPC based on the highest CAPC of the one or more MAC SDUs that are multiplexed in the MAC PDU for the UL transmission; and

transmit, using the radio front end circuitry, the MAC PDU to the base station.

2. The UE of claim 1, wherein the message indicates to use the lowest CAPC in response to an access point (AP) associated with a wireless network being detected, wherein the AP is associated with the UE or the base station.

3. The UE of claim 1, wherein the message indicates to use the highest CAPC in response to an access point (AP) associated with a wireless network not being detected, wherein the AP is associated with the UE or the base station.

4. The UE of claim 1, wherein the UL transmission corresponds to at least one of a configured grant or a dynamic grant.

5. The UE of claim 4, wherein the MAC PDU comprises a first MAC PDU and a second MAC PDU and the processor circuitry is configured to:

multiplex control signaling into the first MAC PDU;

multiplex data signaling into the second MAC PDU;
transmit the first MAC PDU using the dynamic grant; and
transmit the second MAC PDU sing the configured grant.

6. The UE of claim 5, wherein the control signaling comprises at least one of a MAC control element (CE), a Signaling Radio Bearer (SRB), or a Data Radio Bearer (DRB) with the highest CACP.

7. The UE of claim 5, wherein the data signaling comprises a Data Radio Bearer (DRB) not having the highest CACP.

8. The UE of claim 1, wherein the processor circuitry is configured to start or restart a configured grant timer and a configured grant retransmission timer at a same time.

9. The UE of claim 9, wherein the processor circuitry is configured to restart the configured grant timer when the configured grant timer expires and run the configured grant retransmission timer for a predefined number of configured grant retransmissions.

10. A method, comprising:

receiving, at a user equipment (UE), a message from a base station;

based on the received message, determining whether to use a lowest Channel Access Priority Class (CAPC) or a highest CAPC;

in response to the received message indicating to use the lowest CAPC, selecting a CAPC based on the lowest CAPC of one or more Media Access Control (MAC) Service Data Units (SDUs) that are multiplexed in one or more MAC Protocol Data Units (PDUs) for an uplink (UL) transmission;

in response to the received message indicating to use the highest CAPC, selecting the CAPC based on the highest CAPC of the one or more MAC SDUs that are multiplexed in the MAC PDU for the UL transmission; and

transmitting the MAC PDU to the base station.

11. The method of claim 10, wherein the message indicates to use the lowest CAPC in response to an access point (AP) associated with a wireless network being detected, wherein the AP is associated with the UE or the base station.

12. The method of claim 10, wherein the message indicates to use the highest CAPC in response to an access point (AP) associated with a wireless network not being detected, wherein the AP is associated with the UE or the base station.

13. The method of claim 10, wherein the UL transmission corresponds to at least one of a configured grant or a dynamic grant.

14. The method of claim 13, wherein the MAC PDU comprises a first MAC PDU and a second MAC PDU and the method further comprises:
multiplexing control signaling into the first MAC PDU;
multiplexing data signaling into the second MAC PDU;
transmitting the first MAC PDU using the dynamic grant; and
transmitting the second MAC PDU sing the configured grant.

15. The method of claim 14, wherein the control signaling comprises at least one of a MAC control element (CE), a Signaling Radio Bearer (SRB), or a Data Radio Bearer (DRB) with the highest CACP and wherein the data signaling comprises a Data Radio Bearer (DRB) not having the highest CACP.

16. The method of claim 10, further comprising:
starting or restarting a configured grant timer and a configured grant retransmission timer at a same time.

17. The method of claim 16, further comprising:
restarting the configured grant timer when the configured grant timer expires; and
running the configured grant retransmission timer for a predefined number of configured grant retransmissions.

18. A base station, comprising:

radio front end circuitry; and

processor circuitry, coupled to the radio front end circuitry, and configured to:

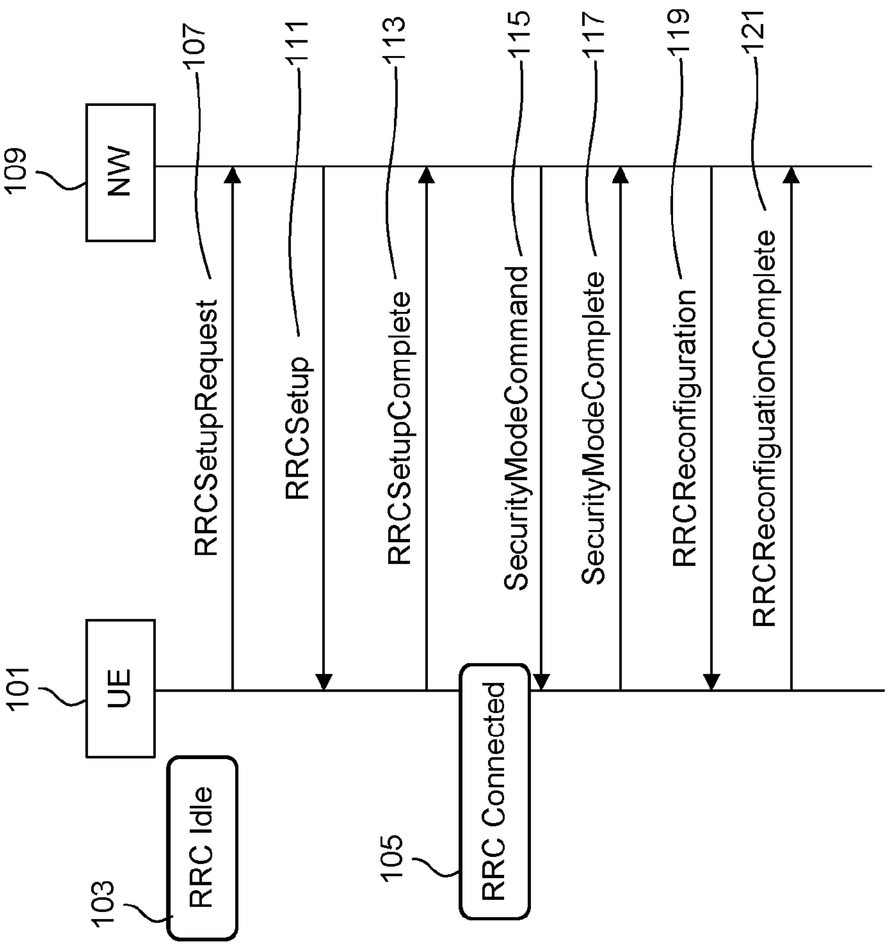
determine whether an access point (AP) associated with a wireless network is detected;

generate a message for a user equipment (UE), wherein the message comprises a parameter set to a lowest Channel Access Priority Class (CAPC) in response to detecting the AP or is set to a highest CAPC in response to not detecting the AP; and

transmit, using the radio front end circuitry, the message to the UE.

19. The base station of claim 1, wherein the processor circuitry is configured to transmit the message using an uplink (UL) grant procedure.

20. The base station of claim 1, wherein the message comprises an information element included in an *RRCReconfiguraiton* message.



101
UE
109
NW
103
RRC Idle
RRCSetupRequest
107
RRCSetup
111
RRCSetupComplete
113
105
RRC Connected
SecurityModeCommand
115
SecurityModeComplete
117
RRCReconfiguration
119
RRCReconfiguationComplete
121

Figure 1

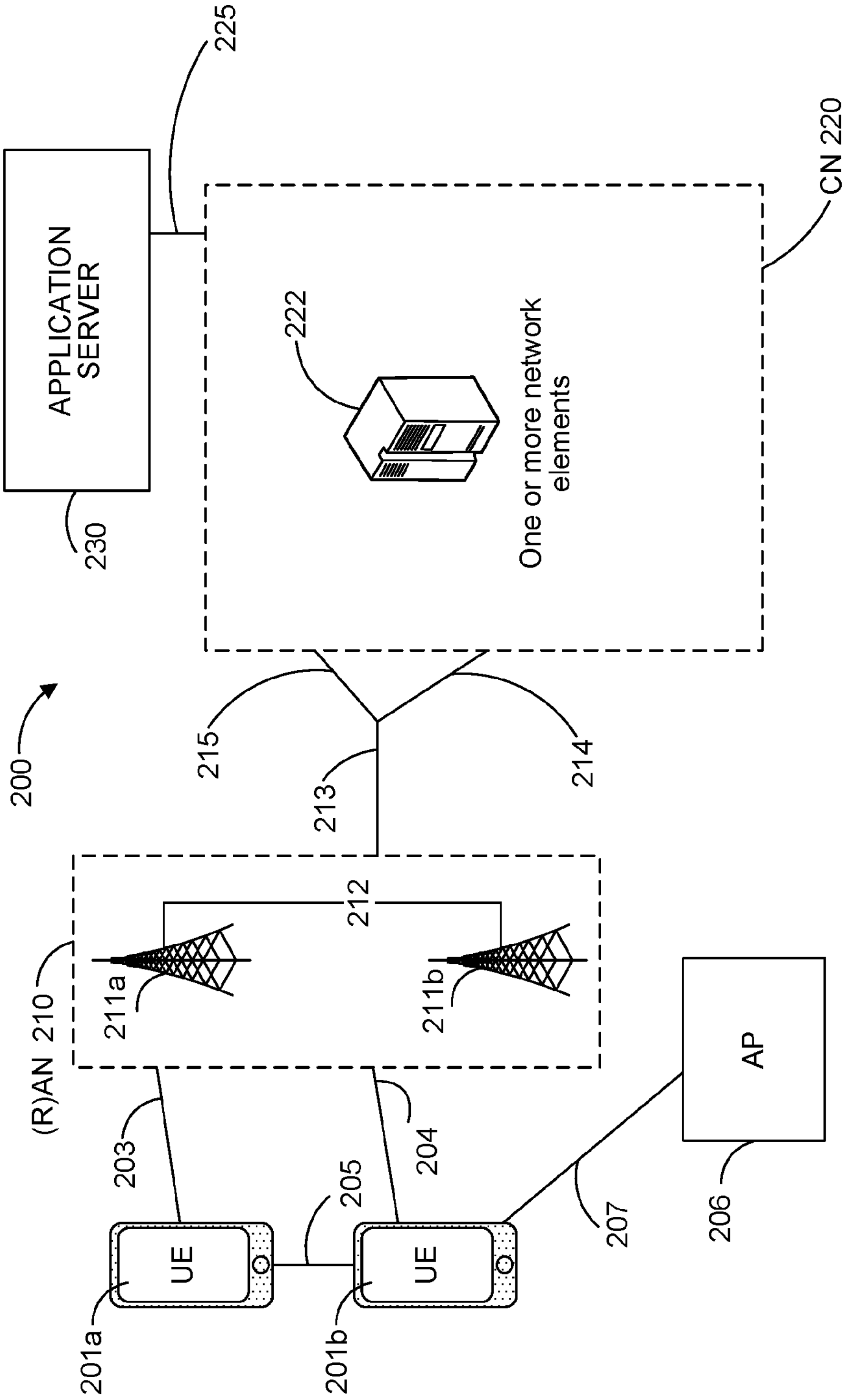

200
APPLICATION SERVER
230
225
CN 220
222
One or more network elements
215
214
213
212
(R)AN 210
211a
211b
203
204
205
UE
UE
201a
201b
207
AP
206

Figure 2

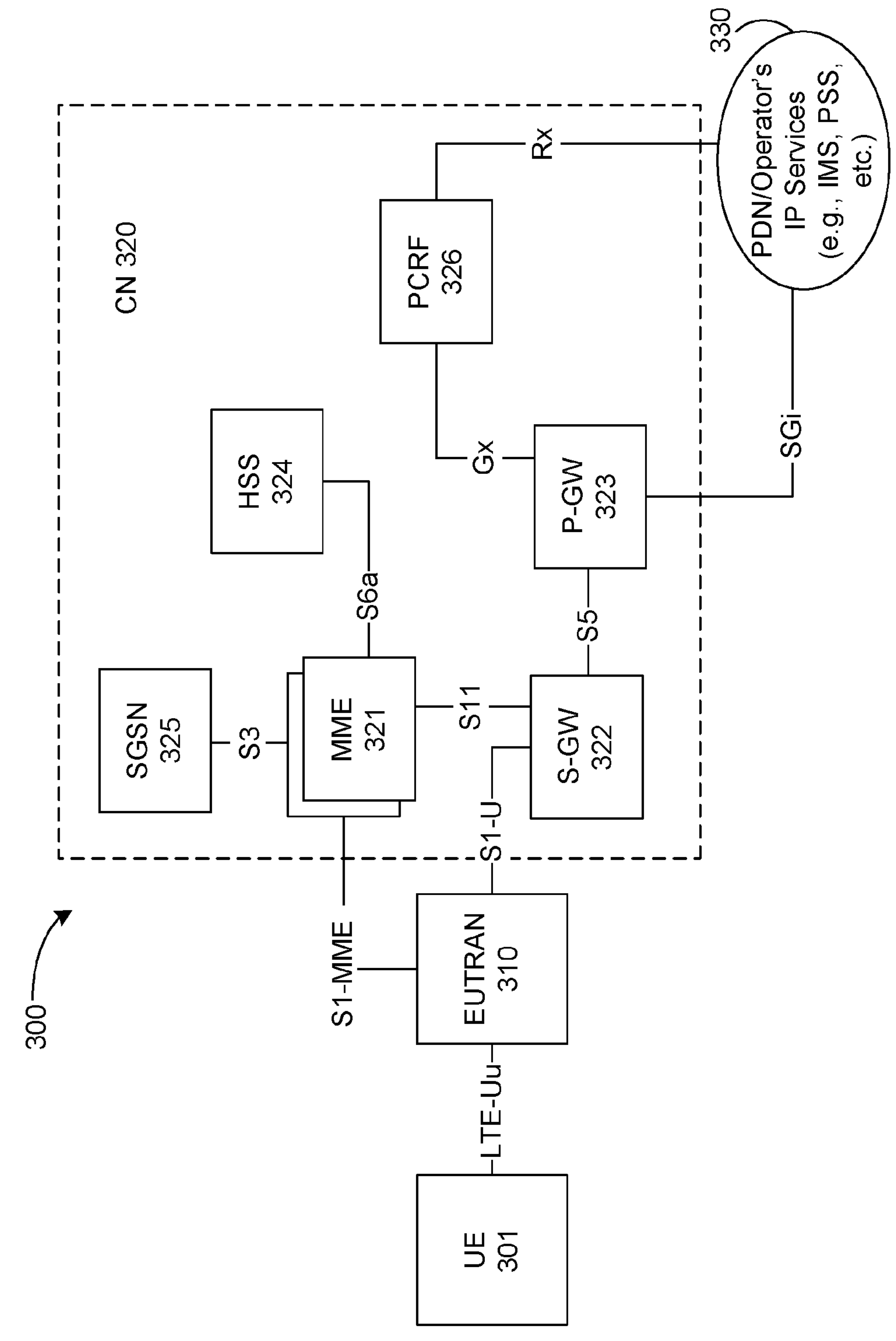
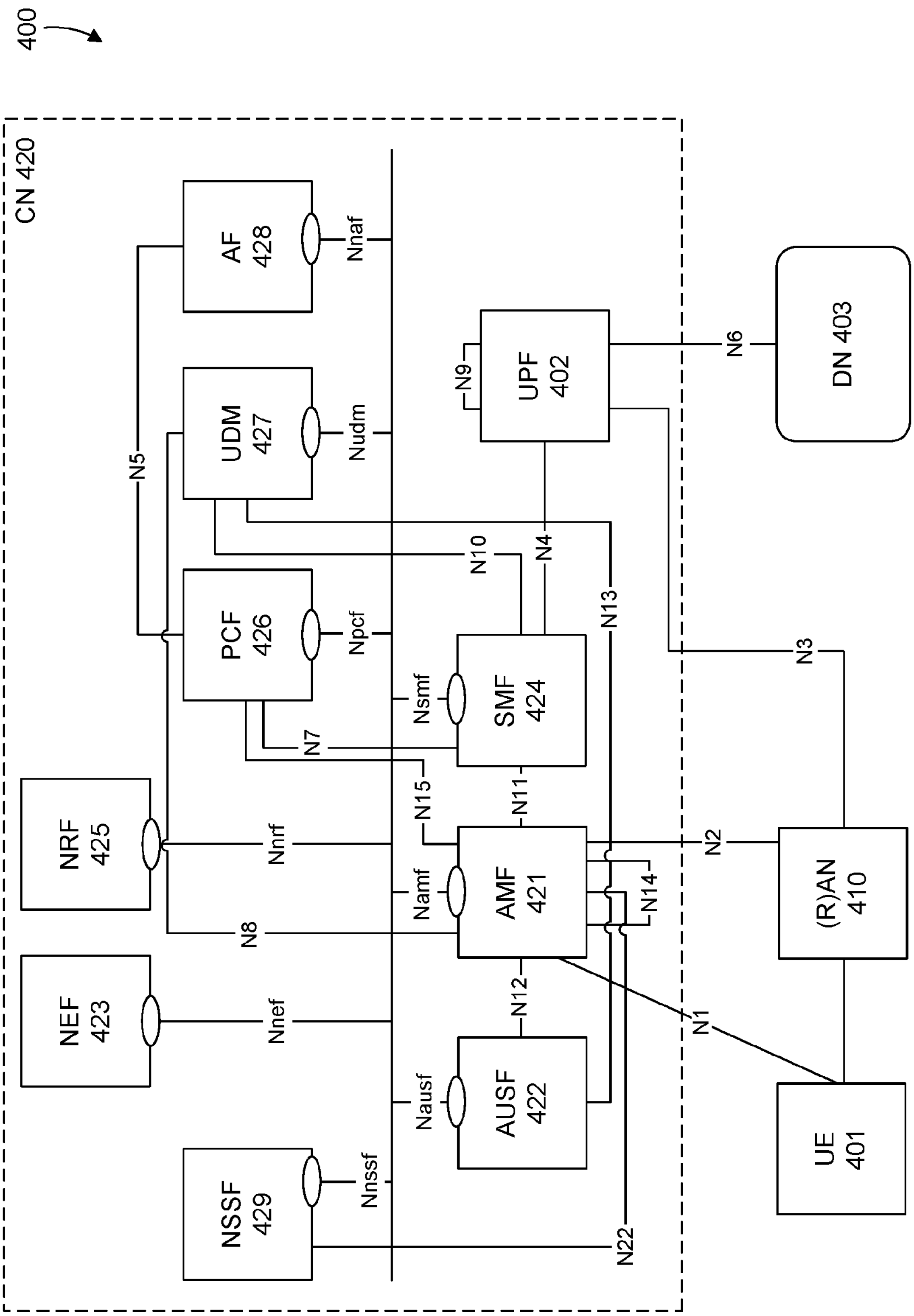

300
CN 320
UE
301
LTE-Uu
EUTRAN
310
S1-MME
S1-U
SGSN
325
S3
MME
321
S6a
HSS
324
S11
S-GW
322
S5
P-GW
323
Gx
PCRF
326
Rx
SGi
PDN/Operator's
IP Services
(e.g., IMS, PSS,
etc.)
330

Figure 3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CN 420
AF 428
UDM 427
PCF 426
NRF 425
NEF 423
NSSF 429
AUSF 422
AMF 421
SMF 424
UPF 402
DN 403
(R)AN 410
UE 401
Nnaf
Nudm
Npcf
Nsmf
Nnrf
Namf
Nnef
Nausf
Nnssf
N1
N2
N3
N4
N5
N6
N7
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N9
N10
N11
N12
N13
N14
N15
N22

Figure 4

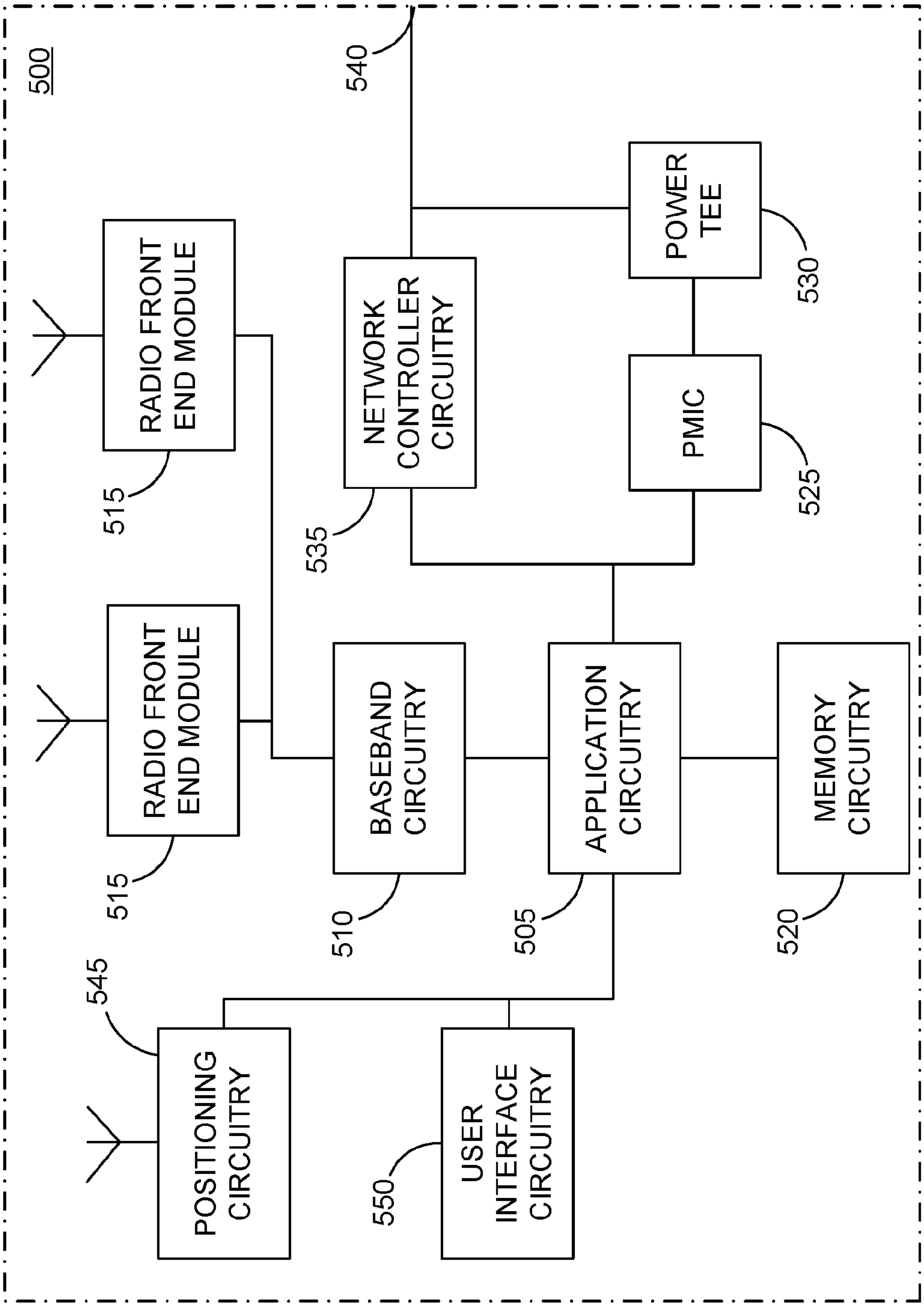
500
540
RADIO FRONT END MODULE
515
RADIO FRONT END MODULE
515
NETWORK CONTROLLER CIRCUITRY
535
POWER TEE
530
PMIC
525
BASEBAND CIRCUITRY
510
APPLICATION CIRCUITRY
505
MEMORY CIRCUITRY
520
POSITIONING CIRCUITRY
545
USER INTERFACE CIRCUITRY
550

Figure 5

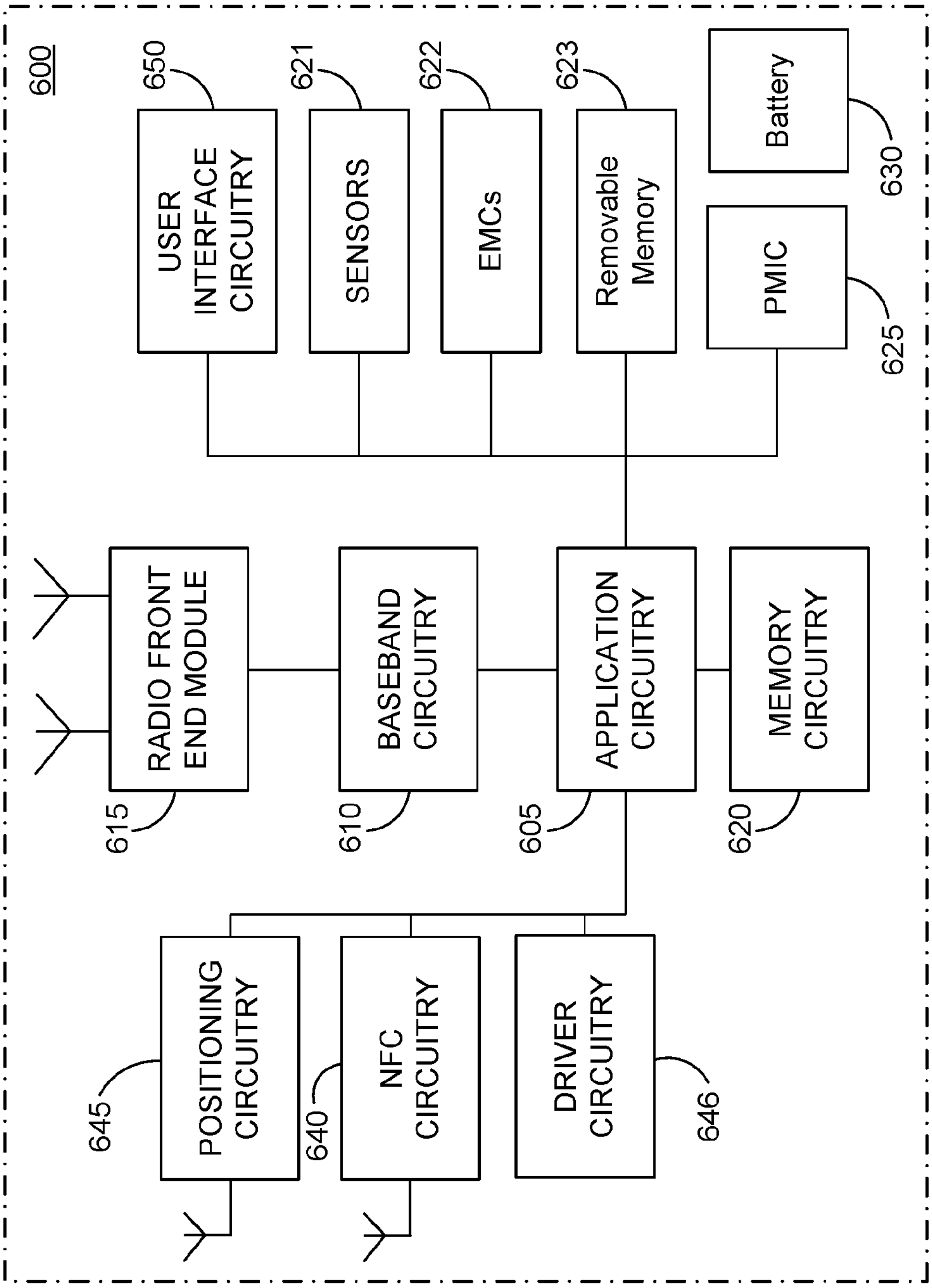
600
USER INTERFACE CIRCUITRY
650
SENSORS
621
EMCs
622
Removable Memory
623
Battery
630
PMIC
625
RADIO FRONT END MODULE
615
BASEBAND CIRCUITRY
610
APPLICATION CIRCUITRY
605
MEMORY CIRCUITRY
620
POSITIONING CIRCUITRY
645
NFC CIRCUITRY
640
DRIVER CIRCUITRY
646

Figure 6

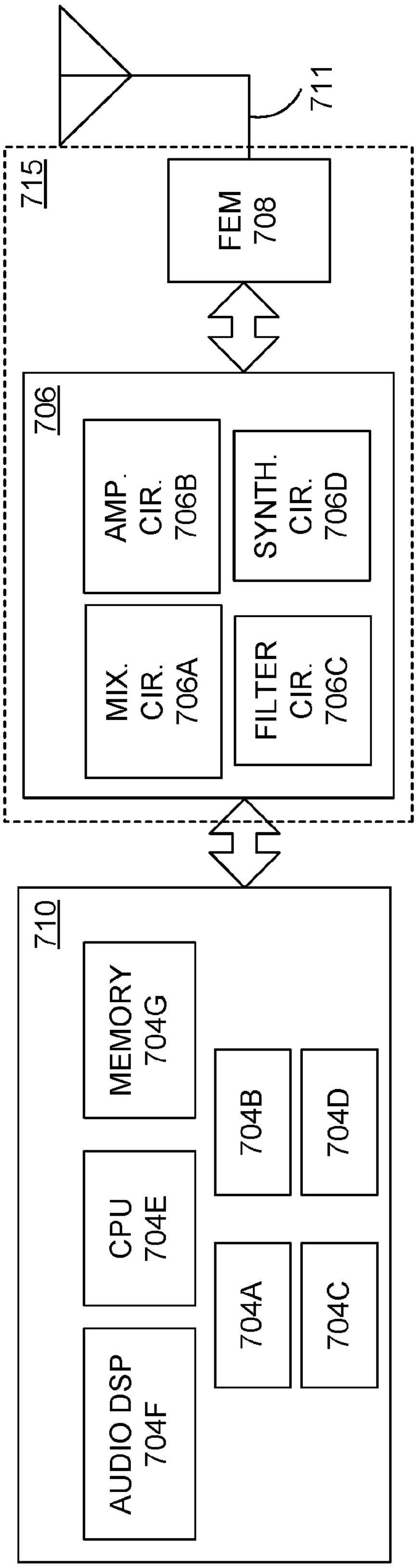
711
715
FEM
708
706
AMP.
CIR.
706B
SYNTH.
CIR.
706D
MIX.
CIR.
706A
FILTER
CIR.
706C
710
MEMORY
704G
CPU
704E
AUDIO DSP
704F
704B
704D
704A
704C

Figure 7

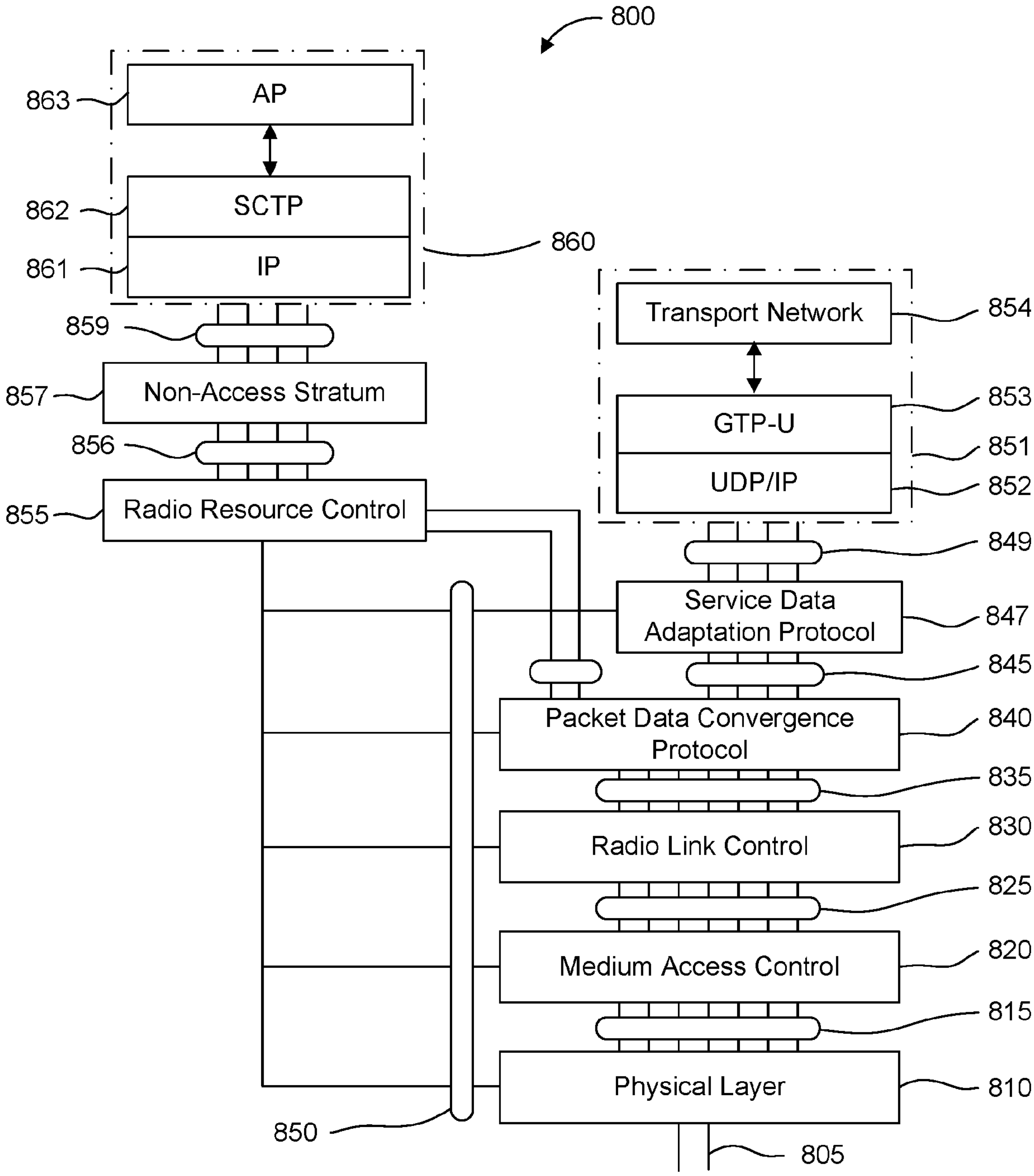
800
863
AP
862
SCTP
861
IP
860
859
857
Non-Access Stratum
856
855
Radio Resource Control
Transport Network
854
GTP-U
853
851
UDP/IP
852
849
Service Data Adaptation Protocol
847
845
Packet Data Convergence Protocol
840
835
Radio Link Control
830
825
Medium Access Control
820
815
Physical Layer
810
850
805

Figure 8

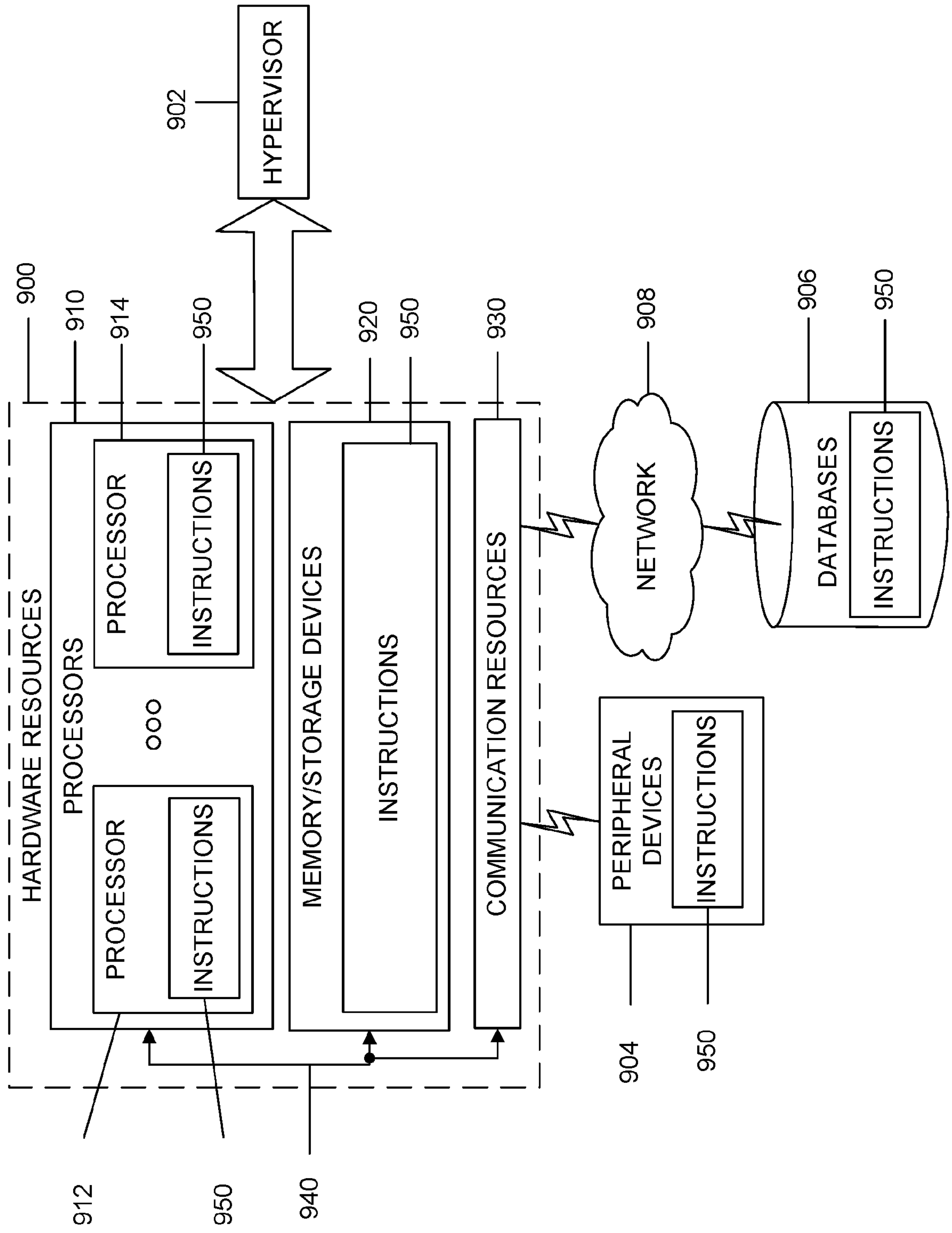
HYPERVISOR
902
900
HARDWARE RESOURCES
910
PROCESSORS
914
PROCESSOR
INSTRUCTIONS
950
ooo
PROCESSOR
INSTRUCTIONS
912
950
920
950
MEMORY/STORAGE DEVICES
INSTRUCTIONS
930
COMMUNICATION RESOURCES
940
908
NETWORK
906
950
DATABASES
INSTRUCTIONS
PERIPHERAL DEVICES
INSTRUCTIONS
904
950

Figure 9

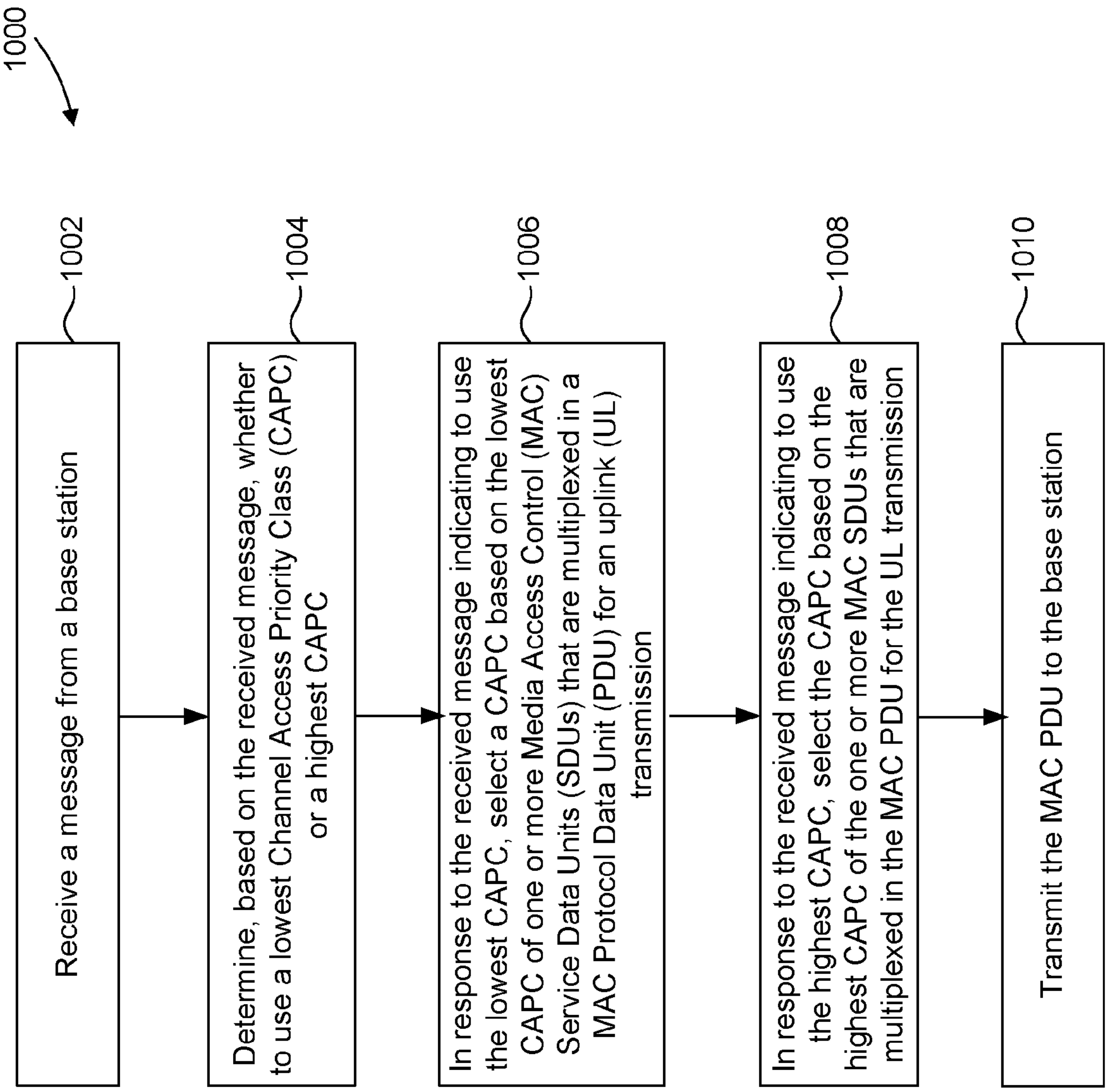
1000
1002
Receive a message from a base station
1004
Determine, based on the received message, whether to use a lowest Channel Access Priority Class (CAPC) or a highest CAPC
1006
In response to the received message indicating to use the lowest CAPC, select a CAPC based on the lowest CAPC of one or more Media Access Control (MAC) Service Data Units (SDUs) that are multiplexed in a MAC Protocol Data Unit (PDU) for an uplink (UL) transmission
1008
In response to the received message indicating to use the highest CAPC, select the CAPC based on the highest CAPC of the one or more MAC SDUs that are multiplexed in the MAC PDU for the UL transmission
1010
Transmit the MAC PDU to the base station

Figure 10

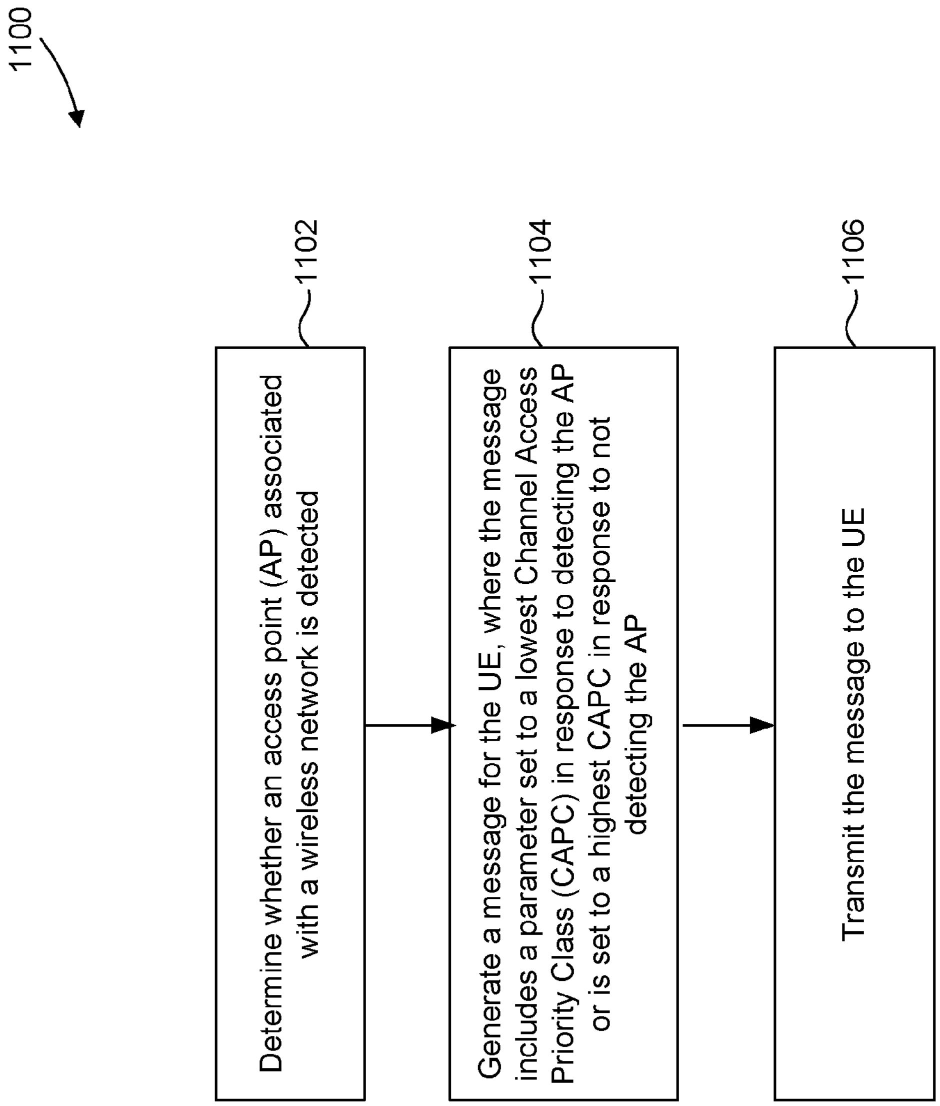
1100
1102
Determine whether an access point (AP) associated with a wireless network is detected
1104
Generate a message for the UE, where the message includes a parameter set to a lowest Channel Access Priority Class (CAPC) in response to detecting the AP or is set to a highest CAPC in response to not detecting the AP
1106
Transmit the message to the UE

Figure 11

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2020/031146

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04W74/00 H04W28/02
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)
H04W

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

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

EPO-Internal, WPI Data, IBM-TDB, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	NOKIA ET AL: "On Channel Access priority Class selection in NR-U", 3GPP DRAFT; R2-1903905 SELECTION OF CAPC IN NR-U - REVISION, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE , vol. RAN WG2, no. Xian, China; 20190408 - 20190412 6 April 2019 (2019-04-06), XP051701223, Retrieved from the Internet: URL:http://www.3gpp.org/ftp/Meetings%5F3GPP%5FSYNC/RAN2/Docs/R2%2D1903905%2Ezip [retrieved on 2019-04-06]	1-7,10, 13-15
A	section 1 section 2.2 -----	8,9,11, 12,16-20
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[X] Further documents are listed in the continuation of Box C.

[X] 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
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"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
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Date of the actual completion of the international search	Date of mailing of the international search report
22 July 2020	13/08/2020

Name and mailing address of the ISA/	Authorized officer
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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y A	WO 2017/163185 A1 (ERICSSON TELEFON AB L M [SE]) 28 September 2017 (2017-09-28) page 4, line 4 - page 5, line 21 page 16, line 2 - page 17, line 23; figure 7 -----	1-7,10, 13-15 8,9,11, 12,16-20
A	HUAWEI ET AL: "Consideration on Channel Access Priority Class", 3GPP DRAFT; R2-1904119 CONSIDERATION ON CHANNEL ACCESS PRIORITY CLASS, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; , vol. RAN WG2, no. Xian, China; 20190408 - 20190412 6 April 2019 (2019-04-06), XP051701433, Retrieved from the Internet: URL:http://www.3gpp.org/ftp/Meetings%5F3GPP%5FSYNC/RAN2/Docs/R2%2D1904119%2Ezip [retrieved on 2019-04-06] section 2.1.1 -----	1-20

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2020/031146

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		CN 108781465 A	09-11-2018
		EP 3434061 A1	30-01-2019
		EP 3634071 A1	08-04-2020
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