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(54) Title: DELIVERING OUT-OF-ORDER PACKET DATA CONVERGENCE PROTOCOL (PDCP) PROTOCOL DATA UNITS (PDUS) TO PDCP

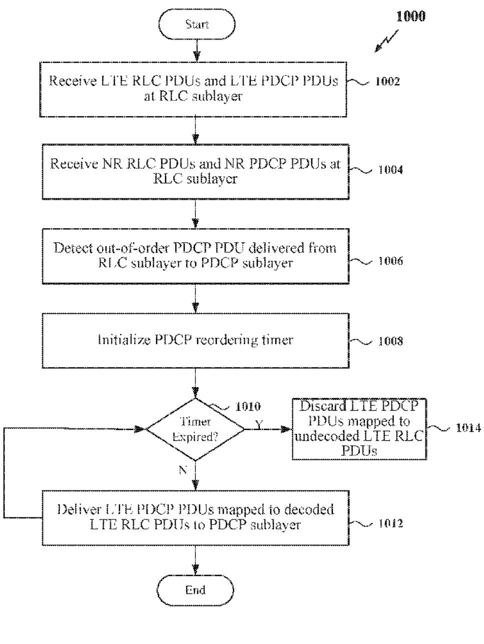

FIG. 10

(57) Abstract: Methods and equipments provide mechanisms for delivering out-of-order PDCP PDUs to the PDCP sublayer. In a user equipment configured for dual connectivity between LTE and NR, upon delivering at least one out-of-order PDCP PDU from the RLC sublayer to the PDCP sublayer, a PDCP reordering timer may be initialized. To prevent discarding of LTE PDCP PDUs while the RLC sublayer is performing a retransmission procedure, prior to expiration of the PDCP reordering timer, the out-of-order LTE PDCP PDUs mapped to decoded LTE RLC PDUs may be delivered from the RLC sublayer to the PDCP sublayer without reordering thereof. When the PDCP reordering timer expires, any LTE PDCP PDUs mapped to missing LTE RLC PDUs may be discarded.

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DELIVERING OUT-OF-ORDER PACKET DATA CONVERGENCE PROTOCOL (PDCP) PROTOCOL DATA UNITS (PDUS) TO PDCP

TECHNICAL FIELD

[0001] The technology discussed below relates generally to wireless communication systems, and more particularly, to processing of Packet Data Convergence Protocol (PDCP) protocol data units (PDUs).

INTRODUCTION

[0002] In 3rd Generation Partnership Project (3GPP) standards, the Packet Data Convergence Protocol (PDCP) sublayer is located in the radio protocol stack in both the Long Term Evolution (LTE) and New Radio (NR) air interface on top of the Radio Link Control (RLC) sublayer. The PDCP sublayer provides various services, such as transfer of user and control plane data, header compression, ciphering, and integrity protection. The RLC sublayer provides segmentation and reassembly of upper layer data packets, retransmission of lost data packets, and reordering of data packets to compensate for out-of-order reception due to hybrid automatic repeat request (HARQ) and automatic repeat request (ARQ).

[0003] In LTE Evolved Universal Terrestrial Radio Access Networks (eUTRANs), the RLC sublayer delivers data packets (e.g., protocol data units (PDUs)) to the PDCP sublayer after RLC reordering and reassembling of PDCP PDUs to ensure that the PDCP sublayer receives PDUs in order. In networks offering dual connectivity between eUTRAN and NR, PDCP reordering may be enabled to allow out-of-order delivery of PDCP PDUs from the NR RLC sublayer to the NR PDCP sublayer. However, if the NR PDCP reordering window advances before the LTE RLC sublayer completes HARQ/ARQ, complete PDCP PDUs sitting in the LTE RLC buffer may be discarded.

BRIEF SUMMARY OF SOME EXAMPLES

[0004] The following presents a simplified summary of one or more aspects of the present disclosure, in order to provide a basic understanding of such aspects. This summary is not an extensive overview of all contemplated features of the disclosure, and is intended neither to identify key or critical elements of all aspects of the disclosure nor to delineate the scope of any or all aspects of the disclosure. Its sole purpose is to present some concepts of one or more aspects of the disclosure in a simplified form as a prelude to the more detailed description that is presented later.

[0005] Various aspects of the present disclosure provide for Evolved-Universal Terrestrial Radio Access Network – New Radio dual connectivity (EN-DC) by a user equipment (UE) in a wireless communication network. In an aspect of the disclosure, the UE may be simultaneously connected to both a eUTRAN (LTE) base station and a NR base station to receive data packets from both the LTE base station and the NR base station. For example, the UE may receive Radio Link Control (RLC) protocol data units (PDUs) and Packet Data Convergence Protocol (PDCP) PDUs from the LTE base station, and RLC PDUs and PDCP PDUs from the NR base station. Each of the LTE RLC PDUs may be mapped to a subset of the LTE PDCP PDUs, and each of the NR RLC PDUs may be mapped to a subset of the NR PDCP PDUs.

[0006] Upon delivering at least one out-of-order NR PDCP PDU from the RLC sublayer to the PDCP sublayer for processing thereof, a PDCP reordering timer may be initialized. In various aspects of the disclosure, to prevent discarding out-of-order LTE PDCP PDUs while the LTE RLC sublayer is performing HARQ/ARQ, prior to expiration of the PDCP reordering timer, the subsets of the LTE PDCP PDUs mapped to decoded LTE RLC PDUs may be delivered from the RLC sublayer to the PDCP sublayer without reordering thereof. When the PDCP reordering timer expires, any LTE PDCP PDUs mapped to remaining undecoded LTE RLC PDUs may be discarded.

[0007] These and other aspects of the invention will become more fully understood upon a review of the detailed description, which follows. Other aspects, features, and embodiments of the present invention will become apparent to those of ordinary skill in the art, upon reviewing the following description of specific, exemplary embodiments of the present invention in conjunction with the accompanying figures. While features of the present invention may be discussed relative to certain embodiments and figures below, all embodiments of the present invention can include one or more of the advantageous features discussed herein. In other words, while one or more embodiments may be discussed as having certain advantageous features, one or more of such features may also be used in accordance with the various embodiments of the invention discussed herein. In similar fashion, while exemplary embodiments may be discussed below as device, system, or method embodiments it should be understood that such exemplary embodiments can be implemented in various devices, systems, and methods.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] FIG. 1 is a schematic illustration of a wireless communication system.

[0009] FIG. 2 is a conceptual illustration of an example of a radio access network.

[0010] FIG. 3 is a diagram illustrating an example of a radio protocol architecture for the user and control plane.

[0011] FIG. 4 is a diagram illustrating an example of a format of a Packet Data Convergence Protocol (PDCP) Packet Data Unit (PDU).

[0012] FIG. 5 is a diagram illustrating an example of a format of a Radio Link Control (RLC) Unacknowledged Mode Data (UMD) Packet Data Unit (PDU).

[0013] FIG. 6 is a diagram illustrating an example of a format of a Radio Link Control (RLC) Acknowledged Mode Data (AMD) Packet Data Unit (PDU).

[0014] FIG. 7 is a diagram illustrating an example of packets received by a user equipment implementing dual connectivity.

[0015] FIG. 8 is a block diagram illustrating an example of a hardware implementation for a user equipment employing a processing system.

[0016] FIG. 9 is a diagram illustrating an RLC sublayer and a PDCP sublayer within a user equipment (UE) implementing dual connectivity.

[0017] FIG. 10 is a flow chart of a method of delivering out-of-order PDCP PDUs to the PDCP sublayer.

DETAILED DESCRIPTION

[0018] The detailed description set forth below in connection with the appended drawings is intended as a description of various configurations and is not intended to represent the only configurations in which the concepts described herein may be practiced. The detailed description includes specific details for the purpose of providing a thorough understanding of various concepts. However, it will be apparent to those skilled in the art that these concepts may be practiced without these specific details. In some instances, well known structures and components are shown in block diagram form in order to avoid obscuring such concepts.

[0019] While aspects and embodiments are described in this application by illustration to some examples, those skilled in the art will understand that additional implementations and use cases may come about in many different arrangements and scenarios. Innovations described herein may be implemented across many differing platform types, devices, systems, shapes, sizes, packaging arrangements. For example, embodiments and/or uses may come about via integrated chip embodiments and other non-module-component based devices (e.g., end-user devices, vehicles, communication devices, computing devices, industrial equipment, retail/purchasing devices, medical devices, AI-enabled devices, etc.). While some examples may or may not be specifically directed to use cases or applications, a wide assortment of applicability of described innovations may occur. Implementations may range a spectrum from chip-level or modular components to non-modular, non-chip-level implementations and further to aggregate, distributed, or OEM devices or systems incorporating one or more aspects of the described innovations. In some practical settings, devices incorporating described aspects and features may also necessarily include additional components and features for implementation and practice of claimed and described embodiments. For example, transmission and reception of wireless signals necessarily includes a number of components for analog and digital purposes (e.g., hardware components including antenna, RF-chains, power amplifiers, modulators, buffer, processor(s), interleaver, adders/summers, etc.). It is intended that innovations described herein may be practiced in a wide variety of devices, chip-level components, systems, distributed arrangements, end-user devices, etc. of varying sizes, shapes and constitution.

[0020] The various concepts presented throughout this disclosure may be implemented across a broad variety of telecommunication systems, network architectures, and communication standards. Referring now to FIG. 1, as an illustrative example without limitation, various aspects of the present disclosure are illustrated with reference to a wireless communication system 100. The wireless communication system 100 includes three interacting domains: a core network 102, a radio access network (RAN) 104, and a user equipment (UE) 106. By virtue of the wireless communication system 100, the UE 106 may be enabled to carry out data communication with an external data network 110, such as (but not limited to) the Internet.

[0021] The RAN 104 may implement any suitable radio access technology (RAT) or RATs to provide radio access to the UE 106. As one example, the RAN 104 may operate according to 3rd Generation Partnership Project (3GPP) New Radio (NR) specifications, often referred to as 5G. As another example, the RAN 104 may operate under a hybrid of 5G NR and Evolved Universal Terrestrial Radio Access Network (eUTRAN) standards, often referred to as LTE. The 3GPP refers to this hybrid RAN as a next-generation RAN, or NG-RAN. In another example, the RAN 104 may operate according to both the LTE and 5G NR standards. Of course, many other examples may be utilized within the scope of the present disclosure.

[0022] As illustrated, the RAN 104 includes a plurality of base stations 108. Broadly, a base station is a network element in a radio access network responsible for radio transmission and reception in one or more cells to or from a UE. In different technologies, standards, or contexts, a base station may variously be referred to by those skilled in the art as a base transceiver station (BTS), a radio base station, a radio transceiver, a transceiver function, a basic service set (BSS), an extended service set (ESS), an access point (AP), a Node B (NB), an eNode B (eNB), a gNode B (gNB), or some other suitable terminology. In examples where the RAN 104 operates according to both the LTE and 5G NR standards, one of the base stations 108 may be an LTE base station, while another base station may be a 5G NR base station.

[0023] The radio access network 104 is further illustrated supporting wireless communication for multiple mobile apparatuses. A mobile apparatus may be referred to as user equipment (UE) 106 in 3GPP standards, but may also be referred to by those skilled in the art as a mobile station (MS), a subscriber station, a mobile unit, a subscriber unit, a wireless unit, a remote unit, a mobile device, a wireless device, a wireless communications device, a remote device, a mobile subscriber station, an access terminal (AT), a mobile terminal, a wireless terminal, a remote terminal, a handset, a terminal, a user agent, a mobile client, a client, or some other suitable terminology. A UE 106 may be an apparatus that provides a user with access to network services. In examples where the RAN 104 operates according to both the LTE and 5G NR standards, the UE 106 may be an Evolved-Universal Terrestrial Radio Access Network – New Radio dual connectivity (EN-DC) UE that is capable of simultaneously connecting to an LTE base station and a NR base station to receive data packets from both the LTE base station and the NR base station.

[0024] Within the present document, a “mobile” apparatus need not necessarily have a capability to move, and may be stationary. The term mobile apparatus or mobile device broadly refers to a diverse array of devices and technologies. UEs may include a number of hardware structural components sized, shaped, and arranged to help in communication; such components can include antennas, antenna arrays, RF chains, amplifiers, one or more processors, etc. electrically coupled to each other. For example, some non-limiting examples of a mobile apparatus include a mobile, a cellular (cell) phone, a smart phone, a session initiation protocol (SIP) phone, a laptop, a personal computer (PC), a notebook, a netbook, a smartbook, a tablet, a personal digital assistant (PDA), and a broad array of embedded systems, e.g., corresponding to an "Internet of Things" (IoT). A mobile apparatus may additionally be an automotive or other transportation vehicle, a remote sensor or actuator, a robot or robotics device, a satellite radio, a global positioning system (GPS) device, an object tracking device, a drone, a multi-copter, a quad-copter, a remote control device, a consumer and/or wearable device, such as eyewear, a wearable camera, a virtual reality device, a smart watch, a health or fitness tracker, a digital audio player (e.g., MP3 player), a camera, a game console, etc. A mobile apparatus may additionally be a digital home or smart home device such as a home audio, video, and/or multimedia device, an appliance, a vending machine, intelligent lighting, a home security system, a smart meter, etc. A mobile apparatus may additionally be a smart energy device, a security device, a solar panel or solar array, a municipal infrastructure device controlling electric power (e.g., a smart grid), lighting, water, etc.; an industrial automation and enterprise device; a logistics controller; agricultural equipment; military defense equipment, vehicles, aircraft, ships, and weaponry, etc. Still further, a mobile apparatus may provide for connected medicine or telemedicine support, i.e., health care at a distance. Telehealth devices may include telehealth monitoring devices and telehealth administration devices, whose communication may be given preferential treatment or prioritized access over other types of information, e.g., in terms of prioritized access for transport of critical service data, and/or relevant QoS for transport of critical service data.

[0025] Wireless communication between a RAN 104 and a UE 106 may be described as utilizing an air interface. Transmissions over the air interface from a base station (e.g., base station 108) to one or more UEs (e.g., UE 106) may be referred to as downlink (DL) transmission. In accordance with certain aspects of the present disclosure, the term downlink may refer to a point-to-multipoint transmission originating at a scheduling entity (described further below; e.g., base station 108). Another way to describe this scheme may be to use the term broadcast channel multiplexing. Transmissions from a UE (e.g., UE 106) to a base station (e.g., base station 108) may be referred to as uplink (UL) transmissions. In accordance with further aspects of the present disclosure, the term uplink may refer to a point-to-point transmission originating at a scheduled entity (described further below; e.g., UE 106).

[0026] In some examples, access to the air interface may be scheduled, wherein a scheduling entity (e.g., a base station 108) allocates resources for communication among some or all devices and equipment within its service area or cell. Within the present disclosure, as discussed further below, the scheduling entity may be responsible for scheduling, assigning, reconfiguring, and releasing resources for one or more scheduled entities. That is, for scheduled communication, UEs 106, which may be scheduled entities, may utilize resources allocated by the scheduling entity 108.

[0027] Base stations 108 are not the only entities that may function as scheduling entities. That is, in some examples, a UE may function as a scheduling entity, scheduling resources for one or more scheduled entities (e.g., one or more other UEs).

[0028] As illustrated in FIG. 1, a scheduling entity 108 may broadcast downlink traffic 112 to one or more scheduled entities 106. Broadly, the scheduling entity 108 is a node or device responsible for scheduling traffic in a wireless communication network, including the downlink traffic 112 and, in some examples, uplink traffic 116 from one or more scheduled entities 106 to the scheduling entity 108. On the other hand, the scheduled entity 106 is a node or device that receives downlink control information 114, including but not limited to scheduling information (e.g., a grant), synchronization or timing information, or other control information from another entity in the wireless communication network such as the scheduling entity 108.

[0029] In addition, the uplink and/or downlink control information and/or traffic information may be time-divided into frames, subframes, slots, and/or symbols. As used herein, a symbol may refer to a unit of time that, in an orthogonal frequency division multiplexed (OFDM) waveform, carries one resource element (RE) per sub-carrier. A slot may carry 7 or 14 OFDM symbols. A subframe may refer to a duration of 1ms. Multiple subframes or slots may be grouped together to form a single frame or radio frame. Of course, these definitions are not required, and any suitable scheme for organizing waveforms may be utilized, and various time divisions of the waveform may have any suitable duration.

[0030] In general, base stations 108 may include a backhaul interface for communication with a backhaul portion 120 of the wireless communication system. The backhaul 120 may provide a link between a base station 108 and the core network 102. Further, in some examples, a backhaul network may provide interconnection between the respective base stations 108. Various types of backhaul interfaces may be employed, such as a direct physical connection, a virtual network, or the like using any suitable transport network.

[0031] The core network 102 may be a part of the wireless communication system 100, and may be independent of the radio access technology used in the RAN 104. In some examples, the core network 102 may be configured according to 5G standards (e.g., 5GC). In other examples, the core network 102 may be configured according to a 4G evolved packet core (EPC), or any other suitable standard or configuration.

[0032] Referring now to FIG. 2, by way of example and without limitation, a schematic illustration of a RAN 200 is provided. In some examples, the RAN 200 may be the same as the RAN 104 described above and illustrated in FIG. 1. The geographic area covered by the RAN 200 may be divided into cellular regions (cells) that can be uniquely identified by a user equipment (UE) based on an identification broadcasted from one access point or base station. FIG. 2 illustrates macrocells 202, 204, and 206, and a small cell 208, each of which may include one or more sectors (not shown). A sector is a sub-area of a cell. All sectors within one cell are served by the same base station. A radio link within a sector can be identified by a single logical identification belonging to that sector. In a cell that is divided into sectors, the multiple sectors within a cell can be formed by groups of antennas with each antenna responsible for communication with UEs in a portion of the cell.

[0033] In FIG. 2, two base stations 210 and 212 are shown in cells 202 and 204; and a third base station 214 is shown controlling a remote radio head (RRH) 216 in cell 206. That is, a base station can have an integrated antenna or can be connected to an antenna or RRH by feeder cables. In the illustrated example, the cells 202, 204, and 126 may be referred to as macrocells, as the base stations 210, 212, and 214 support cells having a large size. Further, a base station 218 is shown in the small cell 208 (e.g., a microcell, picocell, femtocell, home base station, home Node B, home eNode B, etc.) which may overlap with one or more macrocells. In this example, the cell 208 may be referred to as a small cell, as the base station 218 supports a cell having a relatively small size. Cell sizing can be done according to system design as well as component constraints.

[0034] It is to be understood that the radio access network 200 may include any number of wireless base stations and cells. Further, a relay node may be deployed to extend the size or coverage area of a given cell. The base stations 210, 212, 214, 218 provide wireless access points to a core network for any number of mobile apparatuses. In some examples, the base stations 210, 212, 214, and/or 218 may be the same as the base station/scheduling entity 108 described above and illustrated in FIG. 1.

[0035] Within the RAN 200, the cells may include UEs that may be in communication with one or more sectors of each cell. Further, each base station 210, 212, 214, and 218 may be configured to provide an access point to a core network 102 (see FIG. 1) for all the UEs in the respective cells. For example, UEs 222 and 224 may be in communication with base station 210; UEs 226 and 228 may be in communication with base station 212; UEs 230 and 232 may be in communication with base station 214 by way of RRH 216; and UE 234 may be in communication with base station 218. In some examples, the UEs 222, 224, 226, 228, 230, 232, 234, 238, 240, and/or 242 may be the same as the UE/scheduled entity 106 described above and illustrated in FIG. 1.

[0036] In some examples, an unmanned aerial vehicle (UAV) 220, which may be a drone or quadcopter, can be a mobile network node and may be configured to function as a UE. For example, the UAV 220 may operate within cell 202 by communicating with base station 210.

[0037] In a further aspect of the RAN 200, sidelink signals may be used between UEs without necessarily relying on scheduling or control information from a base station. For example, two or more UEs (e.g., UEs 226 and 228) may communicate with each other using peer to peer (P2P) or sidelink signals 227 without relaying that communication through a base station (e.g., base station 212). In a further example, UE 238 is illustrated communicating with UEs 240 and 242. Here, the UE 238 may function as a scheduling entity or a primary sidelink device, and UEs 240 and 242 may function as a scheduled entity or a non-primary (e.g., secondary) sidelink device. In still another example, a UE may function as a scheduling entity in a device-to-device (D2D), peer-to-peer (P2P), or vehicle-to-vehicle (V2V) network, and/or in a mesh network. In a mesh network example, UEs 240 and 242 may optionally communicate directly with one another in addition to communicating with the scheduling entity 238. Thus, in a wireless communication system with scheduled access to time–frequency resources and having a cellular configuration, a P2P configuration, or a mesh configuration, a scheduling entity and one or more scheduled entities may communicate utilizing the scheduled resources. In some examples, the sidelink signals 227 include sidelink traffic and sidelink control. Sidelink control information may in some examples include a request signal, such as a request-to-send (RTS), a source transmit signal (STS), and/or a direction selection signal (DSS). The request signal may provide for a scheduled entity to request a duration of time to keep a sidelink channel available for a sidelink signal. Sidelink control information may further include a response signal, such as a clear-to-send (CTS) and/or a destination receive signal (DRS). The response signal may provide for the scheduled entity to indicate the availability of the sidelink channel, e.g., for a requested duration of time. An exchange of request and response signals (e.g., handshake) may enable different scheduled entities performing sidelink communications to negotiate the availability of the sidelink channel prior to communication of the sidelink traffic information.

[0038] In the radio access network 200, the ability for a UE to communicate while moving, independent of its location, is referred to as mobility. The various physical channels between the UE and the radio access network are generally set up, maintained, and released under the control of an access and mobility management function (AMF, not illustrated, part of the core network 102 in FIG. 1), which may include a security context management function (SCMF) that manages the security context for both the control plane and the user plane functionality, and a security anchor function (SEAF) that performs authentication.

[0039] A radio access network 200 may utilize DL-based mobility or UL-based mobility to enable mobility and handovers (i.e., the transfer of a UE's connection from one radio channel to another). In a network configured for DL-based mobility, during a call with a scheduling entity, or at any other time, a UE may monitor various parameters of the signal from its serving cell as well as various parameters of neighboring cells. Depending on the quality of these parameters, the UE may maintain communication with one or more of the neighboring cells. During this time, if the UE moves from one cell to another, or if signal quality from a neighboring cell exceeds that from the serving cell for a given amount of time, the UE may undertake a handoff or handover from the serving cell to the neighboring (target) cell. For example, UE 224 (illustrated as a vehicle, although any suitable form of UE may be used) may move from the geographic area corresponding to its serving cell 202 to the geographic area corresponding to a neighbor cell 206. When the signal strength or quality from the neighbor cell 206 exceeds that of its serving cell 202 for a given amount of time, the UE 224 may transmit a reporting message to its serving base station 210 indicating this condition. In response, the UE 224 may receive a handover command, and the UE may undergo a handover to the cell 206.

[0040] In a network configured for UL-based mobility, UL reference signals from each UE may be utilized by the network to select a serving cell for each UE. In some examples, the base stations 210, 212, and 214/216 may broadcast unified synchronization signals (e.g., unified Primary Synchronization Signals (PSSs), unified Secondary Synchronization Signals (SSSs) and unified Physical Broadcast Channels (PBCH)). The UEs 222, 224, 226, 228, 230, and 232 may receive the unified synchronization signals, derive the carrier frequency and slot timing from the synchronization signals, and in response to deriving timing, transmit an uplink pilot or reference signal. The uplink pilot signal transmitted by a UE (e.g., UE 224) may be concurrently received by two or more cells (e.g., base stations 210 and 214/216) within the radio access network 200. Each of the cells may measure a strength of the pilot signal, and the radio access network (e.g., one or more of the base stations 210 and 214/216 and/or a central node within the core network) may determine a serving cell for the UE 224. As the UE 224 moves through the radio access network 200, the network may continue to monitor the uplink pilot signal transmitted by the UE 224. When the signal strength or quality of the pilot signal measured by a neighboring cell exceeds that of the signal strength or quality measured by the serving cell, the network 200 may handover the UE 224 from the serving cell to the neighboring cell, with or without informing the UE 224.

[0041] Although the synchronization signal transmitted by the base stations 210, 212, and 214/216 may be unified, the synchronization signal may not identify a particular cell, but rather may identify a zone of multiple cells operating on the same frequency and/or with the same timing. The use of zones in 5G networks or other next generation communication networks enables the uplink-based mobility framework and improves the efficiency of both the UE and the network, since the number of mobility messages that need to be exchanged between the UE and the network may be reduced.

[0042] In various implementations, the air interface in the radio access network 200 may utilize licensed spectrum, unlicensed spectrum, or shared spectrum. Licensed spectrum provides for exclusive use of a portion of the spectrum, generally by virtue of a mobile network operator purchasing a license from a government regulatory body. Unlicensed spectrum provides for shared use of a portion of the spectrum without need for a government-granted license. While compliance with some technical rules is generally still required to access unlicensed spectrum, generally, any operator or device may gain access. Shared spectrum may fall between licensed and unlicensed spectrum, wherein technical rules or limitations may be required to access the spectrum, but the spectrum may still be shared by multiple operators and/or multiple RATs. For example, the holder of a license for a portion of licensed spectrum may provide licensed shared access (LSA) to share that spectrum with other parties, e.g., with suitable licensee-determined conditions to gain access.

[0043] In order for transmissions over the radio access network 200 to obtain a low block error rate (BLER) while still achieving very high data rates, channel coding may be used. That is, wireless communication may generally utilize a suitable error correcting block code. In a typical block code, an information message or sequence is split up into code blocks (CBs), and an encoder (e.g., a CODEC) at the transmitting device then mathematically adds redundancy to the information message. Exploitation of this redundancy in the encoded information message can improve the reliability of the message, enabling correction for any bit errors that may occur due to the noise.

[0044] In early 5G NR specifications, user data traffic is coded using quasi-cyclic low-density parity check (LDPC) with two different base graphs: one base graph is used for large code blocks and/or high code rates, while the other base graph is used otherwise. Control information and the physical broadcast channel (PBCH) are coded using Polar coding, based on nested sequences. For these channels, puncturing, shortening, and repetition are used for rate matching.

[0045] However, those of ordinary skill in the art will understand that aspects of the present disclosure may be implemented utilizing any suitable channel code. Various implementations of scheduling entities 108 and scheduled entities 106 may include suitable hardware and capabilities (e.g., an encoder, a decoder, and/or a CODEC) to utilize one or more of these channel codes for wireless communication.

[0046] The air interface in the radio access network 200 may utilize one or more multiplexing and multiple access algorithms to enable simultaneous communication of the various devices. For example, 5G NR specifications provide multiple access for UL transmissions from UEs 222 and 224 to base station 210, and for multiplexing for DL transmissions from base station 210 to one or more UEs 222 and 224, utilizing orthogonal frequency division multiplexing (OFDM) with a cyclic prefix (CP). In addition, for UL transmissions, 5G NR specifications provide support for discrete Fourier transform-spread-OFDM (DFT-s-OFDM) with a CP (also referred to as single-carrier FDMA (SC-FDMA)). However, within the scope of the present disclosure, multiplexing and multiple access are not limited to the above schemes, and may be provided utilizing time division multiple access (TDMA), code division multiple access (CDMA), frequency division multiple access (FDMA), sparse code multiple access (SCMA), resource spread multiple access (RSMA), or other suitable multiple access schemes. Further, multiplexing DL transmissions from the base station 210 to UEs 222 and 224 may be provided utilizing time division multiplexing (TDM), code division multiplexing (CDM), frequency division multiplexing (FDM), orthogonal frequency division multiplexing (OFDM), sparse code multiplexing (SCM), or other suitable multiplexing schemes.

[0047] The air interface in the radio access network 200 may further utilize one or more duplexing algorithms. Duplex refers to a point-to-point communication link where both endpoints can communicate with one another in both directions. Full duplex means both endpoints can simultaneously communicate with one another. Half duplex means only one endpoint can send information to the other at a time. In a wireless link, a full duplex channel generally relies on physical isolation of a transmitter and receiver, and suitable interference cancellation technologies. Full duplex emulation is frequently implemented for wireless links by utilizing frequency division duplex (FDD) or time division duplex (TDD). In FDD, transmissions in different directions operate at different carrier frequencies. In TDD, transmissions in different directions on a given channel are separated from one another using time division multiplexing. That is, at some times the channel is dedicated for transmissions in one direction, while at other times the channel is dedicated for transmissions in the other direction, where the direction may change very rapidly, e.g., several times per slot.

[0048] The radio protocol architecture for a radio access network, such as the radio access network 104 shown in FIG. 1 and/or the radio access network 200 shown in FIG. 2, may take on various forms depending on the particular application. An example for an LTE or NR radio access network will now be presented with reference to FIG. 3. FIG. 3 is a conceptual diagram illustrating an example of the radio protocol architecture for the user and control planes.

[0049] As illustrated in FIG. 3, the radio protocol architecture for the UE and the base station includes three layers: Layer 1, Layer 2, and Layer 3. Layer 1 is the lowest layer and implements various physical layer signal processing functions. Layer 1 will be referred to herein as the physical layer 306. Layer 2 (L2 layer) 308 is above the physical layer 306 and is responsible for the link between the UE and base station over the physical layer 306.

[0050] In the user plane, the L2 layer 308 includes a media access control (MAC) sublayer 310, a radio link control (RLC) sublayer 312, and a packet data convergence protocol (PDCP) 314 sublayer, which are terminated at the base station on the network side. Although not shown, the UE may have several upper layers above the L2 layer 308 including a network layer (e.g., IP layer) that is terminated at the Packet Data Network (PDN) gateway on the network side, and an application layer that is terminated at the other end of the connection (e.g., far end UE, server, etc.).

[0051] The PDCP sublayer 314 provides multiplexing between different radio bearers and logical channels. The PDCP sublayer 314 also provides header compression for upper layer data packets to reduce radio transmission overhead, security by ciphering the data packets, and handover support for UEs between base stations. The RLC sublayer 312 provides segmentation and reassembly of upper layer data packets, retransmission of lost data packets, and reordering of data packets to compensate for out-of-order reception due to hybrid automatic repeat request (HARQ) and automatic repeat request (ARQ). The MAC sublayer 310 provides multiplexing between logical and transport channels. The MAC sublayer 310 is also responsible for allocating the various radio resources (e.g., resource blocks) in one cell among the UEs. The MAC sublayer 310 is also responsible for HARQ operations. The physical layer 306 is responsible for transmitting and receiving data on physical channels (e.g., within slots).

[0052] In the control plane, the radio protocol architecture for the UE and base station is substantially the same for the physical layer 306 and the L2 layer 308 with the exception that there is no header compression function for the control plane. The control plane also includes a radio resource control (RRC) sublayer 316 in Layer 3. The RRC sublayer 316 is responsible for obtaining radio resources (i.e., radio bearers) and for configuring the lower layers using RRC signaling between the base station and the UE.

[0053] In general, packets received by a sublayer from another sublayer may be referred to as Service Data Units (SDUs), while packets output from a sublayer to another sublayer may be referred to as Protocol Data Units (PDUs). For example, packets received by the PDCP sublayer 314 from an upper layer may be referred to as PDCP SDUs, and packets output from the PDCP sublayer 314 to the RLC sublayer may be referred to as PDCP PDUs or RLC SDUs.

[0054] An example of a PDCP packet data unit (PDU) format is illustrated in FIG. 4. The PDCP PDU format 400 includes a header 402 and body 404. The header 402 includes a D/C field 406 and SN field 408. The D/C field 406 is located within a first octet 412a and may include, for example, a single bit for indicating whether the PCDP PDU contains user plane data or control plane data. In the example shown in FIG. 4, the SN field 408 occupies the remainder of the first octet 412a, along with a second octet

412b. The SN field 408 contains the sequence number (SN) of the PDCP PDU. In some examples, the SN may contain 7 bits or 12 bits. The body 404 contains uncompressed or compressed user or control plane data 410 and may include one or more octets (only one octet 412c of which is shown for simplicity).

[0055] An example of an RLC Unacknowledged Mode Data (UMD) Packet Data Unit (PDU) format is illustrated in FIG. 5. UMD may be used, for example, to transmit delay sensitive packets, such as VoIP packets. In the unacknowledged mode, the receiving device does not acknowledge reception of data packets to the transmitting device (e.g., the receiving device does not transmit ACK/NACK to the transmitting device).

[0056] In the example shown in FIG. 5, the RLC UMD PDU format 500 includes a header 502 and a body 504. The header 502 occupies a first octet 512a that includes a Framing Information (FI) field 506, Extension bit (E) field 508 and SN field 510. The FI field 506 indicates whether the RLC PDU is segmented at the beginning and/or end of the data field. The E field 508 indicates whether a data field or a set of E field and Length Indicator (LI) fields follow the SN field 510. The SN field 510 occupies the remainder of the first octet 512a. The SN field 510 contains the sequence number (SN) of the RLC PDU. In some examples, the SN may contain 5 bits or 10 bits. When the SN contains 5 bits, the header 502 is one byte long, as shown in FIG. 5. However, when the SN contains 10 bits, the header 502 is two bytes long and the SN extends through the second octet with the first three bits of the header 502 being reserved. The body 504 contains uncompressed or compressed user or control plane data 512 and may include one or more octets (only one octet 512b of which is shown for simplicity).

[0057] An example of an RLC Acknowledged Mode Data (AMD) Packet Data Unit (PDU) format is illustrated in FIG. 6. The acknowledged mode supports a HARQ/ARQ mechanism to retransmit lost PDUs. In the example shown in FIG. 6, the RLC AMD PDU format 600 includes a header 602 and a body 604. The header 602 occupies the first two octets 620a and 620b and includes a D/C field 606, a re-segmentation flag (RF) field 608, a polling bit (P) field 610, a Framing Information (FI) field 612, an Extension bit (E) field 614 and SN field 616. The D/C field 606 indicates whether the RLC PDU contains user plane data or control plane data. The RF field 608 indicates whether the RLC PDU is an AMD PDU or an AMD PDU segment. The P field 610 indicates whether the transmitting device is requesting the status of previously transmitted RLC PDUs from the receiving device. The FI field 612 indicates whether the RLC PDU is segmented at the beginning and/or end of the data field. The E field 614 indicates whether a data field or a set of E field and Length Indicator (LI) fields follow the SN field 616. The SN field 616 occupies the remainder of the first octet 620a and the entirety of the second octet 620b. The SN field 616 contains the sequence number (SN) of the RLC PDU. In some examples, the SN may contain 10 bits. The body 604 contains uncompressed or compressed user or control plane data 618 and may include one or more octets (only one octet 620c of which is shown for simplicity).

[0058] FIG. 7 is a diagram illustrating an example of packets received by a user equipment (UE) implementing EN-DC (eUTRAN-NR dual connectivity). In the example shown in FIG. 7, the UE receives a first set of packets 700 from a first base station supporting a first radio access technology (RAT) and a second set of packets 708 from a second base station supporting a second RAT. The first RAT may be, for example, a eUTRAN (LTE) RAT, while the second RAT may be, for example, a NR RAT.

[0059] The first set of packets 700 includes a plurality of LTE RLC PDUs 702, a plurality of PDCP PDUs 704, and a plurality of Internet Protocol (IP) packets 706. The second set of packets 708 includes a plurality of NR RLC PDUs 710, a plurality of PDCP PDUs 712, and a plurality of IP packets 714. Each of the plurality of LTE RLC PDUs 702 includes a respective sequence number (SN) assigned by the LTE RAT and each of the NR RLC PDUs 710 includes a respective SN separately assigned by the NR RAT. For example, the LTE RLC PDUs 702 are illustrated in FIG. 7 as being assigned LTE SNs 0–5, for simplicity, while the NR RLC PDUs 710 are illustrated in FIG. 7 as being assigned NR SNs 0–19, for simplicity. The PDCP PDUs 704 and 712 each include a respective SN that is assigned independent of the RATs (e.g., the PDCP PDU SNs are collectively assigned by both RATs). For example, PDCP PDUs 704 transmitted by the LTE base station are assigned SNs 0–29, while PDCP PDUs 712 transmitted by the NR base station are assigned SNs 30–49.

[0060] Each of the RLC PDUs 702 and 710 are mapped to a respective subset of the PDCP PDUs 704 and 712, where the subsets are non-overlapping. For example, within the first set of packets 700, each of the plurality of LTE RLC PDUs 702 is mapped to a respective subset of the PDCP PDUs 704. In the example shown in FIG. 7, LTE RLC PDU 0 is mapped to PDCP PDUs 0–4, LTE RLC PDU 1 is mapped to PDCP PDUs 5–9, LTE RLC PDU 2 is mapped to PDCP PDUs 10–14, and so on. In addition, within the second set of packets 708, each of the plurality of NR RLC PDUs 710 is mapped to a respective subset of the PDCP PDUs 712. In the example shown in FIG. 7, NR RLC

PDU 0 is mapped to PDCP PDU 30, NR RLC PDU 1 is mapped to PDCP PDU 31, NR RLC PDU 2 is mapped to PDCP PDU 32, and so on.

[0061] In LTE, the RLC sublayer delivers the PDCP PDUs 704 to the PDCP sublayer after reordering and reassembling thereof as there is no PDCP reordering performed in the PDCP sublayer. For example, if the RLC sublayer detects an out-of-order decoded LTE RLC PDU 702, the RLC sublayer may buffer all of the PDCP PDUs 704 received since the last in-order decoded LTE RLC PDU and initialize an RLC reordering timer. Within the RLC reordering timer period, a HARQ process may be conducted to recover the missing LTE RLC PDUs. Upon expiration of the RLC reordering timer, if the missing LTE RLC PDUs have not been recovered, the RLC sublayer may generate and transmit an RLC status PDU to the LTE base station to initiate an ARQ process for retransmission of the missing LTE RLC PDUs. For example, the RLC status PDU may include acknowledgement information (e.g., ACK/NACK) for one or more LTE RLC PDUs 702. The RLC sublayer maintains the received LTE PDCP PDUs 704 in the RLC buffer until the missing LTE RLC PDUs 702 are recovered. In some examples, it may take X ms to recover the missing LTE RLC PDUs 702 via ARQ.

[0062] Using the example shown in FIG. 7, if decoding of LTE RLC PDUs 0 and 1 fails (e.g., the RLC sublayer detects that LTE RLC PDUs 0 and 1 are missing due to, for example, downlink BLER experienced on the LTE link), the RLC sublayer may buffer PDCP PDUs 0–29 and initiate the RLC reordering timer to begin HARQ. Upon expiration of the RLC reordering timer, the RLC sublayer may generate and transmit an RLC status PDU to initiate ARQ retransmission of LTE RLC PDUs 0 and 1. The RLC sublayer may then deliver the LTE PDCP PDUs 0–29 from the RLC buffer to the PDCP sublayer once the LTE RLC PDUs 0 and 1 are recovered.

[0063] In EN-DC, PDCP reordering in the PDCP sublayer may be enabled to allow out-of-order delivery of PDCP PDUs from the NR RLC sublayer to the NR PDCP sublayer. For example, if the NR link is experiencing a low BLER, and therefore, NR RLC PDUs 710 are able to be properly decoded, the RLC sublayer may deliver NR PDCP PDUs 712 to the PDCP sublayer regardless of whether any LTE PDCP PDUs 704 remain buffered in the RLC buffer. Using the same above example, if LTE RLC PDUs 0 and 1 are missing, and therefore, PDCP PDUs 0–29 are buffered in the RLC buffer, the RLC sublayer may deliver PDCP PDUs 30–49 to the PDCP sublayer upon decoding of NR RLC PDUs 0–19. When the PDCP sublayer receives out-of-order PDCP PDU 30, the PDCP sublayer may initiate a PDCP reordering timer.

[0064] However, if the PDCP reordering timer expires before the RLC sublayer completes ARQ of the missing LTE RLC PDUs, all of the PDCP PDUs (e.g., PDCP PDUs 0–29) sitting in the LTE RLC buffer may be discarded, even though some of the PDCP PDUs (e.g., PDCP PDUs 10–29) may be mapped to complete (decoded) LTE RLC PDUs (e.g., LTE RLC PDUs 2–5). In this example, discarding of PDCP PDUs 0–29 may occur if the PDCP reordering timer < (LTE RLC reordering timer + X), where X refers to the amount of time to complete ARQ (e.g., the amount of time needed to recover the missing LTE RLC PDUs via ARQ).

[0065] In various aspects of the disclosure, to reduce the number of dropped packets (e.g., the number of discarded PDCP PDUs), the RLC sublayer may deliver out-of-order LTE PDCP PDUs 704 to the PDCP sublayer after successfully decoding the corresponding LTE RLC PDUs 702 mapped to those PDCP PDUs. Using the above example, after successfully decoding LTE RLC PDUs 2–5, the RLC sublayer may deliver PDCP PDUs 10–29 to the PDCP sublayer. As a result, the RLC sublayer may only buffer PDCP PDUs 0–9 until completion of ARQ. In this example, if the PDCP reordering timer expires before the RLC sublayer is able to complete ARQ, the RLC sublayer may discard PDCP PDUs 0–9. In examples in which the RLC sublayer is operating in unacknowledged mode (UM), the RLC sublayer may deliver out-of-order LTE PDCP PDUs to the PDCP sublayer after expiration of the RLC reordering timer.

[0066] FIG. 8 is a conceptual diagram illustrating an example of a hardware implementation for an exemplary user equipment (UE) 800 employing a processing system 814. For example, the UE 800 may correspond to any of the UEs shown and described above in reference to FIGs. 1 and/or 2.

[0067] The UE 800 may be implemented with a processing system 814 that includes one or more processors 804. Examples of processors 804 include microprocessors, microcontrollers, digital signal processors (DSPs), field programmable gate arrays (FPGAs), programmable logic devices (PLDs), state machines, gated logic, discrete hardware circuits, and other suitable hardware configured to perform the various functionality described throughout this disclosure. In various examples, the UE 800 may be configured to perform any one or more of the functions described herein. That is, the processor 804, as utilized in a UE 800, may be used to implement any one or more of the processes described below and illustrated in FIG. 10.

[0068] In this example, the processing system 814 may be implemented with a bus architecture, represented generally by the bus 802. The bus 802 may include any number of interconnecting buses and bridges depending on the specific application of the processing system 814 and the overall design constraints. The bus 802 communicatively couples together various circuits including one or more processors (represented generally by the processor 804), a memory 805, and computer-readable media (represented generally by the computer-readable medium 806). The bus 802 may also link various other circuits such as timing sources, peripherals, voltage regulators, and power management circuits, which are well known in the art, and therefore, will not be described any further. A bus interface 808 provides an interface between the bus 802 and a transceiver 810. The transceiver 810 provides a means for communicating with various other apparatus over a transmission medium (e.g., air). Depending upon the nature of the apparatus, a user interface 812 (e.g., keypad, display, speaker, microphone, joystick) may also be provided.

[0069] The processor 804 is responsible for managing the bus 802 and general processing, including the execution of software stored on the computer-readable medium 806. The software, when executed by the processor 804, causes the processing system 814 to perform the various functions described below for any particular apparatus. The computer-readable medium 806 and the memory 805 may also be used for storing data that is manipulated by the processor 804 when executing software.

[0070] One or more processors 804 in the processing system may execute software. Software shall be construed broadly to mean instructions, instruction sets, code, code segments, program code, programs, subprograms, software modules, applications, software applications, software packages, routines, subroutines, objects, executables, threads of execution, procedures, functions, etc., whether referred to as software, firmware, middleware, microcode, hardware description language, or otherwise. The software may reside on the computer-readable medium 806.

[0071] The computer-readable medium 806 may be a non-transitory computer-readable medium. A non-transitory computer-readable medium includes, by way of example, a magnetic storage device (e.g., hard disk, floppy disk, magnetic strip), an optical disk (e.g., a compact disc (CD) or a digital versatile disc (DVD)), a smart card, a flash memory device (e.g., a card, a stick, or a key drive), a random access memory (RAM), a read only memory (ROM), a programmable ROM (PROM), an erasable PROM (EPROM), an electrically erasable PROM (EEPROM), a register, a removable disk, and any other suitable medium for storing software and/or instructions that may be accessed and read by a computer. The computer-readable medium 806 may reside in the processing system 814, external to the processing system 814, or distributed across multiple entities including the processing system 814. The computer-readable medium 806 may be embodied in a computer program product. By way of example, a computer program product may include a computer-readable medium in packaging materials. Those skilled in the art will recognize how best to implement the described functionality presented throughout this disclosure depending on the particular application and the overall design constraints imposed on the overall system.

[0072] In some aspects of the disclosure, the processor 804 may include circuitry configured for various functions. For example, the processor 804 may include communication circuitry 842. The communication circuitry 842 may include one or more hardware components that provide the physical structure that performs various processes related to wireless communication (e.g., signal reception and/or signal transmission) as described herein. The communication circuitry 842 may further be configured to execute communication software 852 included on the computer-readable medium 806 to implement one or more functions described herein. The processor 804 may also include signal processing circuitry 844. The signal processing circuitry 844 may include one or more hardware components that provide the physical structure that performs various processes related to signal processing (e.g., processing a received signal and/or processing a signal for transmission) as described herein. The signal processing circuitry 844 may further be configured to execute signal processing software 854 included on the computer-readable medium 806 to implement one or more functions described herein.

[0073] The processor 804 may further include Radio Link Control (RLC) processing circuitry 846 configured to provide an RLC sublayer in the radio protocol architecture and Packet Data Convergence Protocol (PDCP) processing circuitry 848 configured to provide a PDCP sublayer in the radio protocol architecture. In some examples, the RLC processing circuitry 846 may be configured to receive RLC Protocol Data Units (PDUs), Packet Data Convergence Protocol (PDCP) PDUs and Internet Protocol (IP) packets from a lower layer in the radio protocol architecture and to process the received RLC PDUs. In addition, the PDCP processing circuitry 848 may be configured to receive PDCP PDUs and IP packets from the RLC processing circuitry 846 and to process the PDCP PDUs.

[0074] In an aspect of the disclosure, the RLC processing circuitry 846 and PDCP processing circuitry 848 may each be configured to implement dual connectivity during a session to receive data packets from different base stations, each supporting a different radio access technology (RAT). For example, the RLC processing circuitry 846 may be configured to receive a plurality of (or group of) first RLC PDUs and a plurality of (or group of) first PDCP PDUs from a first base station supporting a first RAT, and a plurality of (or group of) second RLC PDUs and a plurality of (or group of) second PDCP PDUs from a second base station supporting a second RAT. In some examples, the first RAT may include a eUTRAN LTE RAT, while the second RAT may include a NR RAT.

[0075] Each of the first RLC PDUs in the group of first RLC PDUs may include a respective first RLC sequence number assigned by the first RAT, each of the second RLC PDUs in the group of second RLC PDUs may include a respective second RLC sequence number assigned by the second RAT, and each of the first and second PDCP PDUs in the groups of first and second PDCP PDUs may include a respective PDCP sequence number assigned independently of (or collectively between) the first and second RAT. For example, the PDCP sequence numbers assigned to the PDCP PDUs in the group of first PDCP PDUs may include a first set of sequential sequence numbers and the PDCP sequence numbers assigned to the PDCP PDUs in the group of second PDCP PDUs may include a second set of sequential sequence numbers immediately following the first set of sequential sequence numbers. For example, the group of first PDCP PDUs may be assigned sequence numbers 0–29, while the group of second PDCP PDUs may be assigned sequence numbers 30–49. Each of the first RLC PDUs may further be mapped to a respective subset of the first PDCP PDUs, and each of the second RLC PDUs may be mapped to a respective subset of the second PDCP PDUs.

[0076] In various aspects of the disclosure, when operating in an acknowledged mode (AM), the RLC processing circuitry 846 may further be configured to attempt to decode each of the first RLC PDUs, and upon successfully decoding each of the first RLC PDUs, decode and deliver the PDCP PDUs mapped to the successfully decoded first RLC PDUs to the PDCP processing circuitry 848. In addition, the RLC processing circuitry 846 may further be configured to attempt to decode each of the second RLC PDUs, and upon successfully decoding each of the second RLC PDUs, decode and deliver the PDCP PDUs mapped to the successfully decoded second RLC PDUs to the PDCP processing circuitry 848. Therefore, in an aspect of the disclosure, instead of waiting for all first RLC PDUs to be decoded to deliver PDCP PDUs in sequence number order to the PDCP processing circuitry 848, the RLC processing circuitry 846 may decode and deliver PDCP PDUs to the PDCP processing circuitry 848 as soon as the corresponding RLC PDUs mapped to those PDCP PDUs have been decoded, regardless of the sequence number order. As such, both first PDCP PDUs and second PDCP PDUs may be delivered out-of-order to the PDCP processing circuitry 848.

[0077] The RLC processing circuitry 846 may further be configured to detect an out-of-order decoded first RLC PDU in the group of first RLC PDUs. For example, the RLC processing circuitry 846 may detect that the first RLC PDU having a sequence number of 1 was decoded, but the first RLC PDU having a sequence number of 0 has yet to be decoded. Upon detecting the out-of-order decoded first RLC PDU, the RLC processing circuitry 846 may further be configured to buffer the first PDCP PDUs mapped to the undecoded first RLC PDU(s) in an RLC buffer 815 maintained, for example, in memory 805. In addition, the RLC processing circuitry 846 may initialize an RLC reordering timer 816 maintained, for example, in memory 805. The RLC reordering timer 816 may be initialized with an amount of time sufficient to complete a hybrid automatic repeat request (HARQ) process for the undecoded first RLC PDU(s).

[0078] If the undecoded first RLC PDU(s) are able to be recovered (e.g., via HARQ) prior to expiration of the RLC reordering timer 816, the RLC processing circuitry 846 may terminate the RLC reordering timer 816 and decode and deliver the corresponding first PDCP PDUs mapped to the now decoded RLC PDU(s). However, upon expiration of the RLC reordering timer 816, if the undecoded first RLC PDU(s) remain undecoded, the RLC processing circuitry 846 may generate and transmit an RLC status PDU including acknowledgement information (e.g., ACK/NACK) for the group of first RLC PDUs. The RLC status PDU may include, for example, a NACK for the undecoded first RLC PDUs to initialize a retransmission (e.g., ARQ) procedure to recover the missing (undecoded) first RLC PDUs.

[0079] Since the RLC processing circuitry 846 is able to deliver out-of-order PDCP PDUs to the PDCP processing circuitry 848, the PDCP processing circuitry 848 may further be configured to detect an out-of-order decoded PDCP PDU (e.g., when one or more of the RLC PDUs remains undecoded). The PDCP processing circuitry 848 may then be configured to initialize a PDCP reordering timer 818 maintained, for example, in memory 805 upon detecting the out-of-order PDCP PDU. For example, the PDCP processing circuitry 848 may be configured to initialize the PDCP reordering timer 818 after the RLC processing circuitry 846 delivers PDCP PDUs mapped to an out-of-order decoded RLC PDU (e.g., either an out-of-order decoded first RLC PDU or an out-of-order decoded second RLC PDU). Thus, the PDCP reordering timer 818 may be initialized substantially simultaneously to the RLC reordering timer 816.

[0080] If the undecoded first RLC PDU(s) are able to be decoded and the corresponding first PDCP PDUs mapped thereto are delivered to the PDCP processing circuitry 848 prior to expiration of the PDCP reordering timer 818, the PDCP processing circuitry 848 may terminate the PDCP reordering timer 818. However, upon expiration of the PDCP reordering timer 818, if the missing first PDCP PDUs remain missing (e.g., the RLC processing circuitry 846 failed to decode the corresponding first RLC PDUs during HARQ/ARQ), the PDCP processing circuitry 848 may instruct the RLC processing circuitry 846 to discard any first PDCP PDUs remaining in the RLC buffer 815. In some examples, the PDCP reordering timer 818 may expire prior to completion of the ARQ process. However, the number of dropped (discarded) PDCP PDUs is limited only to those mapped to RLC PDUs that failed to be decoded at the expiration of the PDCP reordering timer.

[0081] In various aspects of the disclosure, when operating in an unacknowledged mode (UM), the RLC processing circuitry 846 may further be configured to initialize the RLC reordering timer upon detecting an out-of-order decoded first RLC PDU in the group of first RLC PDUs and to buffer all of the first PDCP PDUs mapped to first RLC PDUs received since the last in-order decoded first RLC PDU in the RLC buffer 815. If the undecoded first RLC PDU(s) are able to be recovered/decoded (e.g., via HARQ) prior to expiration of the RLC reordering timer 816, the RLC processing circuitry 846 may terminate the RLC reordering timer 816 and decode and deliver all of the first PDCP PDUs in the RLC buffer 815. However, upon expiration of the RLC reordering timer 816, if the undecoded first RLC PDU(s) remain undecoded, the RLC processing circuitry 846 may decode and deliver any buffered first PDCP PDUs mapped to decoded first RLC PDUs and discard any buffered first PDCP PDUs mapped to the undecoded first RLC PDU(s). In this example, the PDCP processing circuitry 848 may initiate the PDCP reordering timer 818 upon receipt of the first out-of-order second PDCP PDU. However, the PDCP reordering timer 818 may be longer than the RLC reordering timer 816, and therefore, the PDCP reordering timer 818 may not be utilized in determining to drop (discard) first PDCP PDUs mapped to RLC PDUs that failed to be decoded at the expiration of the RLC reordering timer 816.

[0082] The RLC processing circuitry 846 may further be configured to execute RLC processing software 856 included on the computer-readable medium 806 to implement one or more functions described herein. In addition, the PDCP processing circuitry 848 may further be configured to execute PDCP processing software 858 included on the computer-readable medium 806 to implement one or more functions described herein. The circuitry included in the processor 804 is provided as non-limiting examples. Other means for carrying out the described functions exists and is included within various aspects of the present disclosure.

[0083] FIG. 9 is a diagram illustrating an RLC sublayer 902 and a PDCP sublayer 912 within a user equipment (UE) implementing dual connectivity. The RLC sublayer 902 may correspond to, for example, the RLC processing circuitry 846 and RLC processing software 856 shown and described above in connection with FIG. 8. The PDCP sublayer 912 may correspond to, for example, the PDCP processing circuitry 948 and PDCP processing software 958 shown and described above in connection with FIG. 8.

[0084] The RLC sublayer 902 includes an LTE RLC sublayer 904 configured to receive LTE PDUs 920 (e.g., LTE RLC and PDCP PDUs) from a lower layer and to process the LTE RLC PDUs. The RLC sublayer 902 further includes a NR RLC sublayer 906 configured to receive NR PDUs 922 (e.g., NR RLC and PDCP PDUs) from a lower layer and to process the NR RLC PDUs. The PDCP sublayer 912 includes an LTE PDCP sublayer 914 configured to receive and process LTE PDCP PDUs 924 from the LTE RLC sublayer 904 and a NR PDCP sublayer 916 configured to receive and process NR PDCP PDUs 926 from the NR RLC sublayer 906.

[0085] When operating in an acknowledged mode (AM), the LTE RLC sublayer 904 may be configured to attempt to decode each of the LTE RLC PDUs, and upon successfully decoding each of the LTE RLC PDUs, decode and deliver the LTE PDCP PDUs 924 mapped to the successfully decoded LTE RLC PDUs to the LTE PDCP sublayer 914. In addition, the NR RLC sublayer 906 may be configured to attempt to decode each of the NR RLC PDUs, and upon successfully decoding each of the NR RLC PDUs, decode and deliver the NR PDCP PDUs 926 mapped to the successfully decoded NR RLC PDUs to the NR PDCP sublayer 916.

[0086] The LTE RLC sublayer 904 may further be configured to detect an out-of-order decoded LTE RLC PDU as a result of undecoded LTE RLC PDU(s) and to buffer the LTE PDCP PDUs mapped to the undecoded LTE RLC PDU(s) in an RLC buffer 908. The RLC buffer 908 may correspond to, for example, the RLC buffer 815 shown and described above in connection with FIG. 8. The LTE RLC sublayer 904 may further initialize an RLC reordering timer 910 with an amount of time sufficient to complete a

HARQ process to attempt to recover the undecoded LTE RLC PDU(s). The RLC reordering timer 910 may correspond to, for example, the RLC reordering timer 816 shown and described above in connection with FIG. 8.

[0087] If the undecoded first RLC PDU(s) are able to be decoded prior to expiration of the RLC reordering timer 910, the LTE RLC sublayer 904 may terminate the RLC reordering timer 910 and decode and deliver the corresponding LTE PDCP PDUs mapped to the now decoded LTE RLC PDU(s) to the LTE PDCP sublayer 914. However, upon expiration of the RLC reordering timer 910, if the undecoded LTE RLC PDU(s) remain undecoded, the LTE RLC sublayer 904 may generate and transmit an RLC status PDU including, for example, a NACK for the undecoded LTE RLC PDUs to initialize a retransmission (e.g., ARQ) procedure to recover the missing (undecoded) LTE RLC PDUs.

[0088] The LTE PDCP sublayer 914 and the NR PDCP sublayer 916 may collectively be configured to detect an out-of-order decoded PDCP PDU (e.g., when one or more of the LTE RLC PDUs remains undecoded). The NR PDCP sublayer 916 may then be configured to initialize a PDCP reordering timer 918 after the RLC sublayer 902 delivers PDCP PDUs mapped to an out-of-order decoded RLC PDU. The PDCP reordering timer 918 may correspond to, for example, the PDCP reordering timer 818 shown and described above in connection with FIG. 8. If the undecoded LTE RLC PDU(s) are able to be decoded and the corresponding LTE PDCP PDUs mapped thereto are delivered to the LTE PDCP sublayer 914 prior to expiration of the PDCP reordering timer 918, the NR PDCP sublayer 916 may terminate the PDCP reordering timer 918. However, upon expiration of the PDCP reordering timer 918, if the missing LTE PDCP PDUs remain missing, the NR PDCP sublayer 916 may instruct the LTE RLC sublayer 904 via the LTE PDCP sublayer 914 to discard any LTE PDCP PDUs remaining in the RLC buffer 908.

[0089] When operating in an unacknowledged mode (UM), after the LTE RLC sublayer 904 detects an out-of-order decoded LTE RLC PDU, the LTE RLC sublayer 904 may initialize the RLC reordering timer 910 and buffer all of the LTE PDCP PDUs mapped to LTE RLC PDUs received since the last in-order decoded LTE RLC PDU in the RLC buffer 908. If the undecoded LTE RLC PDU(s) are able to be recovered/decoded (e.g., via HARQ) prior to expiration of the RLC reordering timer 910, the LTE RLC sublayer may terminate the RLC reordering timer 910 and decode and deliver all of the LTE PDCP PDUs 924 in the RLC buffer 908. However, upon expiration of the RLC reordering timer 910, if the undecoded LTE RLC PDU(s) remain undecoded, the LTE RLC sublayer 902 may decode and deliver any buffered LTE PDCP PDUs mapped to decoded LTE RLC PDUs and discard any buffered LTE PDCP PDUs mapped to the undecoded LTE RLC PDU(s). In this example, the NR PDCP sublayer 916 may also initiate the PDCP reordering timer 918 upon receipt of the first out-of-order NR PDCP PDU 926.

[0090] FIG. 10 is a flow chart illustrating an exemplary process 1000 for delivering out-of-order PDCP PDUs to the PDCP sublayer in accordance with some aspects of the present disclosure. As described below, some or all illustrated features may be omitted in a particular implementation within the scope of the present disclosure, and some illustrated features may not be required for implementation of all embodiments. In some examples, the process 1000 may be carried out by the UE 800 illustrated in FIG. 8. In some examples, the process 1000 may be carried out by any suitable apparatus or means for carrying out the functions or algorithm described below.

[0091] At block 1002, the UE configured to dual connectivity between LTE and NR RATs may receive a plurality of LTE RLC PDUs and a plurality of LTE PDCP PDUs from an LTE base station in wireless communication with the UE. Each of the LTE RLC PDUs may be mapped to a respective subset of the plurality of LTE PDCP PDUs. In addition, each of the LTE RLC PDUs may include a respective sequence number (SN) assigned by the LTE RAT, and each of the LTE PDCP PDUs may include a respective SN assigned independent of the RAT. For example, the RLC processing circuitry 846 and transceiver 810 shown and described above in reference to FIG. 8 may receive the LTE RLC PDUs and LTE PDCP PDUs.

[0092] At block 1004, the UE may receive a plurality of NR RLC PDUs and a plurality of NR PDCP PDUs from a NR base station in wireless communication with the UE. Each of the NR RLC PDUs may be mapped to a respective subset of the plurality of NR PDCP PDUs. In addition, each of the NR RLC PDUs may include a respective sequence number (SN) assigned by the NR RAT, and each of the NR PDCP PDUs may include a respective SN assigned independent of the RAT. In some examples, the NR PDCP PDUs may include SN's that immediately follow the SNs of the LTE PDCP PDUs. For example, the RLC processing circuitry 846 and transceiver 810 shown and described above in reference to FIG. 8 may receive the NR RLC PDUs and NR PDCP PDUs.

[0093] At block 1006, the UE may detect an out-of-order PDCP PDU delivered to the PDCP sublayer from the RLC sublayer. For example, due to high BLER on the LTE downlink, one or more LTE RLC PDUs may fail to be decoded, thus resulting in the UE requesting retransmission via HARQ and ARQ of the undecoded (missing) LTE RLC PDUs when the RLC sublayer is operating in acknowledged mode (AM). During the retransmission procedure, the LTE PDCP PDUs mapped to the missing LTE RLC PDUs may be buffered, resulting in out-of-order LTE PDCP PDUs and/or NR PDCP PDUs being delivered to the PDCP sublayer. As another example, when the UE is operating in unacknowledged mode (UM), the UE may request retransmission via HARQ of the undecoded (missing) LTE RLC PDUs and buffer LTE PDCP PDUs mapped to LTE RLC PDUs received since the last in-order RLC PDU during the pendency of an RLC reordering timer initiated upon detecting an out-of-order decoded RLC PDU. This may result in the PDCP sublayer detecting an out-of-order NR PDCP PDU (e.g., due to the buffering of the LTE PDCP PDUs). For example, the PDCP processing circuitry 848 shown and described above in reference to FIG. 8 may detect an out-of-order PDCP PDU.

[0094] At block 1008, in response to detecting the out-of-order PDCP PDU, the UE may initiate a PDCP reordering timer. For example, the PDCP processing circuitry 848 shown and described above in reference to FIG. 8 may initiate the PDCP reordering timer.

[0095] At block 1010, the UE determines whether the PDCP reordering timer has expired. If the PDCP reordering timer has not expired (N branch of block 1010), at block 1012, the UE may deliver LTE PDCP PDUs mapped to decoded RLC PDUs from the RLC sublayer to the PDCP sublayer. For example, in acknowledged mode, the UE may deliver LTE PDCP PDUs from the RLC sublayer to the PDCP sublayer as the corresponding LTE RLC PDUs mapped thereto are decoded. As another example, in unacknowledged mode, the UE may deliver buffered LTE PDCP PDUs mapped to decoded LTE RLC PDUs upon expiration of the RLC reordering timer. For example, the RLC processing circuitry 846 and PDCP processing circuitry 848 shown and described above in connection with FIG. 8 may determine whether the PDCP reordering timer has expired, and if not, deliver LTE PDCP PDUs mapped to decoded LTE RLC PDUs from the RLC sublayer to the PDCP sublayer.

[0096] If the PDCP reordering timer has expired (Y branch of block 1010), at block 1014, the UE may discard buffered LTE PDCP PDUs mapped to missing (undecoded) LTE RLC PDUs. For example, the RLC processing circuitry 846 and PDCP processing circuitry 848 shown and described above in connection with FIG. 8 may discard buffered LTE PDCP PDUs upon expiration of the PDCP reordering timer.

[0097] Several aspects of a wireless communication network have been presented with reference to an exemplary implementation. As those skilled in the art will readily appreciate, various aspects described throughout this disclosure may be extended to other telecommunication systems, network architectures and communication standards.

[0098] By way of example, various aspects may be implemented within other systems defined by 3GPP, such as Long-Term Evolution (LTE), the Evolved Packet System (EPS), the Universal Mobile Telecommunication System (UMTS), and/or the Global System for Mobile (GSM). Various aspects may also be extended to systems defined by the 3rd Generation Partnership Project 2 (3GPP2), such as CDMA2000 and/or Evolution-Data Optimized (EV-DO). Other examples may be implemented within systems employing IEEE 802.11 (Wi-Fi), IEEE 802.16 (WiMAX), IEEE 802.20, Ultra-Wideband (UWB), Bluetooth, and/or other suitable systems. The actual telecommunication standard, network architecture, and/or communication standard employed will depend on the specific application and the overall design constraints imposed on the system.

[0099] Within the present disclosure, the word “exemplary” is used to mean “serving as an example, instance, or illustration.” Any implementation or aspect described herein as “exemplary” is not necessarily to be construed as preferred or advantageous over other aspects of the disclosure. Likewise, the term “aspects” does not require that all aspects of the disclosure include the discussed feature, advantage or mode of operation. The term “coupled” is used herein to refer to the direct or indirect coupling between two objects. For example, if object A physically touches object B, and object B touches object C, then objects A and C may still be considered coupled to one another—even if they do not directly physically touch each other. For instance, a first object may be coupled to a second object even though the first object is never directly physically in contact with the second object. The terms “circuit” and “circuitry” are used broadly, and intended to include both hardware implementations of electrical devices and conductors that, when connected and configured, enable the performance of the functions described in the present disclosure, without limitation as to the type of electronic circuits, as well as software implementations of information and instructions that, when executed by a processor, enable the performance of the functions described in the present disclosure.

[0100] One or more of the components, steps, features and/or functions illustrated in FIGs. 1–10 may be rearranged and/or combined into a single component, step, feature or function or embodied in several components, steps, or functions. Additional elements, components, steps, and/or functions may also be added without departing from novel features disclosed herein. The apparatus, devices, and/or components illustrated in FIGs. 1, 2 and 8 may be configured to perform one or more of the methods, features, or steps described herein. The novel algorithms described herein may also be efficiently implemented in software and/or embedded in hardware.

[0101] It is to be understood that the specific order or hierarchy of steps in the methods disclosed is an illustration of exemplary processes. Based upon design preferences, it is understood that the specific order or hierarchy of steps in the methods may be rearranged. The accompanying method claims present elements of the various steps in a sample order, and are not meant to be limited to the specific order or hierarchy presented unless specifically recited therein.

[0102] The previous description is provided to enable any person skilled in the art to practice the various aspects described herein. Various modifications to these aspects will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other aspects. Thus, the claims are not intended to be limited to the aspects shown herein, but are to be accorded the full scope consistent with the language of the claims, wherein reference to an element in the singular is not intended to mean "one and only one" unless specifically so stated, but rather "one or more." Unless specifically stated otherwise, the term "some" refers to one or more. A phrase referring to "at least one of" a list of items refers to any combination of those items, including single members. As an example, "at least one of: a, b, or c" is intended to cover: a; b; c; a and b; a and c; b and c; and a, b and c. All structural and functional equivalents to the elements of the various aspects described throughout this disclosure that are known or later come to be known to those of ordinary skill in the art are expressly incorporated herein by reference and are intended to be encompassed by the claims. Moreover, nothing disclosed herein is intended to be dedicated to the public regardless of whether such disclosure is explicitly recited in the claims.

CLAIMS

1. A method of wireless communication at a user equipment configured for dual connectivity in a wireless communication network, the method comprising:

receiving a plurality of first radio link control (RLC) protocol data units (PDUs) and a plurality of first packet data convergence protocol (PDCP) PDUs from a first base station supporting a first radio access technology (RAT), wherein each of the plurality of first RLC PDUs is mapped to a respective first subset of the plurality of first PDCP PDUs;

receiving a plurality of second RLC PDUs and a plurality of second PDCP PDUs from a second base station supporting a second RAT, wherein each of the plurality of second RLC PDUs is mapped to a respective second subset of the plurality of second PDCP PDUs;

initializing a PDCP reordering timer upon delivering at least one out-of-order second PDCP PDU of the plurality of second PDCP PDUs from a RLC sublayer to a PDCP sublayer within the user equipment for processing of the at least one out-of-order second PDCP PDU; and

prior to expiration of the PDCP reordering timer, delivering each respective first subset of the plurality of first PDCP PDUs mapped to each respective decoded first RLC PDU of the plurality of first RLC PDUs from the RLC sublayer to the PDCP sublayer for processing thereof.

2. The method of claim 1, wherein delivering each respective first subset of the plurality of first PDCP PDUs mapped to each respective decoded RLC PDU of the plurality of first RLC PDUs from the RLC sublayer to the PDCP sublayer for processing thereof further comprises:

delivering each respective first subset of the plurality of first PDCP PDUs from the RLC sublayer to the PDCP sublayer upon decoding corresponding in-order decoded first RLC PDUs of the plurality of first RLC PDUs mapped thereto.

3. The method of claim 2, further comprising:

detecting an out-of-order decoded first RLC PDU of the plurality of first RLC PDUs;

buffering each respective first subset of the plurality of second PDCP PDUs mapped to respective corresponding ones of the plurality of first RLC PDUs received since a last in-order decoded first RLC PDU of the plurality of first RLC PDUs in an RLC buffer; and

initializing an RLC reordering timer upon detecting the out-of-order decoded first RLC PDU.

4. The method of claim 3, wherein the RLC sublayer is configured to operate in an acknowledged mode, and further comprising:

unsuccessfully decoding an undecoded first RLC PDU of the plurality of first RLC PDUs between the last in-order decoded first RLC PDU and the out-of-order decoded first RLC PDU; and

initiating a retransmission procedure to request retransmission of the undecoded first RLC PDU upon expiration of the RLC reordering timer.

5. The method of claim 4, wherein delivering each respective first subset of the plurality of first PDCP PDUs mapped to each respective decoded first RLC PDU of the plurality of first RLC PDUs from the RLC sublayer to the PDCP sublayer for processing thereof further comprises:

delivering each respective first subset of the plurality of first PDCP PDUs mapped to each respective decoded first RLC PDU of the plurality of first RLC PDUs from the RLC buffer upon successfully decoding of each of the decoded first RLC PDUs during the retransmission procedure and prior to expiration of the PDCP reordering timer; and

discarding each respective first subset of the plurality of first PDCP PDUs mapped to each respective undecoded first RLC PDU of the plurality of first RLC PDUs from the RLC buffer upon completion of the retransmission procedure when completion of the retransmission procedure occurs subsequent to expiration of the PDCP reordering timer.

6. The method of claim 3, wherein the RLC sublayer is configured to operate in an unacknowledged mode, and further comprising:

delivering each respective first subset of the plurality of first PDCP PDUs mapped to each respective decoded first RLC PDU of the plurality of first RLC PDUs from the RLC buffer upon successfully decoding of each of the decoded first RLC PDUs prior to expiration of the RLC reordering timer; and

discarding each respective first subset of the plurality of first PDCP PDUs mapped to each respective undecoded first RLC PDU of the plurality of first RLC PDUs from the RLC buffer upon expiration of the RLC reordering timer.

7. The method of claim 1, wherein:

each of the plurality of first RLC PDUs comprises a respective first RLC sequence number assigned by the first RAT and each of the plurality of second RLC PDUs comprises a respective second RLC number assigned by the second RAT; and

each of the plurality of first PDCP PDUs and each of the plurality of second PDCP PDUs comprises a respective PDCP sequence number assigned independent of the first RAT and the second RAT.

8. The method of claim 7, wherein the respective PDCP sequence numbers assigned to the plurality of first PDCP PDUs comprises a first set of sequential sequence numbers and the respective PDCP sequence numbers assigned to the plurality of second PDCP PDUs comprises a second set of sequence numbers immediately following the first set of sequence numbers.

9. The method of claim 1, wherein delivering each respective first subset of the plurality of first PDCP PDUs mapped to each respective decoded first RLC PDU of the plurality of first RLC PDUs from the RLC sublayer to the PDCP sublayer for processing thereof further comprises:

decoding each of the plurality of first PDCP PDUs mapped to each respective decoded first RLC PDU to produce a plurality of first decoded PDCP PDUs; and

delivering the plurality of first decoded PDCP PDUs from the RLC sublayer to the PDCP sublayer.

10. The method of claim 1, wherein the first RAT comprises an Evolved Universal Terrestrial Radio Access RAT and the second RAT comprises a New Radio RAT.

11. The method of claim 1, wherein the RLC sublayer comprises a first RLC sublayer configured for the first RAT and a second RLC sublayer configured for the second RAT.

12. A user equipment configured for dual connectivity in a wireless communication network, comprising:

a transceiver configured for dual connectivity to communicate with a first base station supporting a first radio access technology (RAT) and a second base station supporting a second RAT;

a memory; and

a processor communicatively coupled to the transceiver and the memory, the processor configured to:

receive, via the transceiver, a plurality of first radio link control (RLC) protocol data units (PDUs) and a plurality of first packet data convergence protocol (PDCP) PDUs from the first base station, wherein each of the plurality of first RLC PDUs is mapped to a respective first subset of the plurality of first PDCP PDUs;

receive, via the transceiver, a plurality of second RLC PDUs and a plurality of second PDCP PDUs from the second base station, wherein each of the plurality of second RLC PDUs is mapped to a respective second subset of the plurality of second PDCP PDUs;

initialize a PDCP reordering timer upon delivering at least one out-of-order second PDCP PDU of the plurality of second PDCP PDUs from a RLC sublayer to a PDCP sublayer for processing of the at least one out-of-order second PDCP PDU; and

prior to expiration of the PDCP reordering timer, deliver each respective first subset of the plurality of first PDCP PDUs mapped to each respective decoded first RLC PDU of the plurality of first RLC PDUs from the RLC sublayer to the PDCP sublayer for processing thereof.

13. The user equipment of claim 12, wherein the processor is further configured to:

deliver each respective first subset of the plurality of first PDCP PDUs from the RLC sublayer to the PDCP sublayer upon decoding corresponding in-order decoded first RLC PDUs of the plurality of first RLC PDUs mapped thereto.

14. The user equipment of claim 13, wherein the processor is further configured to:

detect an out-of-order decoded first RLC PDU of the plurality of first RLC PDUs;

buffer each respective first subset of the plurality of second PDCP PDUs mapped to respective corresponding ones of the plurality of first RLC PDUs received since a last in-order decoded first RLC PDU of the plurality of first RLC PDUs in an RLC buffer within the memory; and

initialize an RLC reordering timer upon detecting the out-of-order decoded first RLC PDU.

15. The user equipment of claim 14, wherein the RLC sublayer is configured to operate in an acknowledged mode, and wherein the processor is further configured to:

unsuccessfully decode an undecoded first RLC PDU of the plurality of first RLC PDUs between the last in-order decoded first RLC PDU and the out-of-order decoded first RLC PDU; and

initiate a retransmission procedure to request retransmission of the undecoded first RLC PDU upon expiration of the RLC reordering timer.

16. The user equipment of claim 15, wherein the processor is further configured to:

deliver each respective first subset of the plurality of first PDCP PDUs mapped to each respective decoded first RLC PDU of the plurality of first RLC PDUs from the RLC buffer upon successfully decoding of each of the decoded first RLC PDUs during the retransmission procedure and prior to expiration of the PDCP reordering timer; and

discard each respective first subset of the plurality of first PDCP PDUs mapped to each respective undecoded first RLC PDU of the plurality of first RLC PDUs from the RLC buffer upon completion of the retransmission procedure when completion of the retransmission procedure occurs subsequent to expiration of the PDCP reordering timer.

17. The user equipment of claim 14, wherein the RLC sublayer is configured to operate in an unacknowledged mode, and wherein the processor is further configured to:

deliver each respective first subset of the plurality of first PDCP PDUs mapped to each respective decoded first RLC PDU of the plurality of first RLC PDUs from the RLC buffer upon successfully decoding of each of the decoded first RLC PDUs prior to expiration of the RLC reordering timer; and

discard each respective first subset of the plurality of first PDCP PDUs mapped to each respective undecoded first RLC PDU of the plurality of first RLC PDUs from the RLC buffer upon expiration of the RLC reordering timer.

18. The user equipment of claim 12, wherein:

each of the plurality of first RLC PDUs comprises a respective first RLC sequence number assigned by the first RAT and each of the plurality of second RLC PDUs comprises a respective second RLC number assigned by the second RAT; and

each of the plurality of first PDCP PDUs and each of the plurality of second PDCP PDUs comprises a respective PDCP sequence number assigned independent of the first RAT and the second RAT.

19. The user equipment of claim 18, wherein the respective PDCP sequence numbers assigned to the plurality of first PDCP PDUs comprises a first set of sequential sequence numbers and the respective PDCP sequence numbers assigned to the plurality of second PDCP PDUs comprises a second set of sequence numbers immediately following the first set of sequence numbers.

20. The user equipment of claim 12, wherein the processor is further configured to:

decode each of the plurality of first PDCP PDUs mapped to each respective decoded first RLC PDU to produce a plurality of first decoded PDCP PDUs; and

deliver the plurality of first decoded PDCP PDUs from the RLC sublayer to the PDCP sublayer.

21. The user equipment of claim 12, wherein the first RAT comprises an Evolved Universal Terrestrial Radio Access RAT and the second RAT comprises a New Radio RAT.

22. The user equipment of claim 12, wherein the RLC sublayer comprises a first RLC sublayer configured for the first RAT and a second RLC sublayer configured for the second RAT.

23. A user equipment configured for dual connectivity in a wireless communication network, comprising:

means for receiving a plurality of first radio link control (RLC) protocol data units (PDUs) and a plurality of first packet data convergence protocol (PDCP) PDUs from a first base station supporting a first radio access technology (RAT), wherein each of the plurality of first RLC PDUs is mapped to a respective first subset of the plurality of first PDCP PDUs;

means for receiving a plurality of second RLC PDUs and a plurality of second PDCP PDUs from a second base station supporting a second RAT, wherein each of the plurality of second RLC PDUs is mapped to a respective second subset of the plurality of second PDCP PDUs;

means for initializing a PDCP reordering timer upon delivering at least one out-of-order second PDCP PDU of the plurality of second PDCP PDUs from a RLC sublayer to a PDCP sublayer within the user equipment for processing of the at least one out-of-order second PDCP PDU; and

means for delivering each respective first subset of the plurality of first PDCP PDUs mapped to each respective decoded first RLC PDU of the plurality of first RLC PDUs from the RLC sublayer to the PDCP sublayer for processing thereof prior to expiration of the PDCP reordering timer.

24. The user equipment of claim 23, wherein the means for delivering each respective first subset of the plurality of first PDCP PDUs mapped to each respective decoded RLC PDU of the plurality of first RLC PDUs from the RLC sublayer to the PDCP sublayer for processing thereof further comprises:

means for delivering each respective first subset of the plurality of first PDCP PDUs from the RLC sublayer to the PDCP sublayer upon decoding corresponding in-order decoded first RLC PDUs of the plurality of first RLC PDUs mapped thereto.

25. The user equipment of claim 24, further comprising:

means for detecting an out-of-order decoded first RLC PDU of the plurality of first RLC PDUs;

means for buffering each respective first subset of the plurality of second PDCP PDUs mapped to respective corresponding ones of the plurality of first RLC PDUs received since a last in-order decoded first RLC PDU of the plurality of first RLC PDUs in an RLC buffer; and

means for initializing an RLC reordering timer upon detecting the out-of-order decoded first RLC PDU.

26. The user equipment of claim 25, wherein the RLC sublayer is configured to operate in an acknowledged mode, and further comprising:

means for unsuccessfully decoding an undecoded first RLC PDU of the plurality of first RLC PDUs between the last in-order decoded first RLC PDU and the out-of-order decoded first RLC PDU; and

means for initiating a retransmission procedure to request retransmission of the undecoded first RLC PDU upon expiration of the RLC reordering timer.

27. The user equipment of claim 26, wherein the means for delivering each respective first subset of the plurality of first PDCP PDUs mapped to each respective decoded first RLC PDU of the plurality of first RLC PDUs from the RLC sublayer to the PDCP sublayer for processing thereof further comprises:

means for delivering each respective first subset of the plurality of first PDCP PDUs mapped to each respective decoded first RLC PDU of the plurality of first RLC PDUs from the RLC buffer upon successfully decoding of each of the decoded first RLC PDUs during the retransmission procedure and prior to expiration of the PDCP reordering timer; and

means for discarding each respective first subset of the plurality of first PDCP PDUs mapped to each respective undecoded first RLC PDU of the plurality of first RLC PDUs from the RLC buffer upon completion of the retransmission procedure when completion of the retransmission procedure occurs subsequent to expiration of the PDCP reordering timer.

28. The user equipment of claim 25, wherein the RLC sublayer is configured to operate in an unacknowledged mode, and further comprising:

means for delivering each respective first subset of the plurality of first PDCP PDUs mapped to each respective decoded first RLC PDU of the plurality of first RLC PDUs from the RLC buffer upon successfully decoding of each of the decoded first RLC PDUs prior to expiration of the RLC reordering timer; and

means for discarding each respective first subset of the plurality of first PDCP PDUs mapped to each respective undecoded first RLC PDU of the plurality of first RLC PDUs from the RLC buffer upon expiration of the RLC reordering timer.

29. The user equipment of claim 23, wherein:

each of the plurality of first RLC PDUs comprises a respective first RLC sequence number assigned by the first RAT and each of the plurality of second RLC PDUs comprises a respective second RLC number assigned by the second RAT; and

each of the plurality of first PDCP PDUs and each of the plurality of second PDCP PDUs comprises a respective PDCP sequence number assigned independent of the first RAT and the second RAT.

30. The user equipment of claim 29, wherein the respective PDCP sequence numbers assigned to the plurality of first PDCP PDUs comprises a first set of sequential sequence numbers and the respective PDCP sequence numbers assigned to the plurality of second PDCP PDUs comprises a second set of sequence numbers immediately following the first set of sequence numbers.

31. The user equipment of claim 23, wherein the means for delivering each respective first subset of the plurality of first PDCP PDUs mapped to each respective decoded first RLC PDU of the plurality of first RLC PDUs from the RLC sublayer to the PDCP sublayer for processing thereof further comprises:

means for decoding each of the plurality of first PDCP PDUs mapped to each respective decoded first RLC PDU to produce a plurality of first decoded PDCP PDUs; and means for delivering the plurality of first decoded PDCP PDUs from the RLC sublayer to the PDCP sublayer.

32. A non-transitory computer-readable medium storing computer-executable code, comprising code for causing a user equipment to:

receive a plurality of first radio link control (RLC) protocol data units (PDUs) and a plurality of first packet data convergence protocol (PDCP) PDUs from the first base station, wherein each of the plurality of first RLC PDUs is mapped to a respective first subset of the plurality of first PDCP PDUs;

receive a plurality of second RLC PDUs and a plurality of second PDCP PDUs from the second base station, wherein each of the plurality of second RLC PDUs is mapped to a respective second subset of the plurality of second PDCP PDUs;

initialize a PDCP reordering timer upon delivering at least one out-of-order second PDCP PDU of the plurality of second PDCP PDUs from a RLC sublayer to a PDCP sublayer for processing of the at least one out-of-order second PDCP PDU; and

prior to expiration of the PDCP reordering timer, deliver each respective first subset of the plurality of first PDCP PDUs mapped to each respective decoded first RLC PDU of the plurality of first RLC PDUs from the RLC sublayer to the PDCP sublayer for processing thereof.

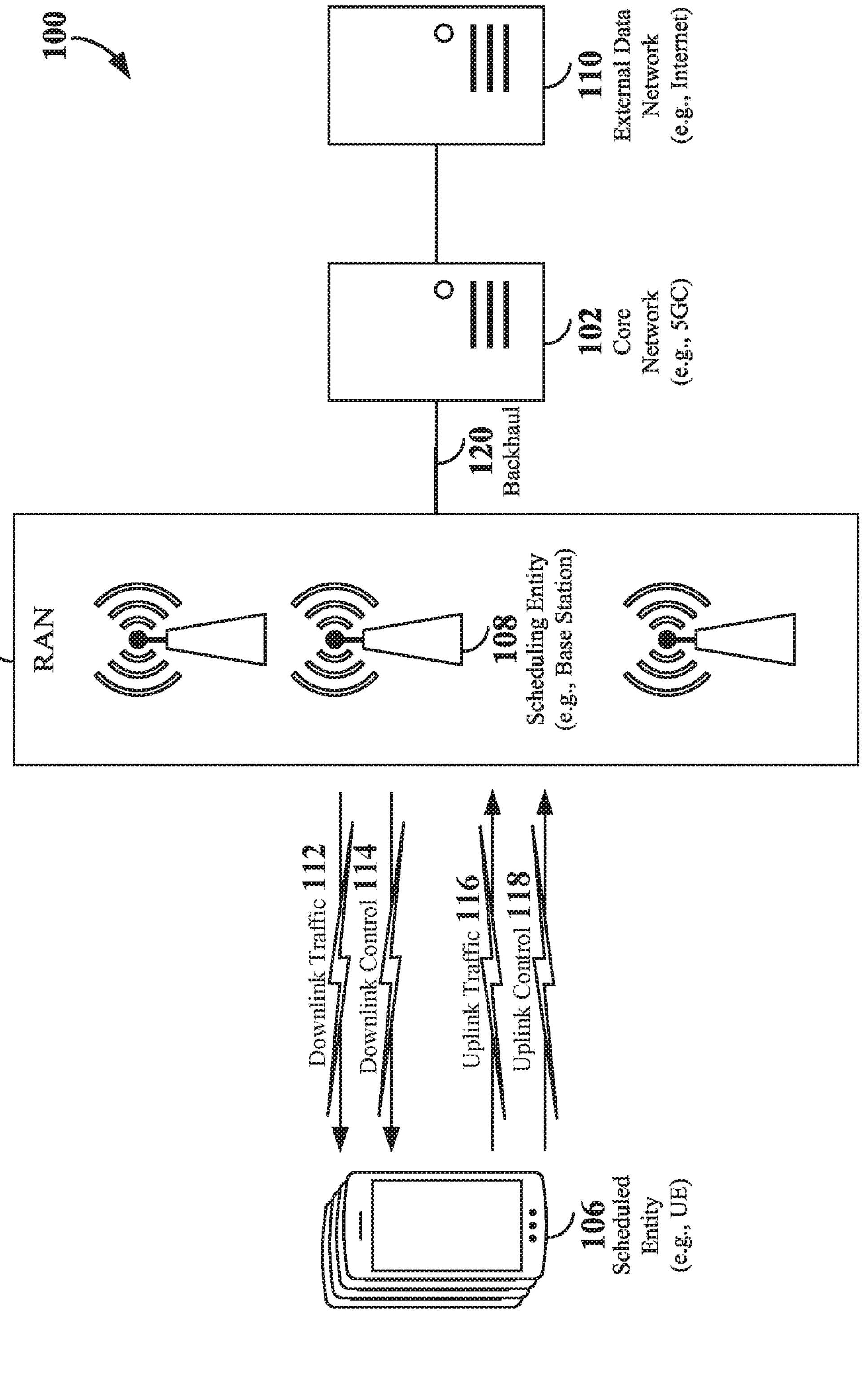
100
110
External Data
Network
(e.g., Internet)
102
Core
Network
(e.g., 5GC)
120
Backhaul
104
RAN
108
Scheduling Entity
(e.g., Base Station)
Downlink Traffic 112
Downlink Control 114
Uplink Traffic 116
Uplink Control 118
106
Scheduled
Entity
(e.g., UE)

FIG. 1

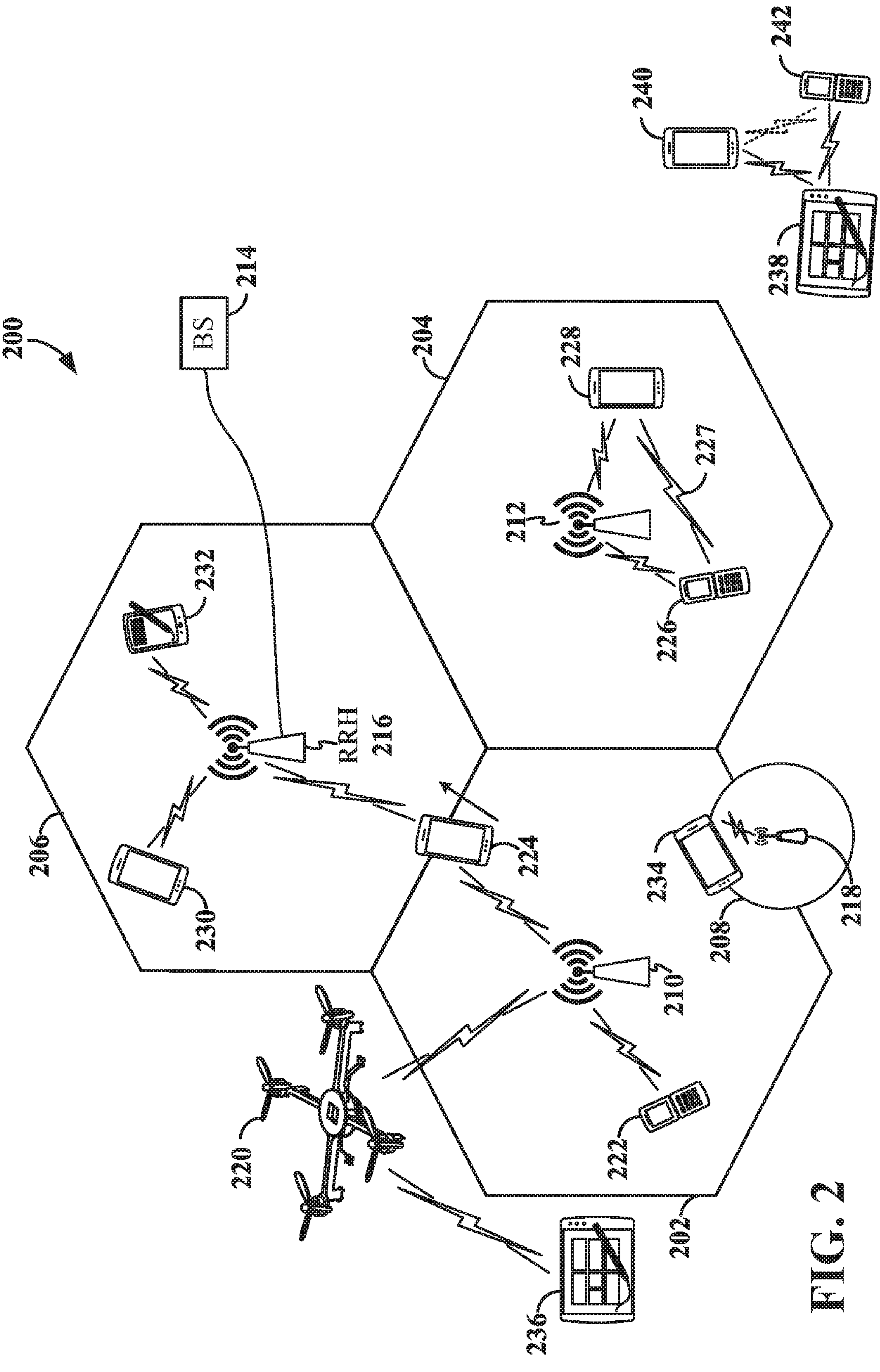
200
BS
214
204
228
227
212
226
232
RRH
216
206
230
224
210
208
234
218
220
222
202
236
238
240
242

FIG. 2

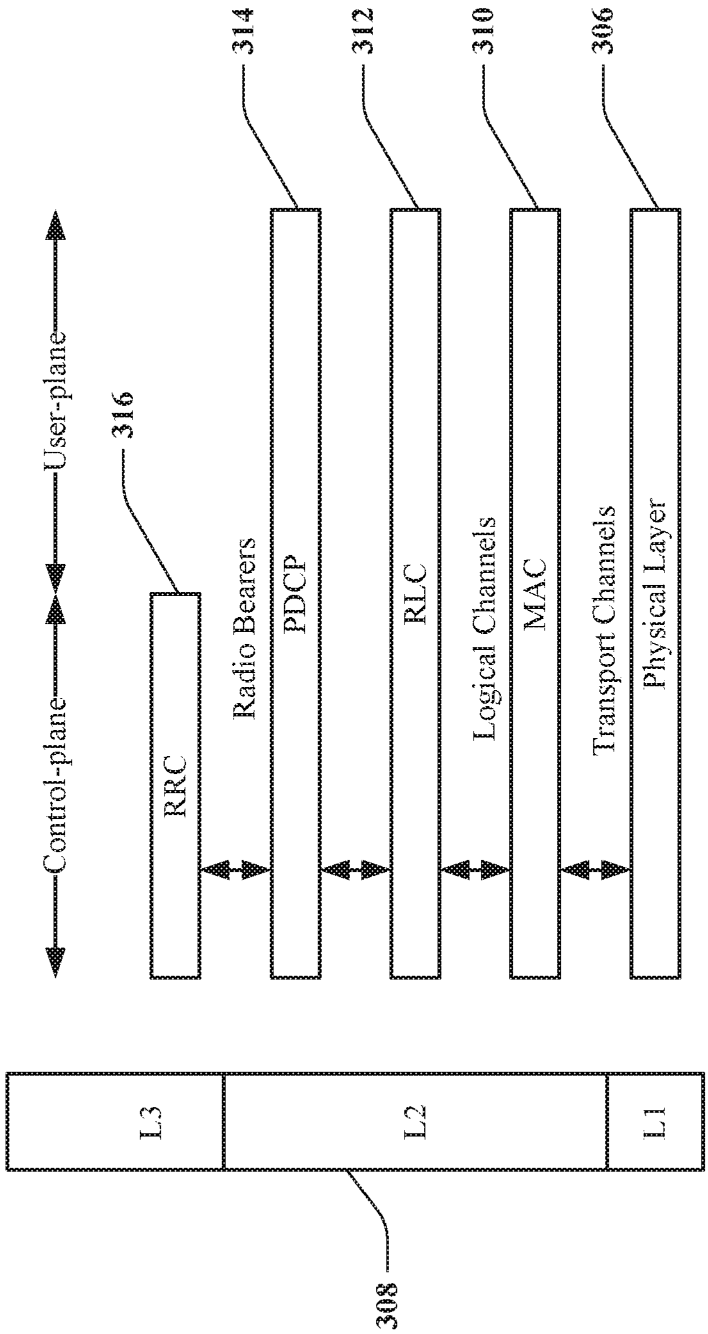
Control-plane
User-plane
316
RRC
Radio Bearers
314
PDCP
312
RLC
Logical Channels
310
MAC
Transport Channels
306
Physical Layer
L3
L2
L1
308

FIG. 3

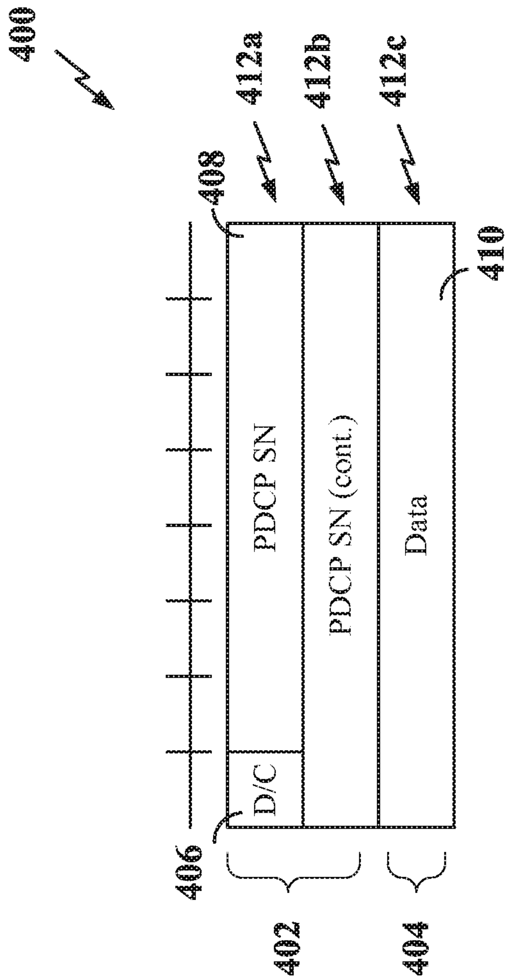
400
412a
412b
412c
408
410
PDCP SN
PDCP SN (cont.)
Data
D/C
406
402
404

FIG. 4

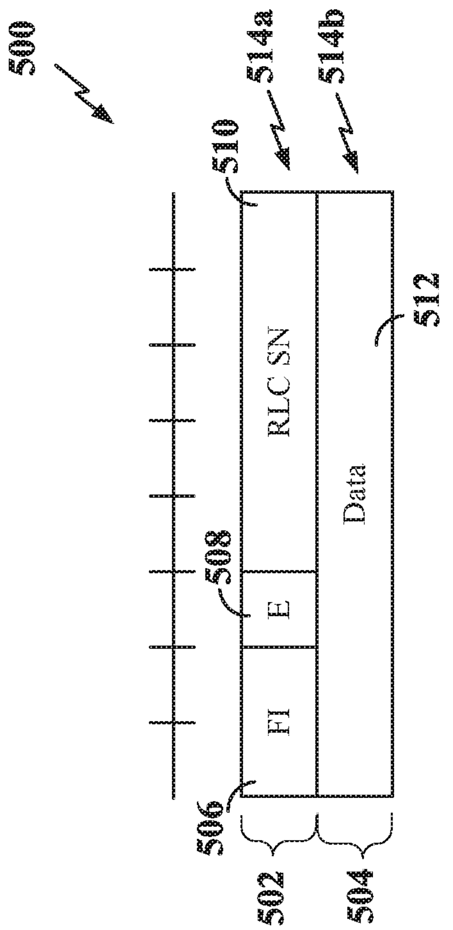

FIG. 5

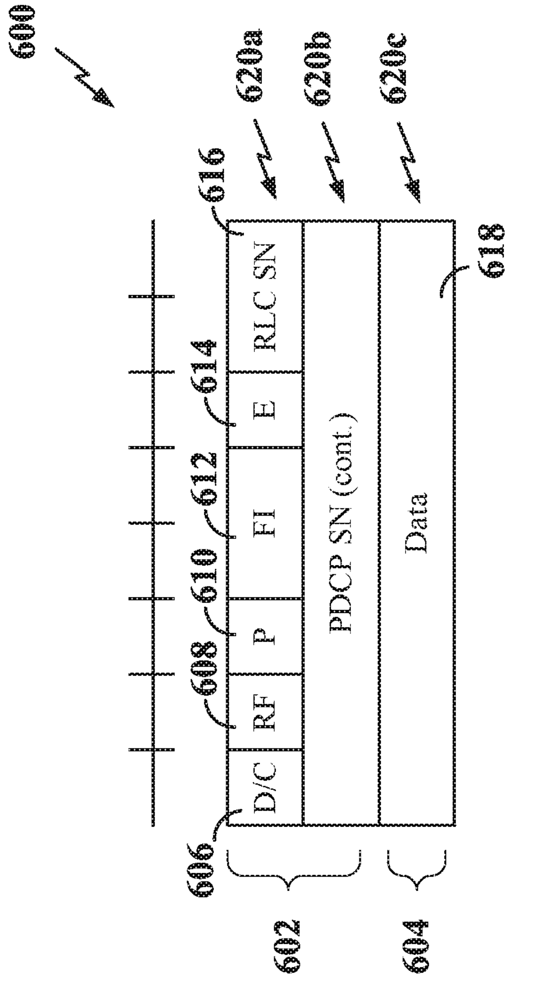
600
620a
620b
620c
616
614
612
610
608
606
D/C
RF
P
FI
E
RLC SN
PDCP SN (cont.)
Data
618
602
604

FIG. 6

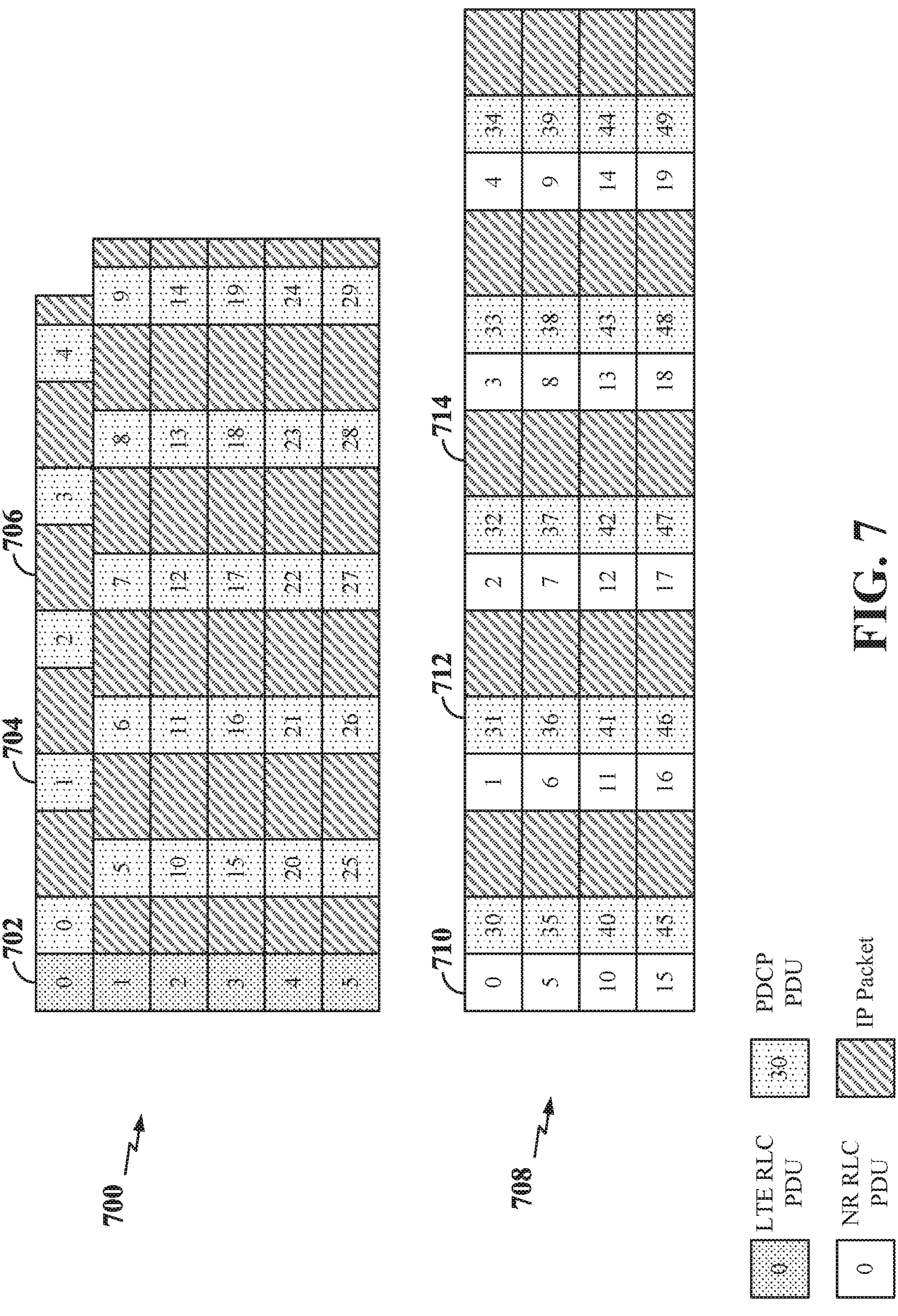
700
702
704
706
708
710
712
714
LTE RLC PDU
NR RLC PDU
PDCP PDU
IP Packet

FIG. 7

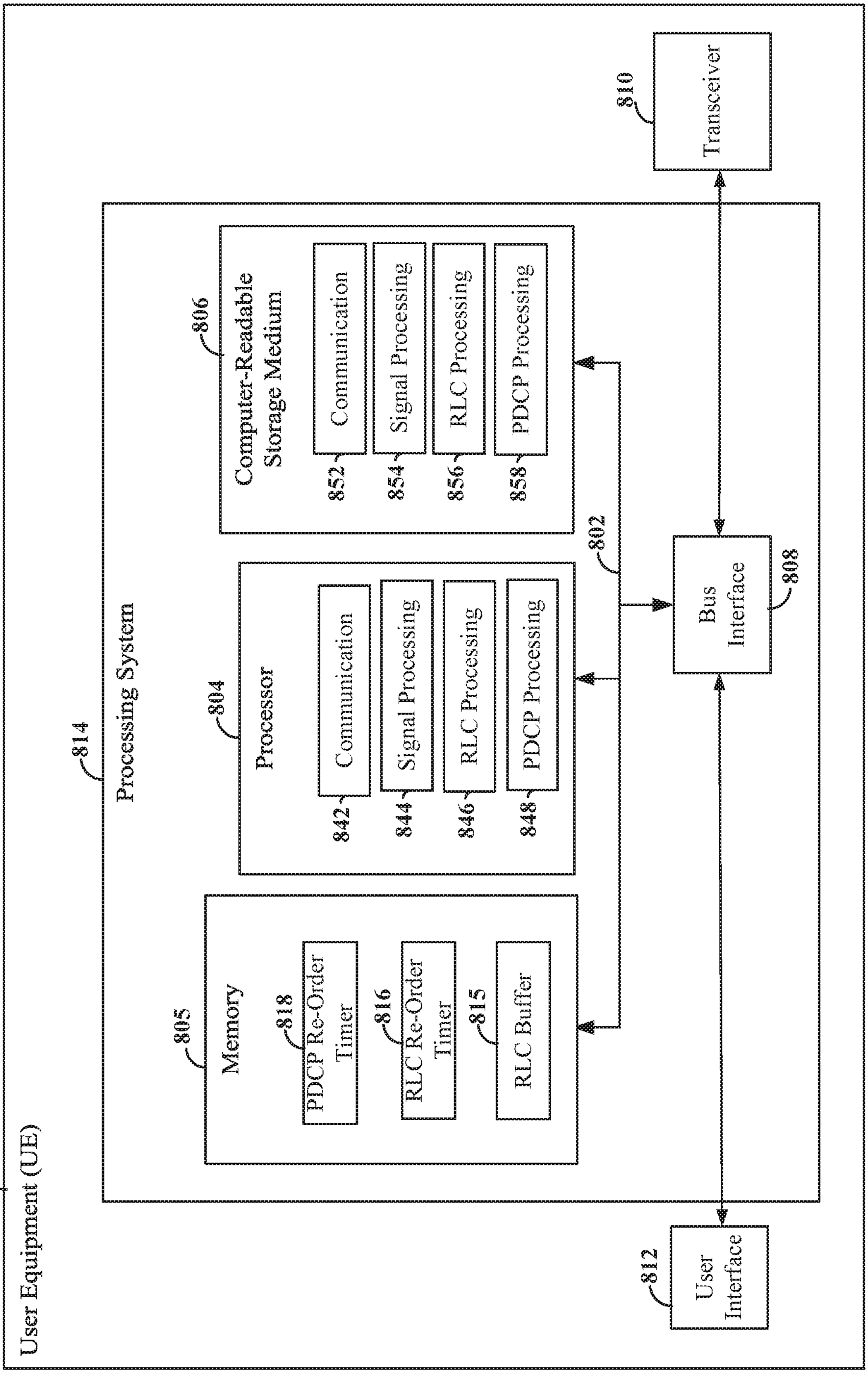
800
User Equipment (UE)
814
Processing System
805
Memory
818
PDCP Re-Order Timer
816
RLC Re-Order Timer
815
RLC Buffer
804
Processor
842
Communication
844
Signal Processing
846
RLC Processing
848
PDCP Processing
806
Computer-Readable Storage Medium
852
Communication
854
Signal Processing
856
RLC Processing
858
PDCP Processing
802
808
Bus Interface
810
Transceiver
812
User Interface

FIG. 8

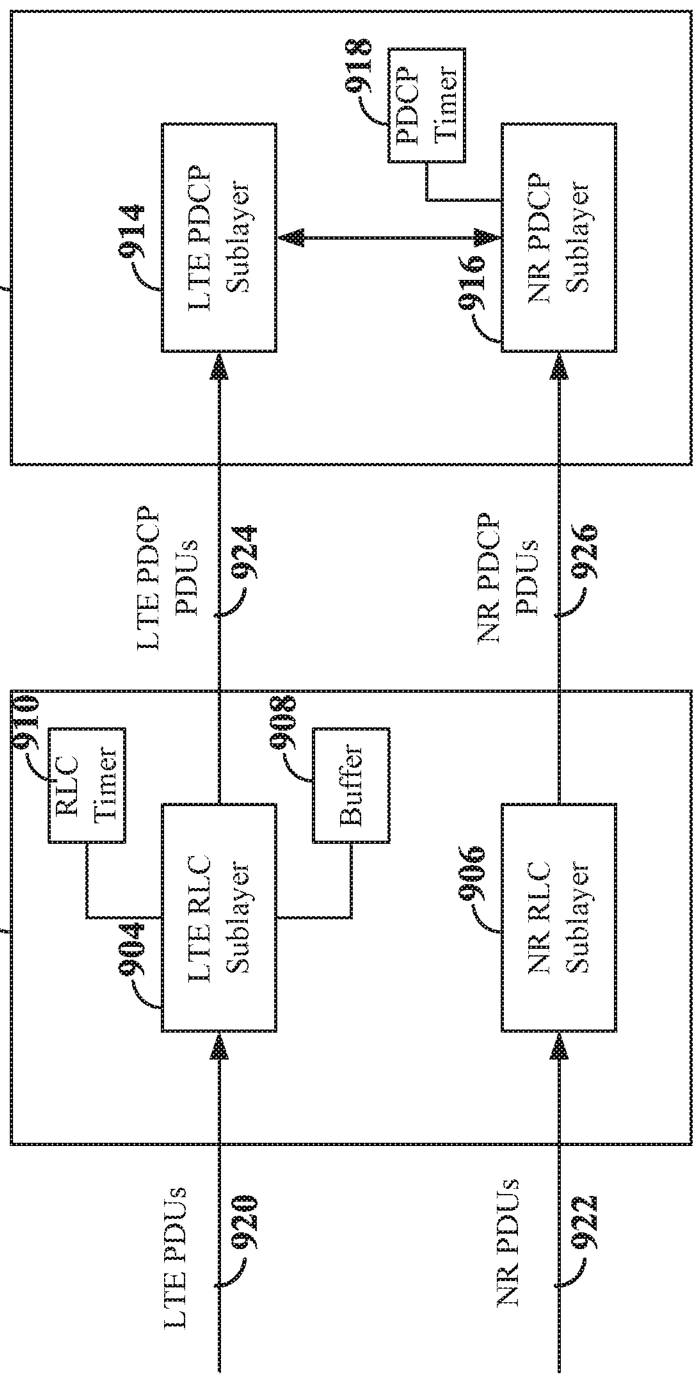
LTE PDUs
920
NR PDUs
922
902
904
LTE RLC Sublayer
910
RLC Timer
908
Buffer
906
NR RLC Sublayer
LTE PDCP PDUs
924
NR PDCP PDUs
926
912
914
LTE PDCP Sublayer
918
PDCP Timer
916
NR PDCP Sublayer

FIG. 9

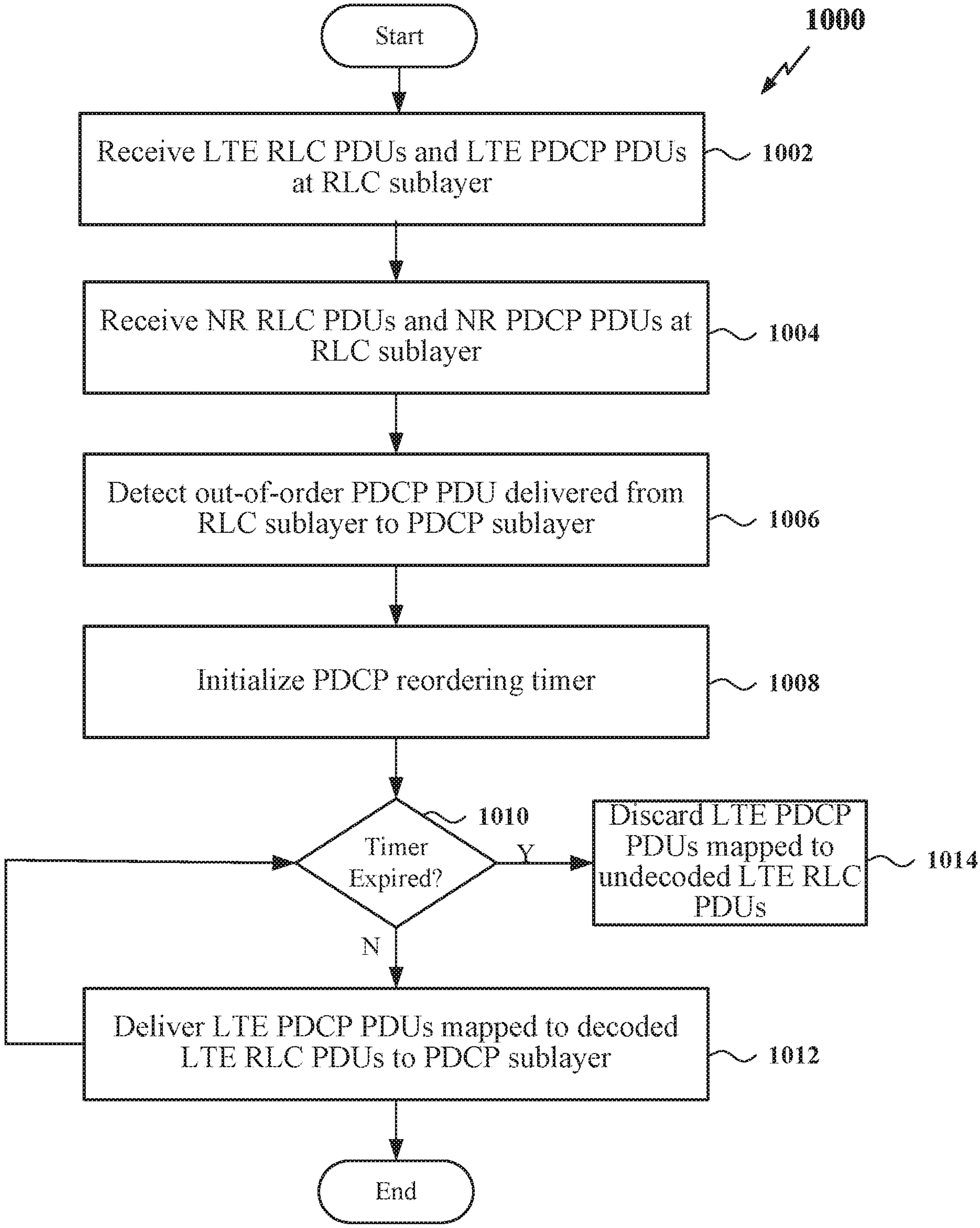
1000
Start
Receive LTE RLC PDUs and LTE PDCP PDUs at RLC sublayer
1002
Receive NR RLC PDUs and NR PDCP PDUs at RLC sublayer
1004
Detect out-of-order PDCP PDU delivered from RLC sublayer to PDCP sublayer
1006
Initialize PDCP reordering timer
1008
Timer Expired?
1010
Y
Discard LTE PDCP PDUs mapped to undecoded LTE RLC PDUs
1014
N
Deliver LTE PDCP PDUs mapped to decoded LTE RLC PDUs to PDCP sublayer
1012
End

FIG. 10

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2018/114114

A. CLASSIFICATION OF SUBJECT MATTER

H04W 72/12(2009.01)i

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)

WPI, EPODOC, BAIDU, CNPAT, CNKI, IEEE, 3GPP: dual, connect+, reorder+, out, order, timer, expir+, RLC, PDCP, PDU

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2017181185 A1 (LG ELECTRONICS INC.) 22 June 2017 (2017-06-22) description, paragraphs [0131]-[0141]	1-32
A	US 2016234127 A1 (INTERNATIONAL BUSINESS MACHINES CORPORATION) 11 August 2016 (2016-08-11) the whole document	1-32
A	US 2018317279 A1 (SAMSUNG ELECTRONICS CO., LTD.) 01 November 2018 (2018-11-01) the whole document	1-32
A	US 2017264562 A1 (LG ELECTRONICS INC.) 14 September 2017 (2017-09-14) the whole document	1-32

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

* Special categories of cited documents:
- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier application or patent but published on or after the international filing date
- "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed
- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
- "&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
26 July 2019	**06 August 2019**

Name and mailing address of the ISA/CN	Authorized officer
National Intellectual Property Administration, PRC 6, Xitucheng Rd., Jimen Bridge, Haidian District, Beijing 100088 China	**WU,Shaohong**
Facsimile No. **(86-10)62019451**	Telephone No. **86-(10)-53961533**

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2018/114114

Patent document cited in search report			Publication date (day/month/year)	Patent family member(s)			Publication date (day/month/year)
US	2017181185	A1	22 June 2017	WO	2015133767	A1	11 September 2015
US	2016234127	A1	11 August 2016	WO	2016128193	A1	18 August 2016
US	2018317279	A1	01 November 2018	US	2015215987	A1	30 July 2015
				WO	2015115854	A1	06 August 2015
				US	2018192451	A9	05 July 2018
US	2017264562	A1	14 September 2017	WO	2015174658	A1	19 November 2015