(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
26 October 2017 (26.10.2017)

WIPO | PCT

(10) International Publication Number
WO 2017/182704 A1

(51) International Patent Classification:
H04L 12/801 (2013.01) *H04L 1/18* (2006.01)
H04L 1/00 (2006.01) *H04W 80/02* (2009.01)
H04L 1/16 (2006.01) *H04L 29/06* (2006.01)

(21) International Application Number:
PCT/FI2017/050278

(22) International Filing Date:
13 April 2017 (13.04.2017)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
62/324,597 19 April 2016 (19.04.2016) US

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ,

(54) Title: REUSING PDCP SN AT RLC IN MULTI-CONNECTIVITY ENVIRONMENT

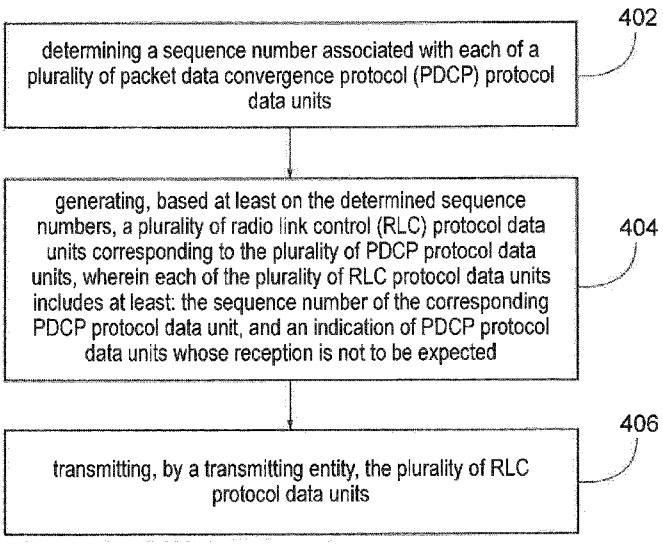


FIG. 4

(57) Abstract: There is provided a method for determining a sequence number associated with each of a plurality of packet data convergence protocol (PDCP) protocol data units; generating, based at least on the determined sequence numbers, a plurality of radio link control (RLC) protocol data units corresponding to the plurality of PDCP protocol data units, wherein each of the plurality of RLC protocol data units includes at least: the sequence number of the corresponding PDCP protocol data unit, and an indication of PDCP protocol data units whose reception is not to be expected; and transmitting, by a transmitting entity, the plurality of RLC protocol data units.

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TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— *of inventorship (Rule 4.17(iv))*

Published:

— *with international search report (Art. 21(3))*

Reusing PDCP SN at RLC in Multi-Connectivity Environment

TECHNICAL FIELD

[0001] This invention relates generally to wireless communications, and, more specifically, relates to radio protocols in multi-connectivity environments.

BACKGROUND

[0002] This section is intended to provide a background or context to the invention disclosed below. The description herein may include concepts that could be pursued, but are not necessarily ones that have been previously conceived, implemented or described. Therefore, unless otherwise explicitly indicated herein, what is described in this section is not prior art to the description in this application and is not admitted to be prior art by inclusion in this section. Abbreviations that may be found in the specification and/or the drawing figures are defined below, after the main part of the detailed description section.

[0003] In data networks, packets of a data stream may reach their destination via multiple paths. Multi-connectivity refers to using different radio links (or paths) to convey user data. E-UTRAN supporting Dual Connectivity (DC) operation provides an example of such a network. When DC is configured, Packet Data Convergence Protocol layer (PDCP) becomes responsible for merging the two paths at the receive side by reordering the packets.

BRIEF SUMMARY

[0004] This section is intended to include examples and is not intended to be limiting.

[0005] In an example of an embodiment, a method is disclosed that includes determining a sequence number associated with each of a plurality of packet data convergence protocol (PDCP) protocol data units; generating, based at least on the determined sequence numbers, a plurality of radio link control (RLC) protocol data units corresponding to the plurality of PDCP protocol data units, wherein each of the plurality of RLC protocol data units includes at least: the sequence number of the corresponding PDCP protocol data unit, and an

indication of PDCP protocol data units whose reception is not to be expected; and transmitting, by a transmitting entity, the plurality of RLC protocol data units.

[0006] An additional example of an embodiment includes a computer program, comprising code for performing the method of the previous paragraph, when the computer program is run on a processor. The computer program according to this paragraph, wherein the computer program is a computer program product comprising a computer-readable medium bearing computer program code embodied therein for use with a computer.

[0007] An example of an apparatus includes at least one processor; and at least one non-transitory memory including computer program code, the at least one memory and the computer program code configured to, with the at least one processor, cause the apparatus to: determine a sequence number associated with each of a plurality of packet data convergence protocol (PDCP) protocol data units; generate, based at least on the determined sequence numbers, a plurality of radio link control (RLC) protocol data units corresponding to the plurality of PDCP protocol data units, wherein each of the plurality of RLC protocol data units includes at least: the sequence number of the corresponding PDCP protocol data unit, and an indication of PDCP protocol data units whose reception is not to be expected; and transmit, by a transmitting entity, the plurality of RLC protocol data units.

[0008] A further example of an apparatus includes means for determining a sequence number associated with each of a plurality of packet data convergence protocol (PDCP) protocol data units; means for generating, based at least on the determined sequence numbers, a plurality of radio link control (RLC) protocol data units corresponding to the plurality of PDCP protocol data units, wherein each of the plurality of RLC protocol data units includes at least: the sequence number of the corresponding PDCP protocol data unit, and an indication of PDCP protocol data units whose reception is not to be expected; and means for transmitting, by a transmitting entity, the plurality of RLC protocol data units.

[0009] In an example of an embodiment, a method is disclosed that includes receiving a plurality of radio link control (RLC) protocol data units at a receiver, wherein each of the plurality of RLC protocol data units comprises at least: a sequence number corresponding to a packet data convergence protocol (PDCP) protocol data unit of a plurality of PDCP protocol data units, and an indication of the sequence numbers of PDCP protocol data units from the plurality of PDCP protocol data units whose reception is not to be expected; and

transmitting an acknowledgment or negative acknowledgement for the PDCP protocol data units whose reception is to be expected based on the indication.

[0010] An additional example of an embodiment includes a computer program, comprising code for performing the method of the previous paragraph, when the computer program is run on a processor. The computer program according to this paragraph, wherein the computer program is a computer program product comprising a computer-readable medium bearing computer program code embodied therein for use with a computer.

[0011] An example of an apparatus includes at least one processor; and at least one non-transitory memory including computer program code, the at least one memory and the computer program code configured to, with the at least one processor, cause the apparatus to: receive a plurality of radio link control (RLC) protocol data units at a receiver, wherein each of the plurality of RLC protocol data units comprises at least a sequence number corresponding to a packet data convergence protocol (PDCP) protocol data unit of a plurality of PDCP protocol data units, and an indication of the sequence numbers of PDCP protocol data units from the plurality of PDCP protocol data units whose reception is not to be expected; and transmit an acknowledgment or negative acknowledgement for each of the PDCP protocol data units whose reception is to be expected based on the indication.

[0012] In another example of an embodiment, an apparatus comprises means for receiving a plurality of radio link control (RLC) protocol data units at a receiver, wherein each of the plurality of RLC protocol data units comprises at least: a sequence number corresponding to a packet data convergence protocol (PDCP) protocol data unit of a plurality of PDCP protocol data units, and an indication of the sequence numbers of PDCP protocol data units from the plurality of PDCP protocol data units whose reception is not to be expected; and means for transmitting an acknowledgment or negative acknowledgement for the PDCP protocol data units whose reception is to be expected based on the indication.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] In the attached Drawing Figures:

[0014] FIG. 1 is a block diagram of one possible and non-limiting exemplary system in which the exemplary embodiments may be practiced;

[0015] FIG. 2 is an example of a PDCP PDU structure;

[0016] FIG. 3 is an example of RLC PDU structure;

[0017] FIG. 4 is a logic flow diagram for reusing PDCP SN at RLC in a multi-connectivity environment, and illustrates the operation of an exemplary method, a result of execution of computer program instructions embodied on a computer readable memory, functions performed by logic implemented in hardware, and/or interconnected means for performing functions in accordance with exemplary embodiments; and

[0018] FIG. 5 is a logic flow diagram for reusing PDCP SN at RLC in a multi-connectivity environment, and illustrates the operation of an exemplary method, a result of execution of computer program instructions embodied on a computer readable memory, functions performed by logic implemented in hardware, and/or interconnected means for performing functions in accordance with exemplary embodiments.

DETAILED DESCRIPTION OF THE DRAWINGS

[0019] The word "exemplary" is used herein to mean "serving as an example, instance, or illustration." Any embodiment described herein as "exemplary" is not necessarily to be construed as preferred or advantageous over other embodiments. All of the embodiments described in this Detailed Description are exemplary embodiments provided to enable persons skilled in the art to make or use the invention and not to limit the scope of the invention which is defined by the claims.

[0020] The exemplary embodiments herein describe techniques for reusing PDCP SN at RLC in Multi-Connectivity Environment. Additional description of these techniques is presented after a system into which the exemplary embodiments may be used is described.

[0021] Turning to FIG. 1, this figure shows a block diagram of one possible and non-limiting exemplary system in which the exemplary embodiments may be practiced. In FIG. 1, a user equipment (UE) 110 is in wireless communication with a wireless network 100. A UE is a wireless, typically mobile device that can access a wireless network. The UE 110 includes one or more processors 120, one or more memories 125, and one or more transceivers 130 interconnected through one or more buses 127. Each of the one or more

transceivers 130 includes a receiver, Rx, 132 and a transmitter, Tx, 133. The one or more buses 127 may be address, data, or control buses, and may include any interconnection mechanism, such as a series of lines on a motherboard or integrated circuit, fiber optics or other optical communication equipment, and the like. The one or more transceivers 130 are connected to one or more antennas 128. The one or more memories 125 include computer program code 123. The UE 110 includes a control module 140, comprising one of or both parts 140-1 and/or 140-2, which may be implemented in a number of ways. The control module 140 may be implemented in hardware as control module 140-1, such as being implemented as part of the one or more processors 120. The control module 140-1 may be implemented also as an integrated circuit or through other hardware such as a programmable gate array. In another example, the control module 140 may be implemented as control module 140-2, which is implemented as computer program code 123 and is executed by the one or more processors 120. For instance, the one or more memories 125 and the computer program code 123 may be configured to, with the one or more processors 120, cause the user equipment 110 to perform one or more of the operations as described herein. The UE 110 communicates with eNB 170 via a wireless link 111.

[0022] The eNB (evolved NodeB) 170 is a base station (e.g., for LTE, long term evolution) that provides access by wireless devices such as the UE 110 to the wireless network 100. The eNB 170 includes one or more processors 152, one or more memories 155, one or more network interfaces (N/W I/F(s)) 161, and one or more transceivers 160 interconnected through one or more buses 157. Each of the one or more transceivers 160 includes a receiver, Rx, 162 and a transmitter, Tx, 163. The one or more transceivers 160 are connected to one or more antennas 158. The one or more memories 155 include computer program code 153. The eNB 170 includes a control module 150, comprising one of or both parts 150-1 and/or 150-2, which may be implemented in a number of ways. The control module 150 may be implemented in hardware as control module 150-1, such as being implemented as part of the one or more processors 152. The control module 150-1 may be implemented also as an integrated circuit or through other hardware such as a programmable gate array. In another example, the control module 150 may be implemented as control module 150-2, which is implemented as computer program code 153 and is executed by the one or more processors 152. For instance, the one or more memories 155 and the computer program code 153 are configured to, with the one or more processors 152, cause the eNB

170 to perform one or more of the operations as described herein. The one or more network interfaces 161 communicate over a network such as via the links 176 and 131. Two or more eNBs 170 communicate using, e.g., link 176. The link 176 may be wired or wireless or both and may implement, e.g., an X2 interface.

[0023] The one or more buses 157 may be address, data, or control buses, and may include any interconnection mechanism, such as a series of lines on a motherboard or integrated circuit, fiber optics or other optical communication equipment, wireless channels, and the like. For example, the one or more transceivers 160 may be implemented as a remote radio head (RRH) 195, with the other elements of the eNB 170 being physically in a different location from the RRH, and the one or more buses 157 could be implemented in part as fiber optic cable to connect the other elements of the eNB 170 to the RRH 195.

[0024] The wireless network 100 may include a network control element (NCE) 190 that may include MME (Mobility Management Entity)/SGW (Serving Gateway) functionality, and which provides connectivity with a further network, such as a telephone network and/or a data communications network (e.g., the Internet). The eNB 170 is coupled via a link 131 to the NCE 190. The link 131 may be implemented as, e.g., an S1 interface. The NCE 190 includes one or more processors 175, one or more memories 171, and one or more network interfaces (N/W I/F(s)) 180, interconnected through one or more buses 185. The one or more memories 171 include computer program code 173. The one or more memories 171 and the computer program code 173 are configured to, with the one or more processors 175, cause the NCE 190 to perform one or more operations.

[0025] The wireless network 100 may implement network virtualization, which is the process of combining hardware and software network resources and network functionality into a single, software-based administrative entity, a virtual network. Network virtualization involves platform virtualization, often combined with resource virtualization. Network virtualization is categorized as either external, combining many networks, or parts of networks, into a virtual unit, or internal, providing network-like functionality to software containers on a single system. Note that the virtualized entities that result from the network virtualization are still implemented, at some level, using hardware such as processors 152 or 175 and memories 155 and 171, and also such virtualized entities create technical effects.

[0026] The computer readable memories 125, 155, and 171 may be of any type suitable to the local technical environment and may be implemented using any suitable data storage technology, such as semiconductor based memory devices, flash memory, magnetic memory devices and systems, optical memory devices and systems, fixed memory and removable memory. The computer readable memories 125, 155, and 171 may be means for performing storage functions. The processors 120, 152, and 175 may be of any type suitable to the local technical environment, and may include one or more of general purpose computers, special purpose computers, microprocessors, digital signal processors (DSPs) and processors based on a multi-core processor architecture, as non-limiting examples. The processors 120, 152, and 175 may be means for performing functions, such as controlling the UE 110, eNB 170, and other functions as described herein.

[0027] In general, the various embodiments of the user equipment 110 can include, but are not limited to, cellular telephones such as smart phones, tablets, personal digital assistants (PDAs) having wireless communication capabilities, portable computers having wireless communication capabilities, image capture devices such as digital cameras having wireless communication capabilities, gaming devices having wireless communication capabilities, music storage and playback appliances having wireless communication capabilities, Internet appliances permitting wireless Internet access and browsing, tablets with wireless communication capabilities, as well as portable units or terminals that incorporate combinations of such functions.

[0028] Having thus introduced one suitable but non-limiting technical context for the practice of the exemplary embodiments of this invention, the exemplary embodiments will now be described with greater specificity.

[0029] In some typical wireless networks the radio protocols for the user plane consist of three layers: Packet Data Convergence Protocol (PDCP), Radio Link Control (RLC) and Medium Access Control (MAC). The main services and functions of the PDCP sublayer include: header compression and decompression; transfer of user data; ciphering and deciphering; as well as timer-based SDU discard. When dual connectivity is configured, the PDCP layer also performs reordering. These functions rely on a PDCP SN in the PDCP header of every PDCP PDU.

[0030] Below PDCP, lies the RLC sublayer whose main services and functions include: transfer of upper layer PDUs; error Correction through ARQ (only for AM data transfer); concatenation, segmentation and reassembly of RLC SDUs (only for UM and AM data transfer); re-segmentation of RLC data PDUs (only for AM data transfer); reordering of RLC data PDUs (only for UM and AM data transfer); duplicate detection (only for UM and AM data transfer); protocol error detection (only for AM data transfer). These functions also rely on an RLC SN in the RLC header of every RLC PDU.

[0031] Finally, below RLC lies the MAC sublayer whose main services and functions include: mapping between logical channels and transport channels; multiplexing and demultiplexing of MAC SDUs belonging to one or different logical channels into/from transport blocks (TB) delivered to/from the physical layer on transport channels; scheduling information reporting; error correction through HARQ; priority handling between logical channels of one UE; priority handling between UEs by means of dynamic scheduling; transport format selection; padding.

[0032] Referring to Fig. 2, a PDCP data PDU structure 200 is shown. The PDCP data PDU structure 200 includes a PDCP header 202, and a PDCP SDU 204 after possible ciphering. Different formats for the PDCP header 202 may be used, dependent on the type of data to be transported. For example, in LTE, different header formats are used for Control Plane PDCP Data PDU, for User plane PDCP Data PDU with long PDCP SN (12 bits), for User plane PDCP Data PDU with short PDCP SN (7 bits) and others. A PDCP data PDU may also include fields other than the header and the payload, such as trailing fields for the purpose of integrity protection.

[0033] Referring also to Fig. 3, an example RLC SDU 300 structure and corresponding RLC PDU 302 structure are shown. In LTE, the RLC SDUs 300 (which in Fig. 3 are numbered: n, n+1, n+2, n+2 ...) are received from the PDCP layer. The various RLC PDUs 302 are formed, for example, through segmentation, concatenation, and adding an RLC header 304 to the RLC SDUs 300.

[0034] As mentioned above, Multi-Connectivity refers to using different radio links (or paths) to convey user data. PDCP may be responsible to handle Multi-Connectivity by feeding PDCP SDUs to the RLC entity of each radio link. A new 3GPP study item on New Radio Access Technology (NR) has been agreed upon and is described in the document RP-

160671 entitled NEW SID PROPOSAL: STUDY ON NEW RADIO ACCESS TECHNOLOGY [3GPP TSG RAN Meeting #71; Göteborg, Sweden, 7.-10. March, 2016]. One goal of the NR is to support the very high bit rates required for 5G. In order to support such bit rates, it has been proposed to move segmentation and concatenation to MAC, leaving to RLC the main functions of error correction, reordering and duplicate detection. In order to reduce overhead, it has also been suggested to reuse the same SN at both PDCP and RLC. Reusing the same SN introduces some challenges when dealing with Multi-Connectivity. One challenge is that the RLC entity of each individual path does not see a continuous stream of PDCP PDUs. For instance, in a scenario where the user data is equally split between two radio links, PDCP PDUs with odd SN can be sent towards the RLC entity of the first path while the PDCP PDUs with an even SN can be sent towards the RLC entity of the second path. However, usually the equal split cannot be assumed due to, for example, the different bandwidth used in the different links and current radio conditions. Exemplary embodiments described herein address these challenges.

[0035] According to exemplary embodiments described herein, when reusing the PDCP SN at RLC, the RLC entity on the receive side may be made aware of missing SN in order to function properly, e.g., by not sending NACK for PDCP PDUs having SNs that the receiving RLC entity is not meant to receive. The embodiments described herein refer to the PDCP and RLC layers, however, these are non-limiting examples. It should be understood that the teachings herein are equally applicable to any consecutive protocol layers which utilize the same SN.

[0036] According to one embodiment, a field is added to an RLC header (such as, e.g., the RLC header 304 shown in Fig. 3). The field indicates the SNs of RLC PDUs whose reception is not to be expected between the current RLC PDU and the *previous* RLC PDU. For example, if the transmitter obtains PDCP PDUs with SNs 0, 1, 5 then the RLC headers of the corresponding RLC PDUs may include: [0], [0], [3] to indicate that there is no gap between the first two SNs but three PDUs are missing in between the second and third RLC PDU. In another embodiment, the RLC headers of the corresponding RLC PDUs for the above example may include [0,0], [1,0], [5,3] It is noted that, using the *next* RLC PDU as reference to signal the gap may complicate the signaling of the last PDU.

[0037] According to another exemplary embodiment, empty RLC PDUs, i.e. RLC PDUs without any payload, may be generated and sent by the transmitting entity such that the empty RLC PDUs include the SNs of the corresponding missing PDCP PDUs. When the empty RLC PDUs are received by the receiving entity, the receiver may discard them.

[0038] A combination of both of the techniques described above is also possible. For example, the field indicating a gap in a SN of the current RLC PDU as compared to the previous RLC PDU may be used and corresponding empty RLC PDUs may also be sent. In certain embodiments, empty RLC PDUs may be generated when it is determined that the gap (i.e. the number of consecutive missing PDCP PDUs between the current RLC PDU and a previous RLC PDU) is larger than what can be signaled with the additional header field. For example, if the header field size is, e.g., five bits, then the header field can indicate a maximum gap of 32 missing PDCP PDUs. If there are more than 32 consecutive missing PDCP PDUs, then empty PDUs could be generated by the PDCP entity and be provided to the RLC entity; or the empty PDUs could be autonomously generated by the RLC layer. In some embodiments, the empty RLC PDUs will include the new field indicating the SN gap to the *previous* RLC PDU. For example, if the transmitter obtains PDCP PDUs with SNs 0, 1, 5 and empty RLC PDUs are generated for the corresponding to PDCP PDUs with SNs 2, 3, and 4, then the new field of the RLC headers may include: [0], [0], [0], [0], [0], [0].

[0039] According to another embodiment, information on PDCP PDUs that are not to be received by a given data-receiving RLC can also be passed to the overlying PDCP entity: this information can be used by the PDCP to optimize its reordering operation. For example, if the different paths of the connection have different delays, it can be useful for a data-receiving PDCP entity not to expect a missing PDU over a path known to have a longer delay.

[0040] To allow proper ARQ operation for a PDCP PDU retransmitted over an RLC other than that used for the initial transmission, when an RLC receives from PDCP for transmission a PDCP PDU with lower SN (i.e. with SN less ahead of the lower edge of the transmission window, the part of the SN space where transmitted PDUs can be outstanding waiting to be acknowledged at a specific point in time) than those previously received, such a PDCP PDU should be transmitted with a poll (i.e. with a request for acknowledgement feedback), and be explicitly acknowledged when successfully received.

[0041] According to some embodiments, to allow minimum overhead OTA (over-the-air), for an RLC PDU that has been previously submitted for a transmission by lower layers and has been discarded due to PDCP timer discard, an empty RLC PDU may be sent with the same PDCP SN as the discarded RLC PDU upon receiving a re-transmission request. A discard timer may be used at a data-transmitting PDCP entity to discard SDUs whose transmission has been pending so long that their reception would no longer be useful. Such a timer may be started for each SDU when the SDU is received from upper layers, and the SDU along with any possible PDU containing the SDU is discarded when the timer expires.

[0042] In some embodiments, to allow flexibility for the network, the field size could be determined according to the amount of links for multi-connectivity, for instance, the field size could be bigger for multi-connectivity with 3 communication links compared to 2 links (i.e. dual-connectivity). As a result, the new additional header field size used could be configurable by the NW for different deployment scenarios. Alternatively, the header field size could be signaled inband so as to accommodate different SN gaps dynamically. For instance, the possible sizes could be allowed:

- 0 bit: when there is no gap
- 5 bit: to cope with a maximum gap of 32
- 13 bit: to cope with a maximum gap of 8192

[0043] FIG. 4 is a logic flow diagram for reusing PDCP SN at RLC in a multi-connectivity environment. This figure further illustrates the operation of an exemplary method, a result of execution of computer program instructions embodied on a computer readable memory, functions performed by logic implemented in hardware, and/or interconnected means for performing functions in accordance with exemplary embodiments. For instance, the control module 140 or control module 150 may include multiples ones of the blocks in FIG. 4, where each included block is an interconnected means for performing the function in the block. The blocks in FIG. 4 may be performed by the UE 110, e.g., under control of the control module 140 at least in part, or by a base station such as eNB 170, e.g., under control of the control module 150 at least in part.

[0044] Referring to FIG. 4, an example method may comprise determining a sequence number associated with each of a plurality of packet data convergence protocol (PDCP)

protocol data units as indicated by block 402; generating, based at least on the determined sequence numbers, a plurality of radio link control (RLC) protocol data units corresponding to the plurality of PDCP protocol data units, wherein each of the plurality of RLC protocol data units may include at least: the sequence number of the corresponding PDCP protocol data unit, and an indication of PDCP protocol data units whose reception is not to be expected as indicated by block 404; and transmitting, by a transmitting entity, the plurality of RLC protocol data units as indicated by block 406.

[0045] The indication of PDCP protocol data units whose reception is not to be expected may be at least one of: a field in a header of each of the plurality of RLC protocol data units indicating how many PDCP protocol data units are missing between a current RLC protocol data unit and a previous RLC protocol data unit; and one or more of the RLC protocol data units being empty RLC protocol data units corresponding to one or more missing PDCP protocol data units from the plurality of PDCP protocol data units.

[0046] A size of the field may be based at least partially upon a number of communication links between the transmitting entity and a receiving entity.

[0047] A size of the field may be dynamically changed based on the number of consecutive one or more missing PDCP protocol data units between the current RLC protocol data unit and the previous RLC protocol data unit.

[0048] The method may comprise determining that the size of the field is not capable of indicating the number of consecutive one or more missing PDCP protocol data units between the current RLC protocol data unit and the previous RLC protocol data unit; wherein the one or more empty RLC protocol data units corresponding to one or more missing PDCP protocol data units from the plurality of PDCP protocol data units may be generated such that the remaining gaps can be indicated by the field.

[0049] The generated empty RLC protocol data units may include a sequence number that corresponds with the sequence number of the respective one or more missing PDCP protocol data units.

[0050] The method may further comprise determining that the sequence number of one of the plurality of PDCP protocol data units is lower than a previous one of the plurality of PDCP protocol data units; and transmitting an RLC protocol data unit corresponding to the

one PDCP protocol data unit, wherein the RLC may comprise a request to acknowledge that the one PDCP protocol data unit was received.

[0051] The method may further comprise discarding at least one of the plurality of PDCP protocol data units based on a discard timer; receiving a request for re-transmission for the discarded PDCP protocol data unit from the receiving entity; in response to receiving the request, generating an empty PDCP protocol data unit having a same sequence number as the discarded PDCP protocol data unit; and transmitting the empty PDCP protocol data unit to the receiving entity.

[0052] The method may further comprise receiving, from the receiving entity, an acknowledgment or negative acknowledgement for only the plurality of PDCP protocol data units that are not missing.

[0053] An example embodiment may be provided in an apparatus comprising at least one processor; and at least one non-transitory memory including computer program code, the at least one memory and the computer program code configured to, with the at least one processor, cause the apparatus to: determine a sequence number associated with each of a plurality of packet data convergence protocol (PDCP) protocol data units; generate, based at least on the determined sequence numbers, a plurality of radio link control (RLC) protocol data units corresponding to the plurality of PDCP protocol data units, wherein each of the plurality of RLC protocol data units may include at least: the sequence number of the corresponding PDCP protocol data unit, and an indication of PDCP protocol data units whose reception is not to be expected; and transmit, by a transmitting entity, the plurality of RLC protocol data units.

[0054] The indication of PDCP protocol data units whose reception is not to be expected may be at least one of: a field in a header of each of the plurality of RLC protocol data units indicating how many PDCP protocol data units are missing between a current RLC protocol data unit and a previous RLC protocol data unit; and one or more of the RLC protocol data units being empty RLC protocol data units corresponding to one or more missing PDCP protocol data units from the plurality of PDCP protocol data units.

[0055] A size of the field may be based at least partially upon a number of communication links between the transmitting entity and a receiving entity.

[0056] A size of the field may be dynamically changed based on the number of consecutive one or more missing PDCP protocol data units between the current RLC protocol data unit and the previous RLC protocol data unit.

[0057] The at least one memory and the computer program code may be configured to, with the at least one processor, cause the apparatus to: determine that the size of the field is not capable of indicating the number of consecutive one or more missing PDCP protocol data units between the current RLC protocol data unit and the previous RLC protocol data unit, wherein the one or more empty RLC protocol data units corresponding to one or more missing PDCP protocol data units from the plurality of PDCP protocol data units may be generated such that the remaining gaps can be indicated by the field.

[0058] The generated empty RLC protocol data units may include a sequence number that corresponds with the sequence number of the respective one or more missing PDCP protocol data units.

[0059] The at least one memory and the computer program code may be configured to, with the at least one processor, cause the apparatus to: determine that the sequence number of one of the plurality of PDCP protocol data units is lower than a previous one of the plurality of PDCP protocol data units; and transmit an RLC protocol data unit corresponding to the one PDCP protocol data unit, wherein the RLC may include a request to acknowledge that the one PDCP protocol data unit was received.

[0060] The at least one memory and the computer program code configured to, with the at least one processor, cause the apparatus to: discard at least one of the plurality of PDCP protocol data units based on a discard timer; receive a request for re-transmission for the discarded PDCP protocol data unit from the receiving entity; in response to receipt of the request, generate an empty PDCP protocol data unit having a same sequence number as the discarded PDCP protocol data unit; and transmit the empty PDCP protocol data unit to the receiving entity.

[0061] The at least one memory and the computer program code may be configured to, with the at least one processor, cause the apparatus to: receive, from the receiving entity, an acknowledgment or negative acknowledgement for only the plurality of PDCP protocol data units that are not missing.

[0062] FIG. 5 is a logic flow diagram for reusing PDCP SN at RLC in a multi-connectivity environment. This figure further illustrates the operation of an exemplary method, a result of execution of computer program instructions embodied on a computer readable memory, functions performed by logic implemented in hardware, and/or interconnected means for performing functions in accordance with exemplary embodiments. For instance, the control module 140 or control module 150 may include multiples ones of the blocks in FIG. 5, where each included block is an interconnected means for performing the function in the block. The blocks in FIG. 5 may be performed by the UE 110, e.g., under control of the control module 140 at least in part, or by a base station such as eNB 170, e.g., under control of the control module 150 at least in part.

[0063] Referring to FIG. 5, an example method may comprise receiving a plurality of radio link control (RLC) protocol data units at a receiver, wherein each of the plurality of RLC protocol data units may comprise at least: a sequence number corresponding to a packet data convergence protocol (PDCP) protocol data unit of a plurality of PDCP protocol data units, and an indication of the sequence numbers of PDCP protocol data units from the plurality of PDCP protocol data units whose reception is not to be expected as indicated by block 502; and transmitting an acknowledgment or negative acknowledgement for only the PDCP protocol data units whose reception is to be expected based on the indication as indicated by block 504.

[0064] The indication of the sequence numbers of PDCP protocol data units from the plurality of PDCP protocol data units whose reception is not to be expected may be at least one of: a field in a header of each of the plurality of RLC protocol data units indicating how many PDCP protocol data units are missing between a current RLC protocol data unit and a previous RLC protocol data unit; and one or more of the RLC protocol data units being empty RLC protocol data units corresponding to one or more missing PDCP protocol data units from the plurality of PDCP protocol data units.

[0065] The method may further include: discarding the one or more empty RLC protocol data units corresponding to the one or more missing PDCP protocol data units from the plurality of PDCP protocol data units.

[0066] The method may further include: transmitting a request for re-transmission for one of the plurality of PDCP protocol data units that was not received by the receiver and whose

reception was expected; and receiving, in response to the request, a RLC protocol data unit corresponding to the one PDCP protocol data unit, wherein the RLC protocol data unit may comprise a request to acknowledge that the one PDCP protocol data unit was received.

[0067] An example embodiment may be provided in an apparatus comprising at least one processor; and at least one non-transitory memory including computer program code, the at least one memory and the computer program code may be configured to, with the at least one processor, cause the apparatus to: receive a plurality of radio link control (RLC) protocol data units at a receiver, wherein each of the plurality of RLC protocol data units may comprise at least a sequence number corresponding to a packet data convergence protocol (PDCP) protocol data unit of a plurality of PDCP protocol data units, and an indication of the sequence numbers of PDCP protocol data units from the plurality of PDCP protocol data units whose reception is not to be expected; and transmit an acknowledgment or negative acknowledgement for each of the PDCP protocol data units whose reception is to be expected based on the indication.

[0068] The indication of the sequence numbers of the PDCP protocol data units from the plurality of PDCP protocol data units whose reception is not to be expected may be at least one of: a field in a header of each of the plurality of RLC protocol data units indicating how many PDCP protocol data units are missing between a current RLC protocol data unit and a previous RLC protocol data unit; and one or more of the RLC protocol data units being empty RLC protocol data units corresponding to one or more missing PDCP protocol data units from the plurality of PDCP protocol data units.

[0069] The at least one memory and the computer program code may be configured to, with the at least one processor, cause the apparatus to: discard the one or more empty RLC protocol data units corresponding to the one or more missing PDCP protocol data units from the plurality of PDCP protocol data units.

[0070] The at least one memory and the computer program code configured to, with the at least one processor, cause the apparatus to further: transmit a request for re-transmission for one of the plurality of PDCP protocol data units that was not received by the receiver and whose reception was expected; and receive, in response to the request, a RLC protocol data unit corresponding to the one PDCP protocol data unit, wherein the RLC protocol data unit may comprise a request to acknowledge that the one PDCP protocol data unit was received.

[0071] In one example embodiment a user equipment may be provided comprising at least one of the apparatuses described above.

[0072] In another example embodiment base station may be provided comprising at least one of the apparatuses described above.

[0073] In another example embodiment, a communication system is provided comprising at least one of the apparatuses described above.

[0074] In another example embodiment, a computer program may include program code for executing at least one of the methods described above. The computer program may be a computer program product comprising a computer-readable medium bearing computer program code embodied therein for use with a computer.

[0075] Without in any way limiting the scope, interpretation, or application of the claims appearing below, a technical effect of one or more of the example embodiments disclosed herein is a reduction in overhead and efficient support of Multi-Connectivity. Another technical effect of one or more of the example embodiments disclosed herein is effectively supporting PDCP discard mechanism as any SN gaps can be indicated.

[0076] Embodiments herein may be implemented in software (executed by one or more processors), hardware (e.g., an application specific integrated circuit), or a combination of software and hardware. In an example embodiment, the software (e.g., application logic, an instruction set) is maintained on any one of various conventional computer-readable media. In the context of this document, a "computer-readable medium" may be any media or means that can contain, store, communicate, propagate or transport the instructions for use by or in connection with an instruction execution system, apparatus, or device, such as a computer, with one example of a computer described and depicted, e.g., in FIG. 1. A computer-readable medium may comprise a computer-readable storage medium (e.g., memories 125, 155, 171 or other device) that may be any media or means that can contain, store, and/or transport the instructions for use by or in connection with an instruction execution system, apparatus, or device, such as a computer. A computer-readable storage medium does not comprise propagating signals.

[0077] If desired, the different functions discussed herein may be performed in a different order and/or concurrently with each other. Furthermore, if desired, one or more of the above-described functions may be optional or may be combined.

[0078] Although various aspects of the invention are set out in the independent claims, other aspects of the invention comprise other combinations of features from the described embodiments and/or the dependent claims with the features of the independent claims, and not solely the combinations explicitly set out in the claims.

[0079] It is also noted herein that while the above describes example embodiments of the invention, these descriptions should not be viewed in a limiting sense. Rather, there are several variations and modifications which may be made without departing from the scope of the present invention as defined in the appended claims.

[0080] The following abbreviations that may be found in the specification and/or the drawing figures are defined as follows:

eNB (or eNodeB)	evolved Node B (e.g., an LTE base station)
AM	Acknowledged Mode
ARQ	Automatic Repeat request
DC	dual connectivity
HARQ	Hybrid ARQ
I/F	interface
LTE	long term evolution
MAC	Medium Access Control
MME	mobility management entity
NCE	network control element
NR	New Radio
N/W	network
OTA	Over-the-Air
PDCP	Packet Data Convergence Protocol
PDU	Protocol Data Unit
RLC	Radio Link Control
RRH	remote radio head
Rx	receiver

SDU	service data unit
SGW	serving gateway
SN	Sequence Number
TB	Transport Block
Tx	transmitter
UE	user equipment (e.g., a wireless, typically mobile device)
UM	Unacknowledged Mode

CLAIMS

What is claimed is:

1. A method, comprising:

determining a sequence number associated with each of a plurality of packet data convergence protocol (PDCP) protocol data units;

generating, based at least on the determined sequence numbers, a plurality of radio link control (RLC) protocol data units corresponding to the plurality of PDCP protocol data units, wherein each of the plurality of RLC protocol data units includes at least: the sequence number of the corresponding PDCP protocol data unit, and an indication of PDCP protocol data units whose reception is not to be expected; and

transmitting, by a transmitting entity, the plurality of RLC protocol data units.

2. The method of claim 1, wherein the indication of PDCP protocol data units whose reception is not to be expected comprises at least one of:

a field in a header of each of the plurality of RLC protocol data units indicating how many PDCP protocol data units are missing between a current RLC protocol data unit and a previous RLC protocol data unit; and

one or more of the RLC protocol data units being empty RLC protocol data units corresponding to one or more missing PDCP protocol data units from the plurality of PDCP protocol data units.

3. The method of any one of claims 1 and 2, wherein a size of the field is based at least partially upon a number of communication links between the transmitting entity and a receiving entity.

4. The method of any one of claims 1 and 2, wherein a size of the field is dynamically changed based on the number of consecutive one or more missing PDCP protocol data units between the current RLC protocol data unit and the previous RLC protocol data unit.

5. The method of any one of claims 1 to 4, further comprising:

determining that the size of the field is not capable of indicating the number of consecutive one or more missing PDCP protocol data units between the current RLC protocol data unit and the previous RLC protocol data unit, wherein the one or more empty RLC protocol data units corresponding to one or more missing PDCP protocol data units from the plurality of PDCP protocol data units are generated such that the remaining gaps can be indicated by the field.

6. The method according to any one of claims 2 to 5, wherein the generated empty RLC protocol data units include a sequence number that corresponds with the sequence number of the respective one or more missing PDCP protocol data units.

7. The method of any one of the preceding claims, the method further comprising:

determining that the sequence number of one of the plurality of PDCP protocol data units is lower than a previous one of the plurality of PDCP protocol data units; and

transmitting an RLC protocol data unit corresponding to the one PDCP protocol data unit, wherein the RLC comprises a request to acknowledge that the one PDCP protocol data unit was received.

8. The method of any one of the preceding claims, the method further comprising:

discarding at least one of the plurality of PDCP protocol data units based on a discard timer;

receiving a request for re-transmission for the discarded PDCP protocol data unit from the receiving entity;

in response to receiving the request, generating an empty PDCP protocol data unit having a same sequence number as the discarded PDCP protocol data unit; and

transmitting the empty PDCP protocol data unit to the receiving entity.

9. The method of any one of the preceding claims, the method further comprising:

receiving, from the receiving entity, an acknowledgment or negative acknowledgement for only the plurality of PDCP protocol data units that are not missing.

10. A method, comprising:

receiving a plurality of radio link control (RLC) protocol data units at a receiver, wherein each of the plurality of RLC protocol data units comprises at least: a sequence number corresponding to a packet data convergence protocol (PDCP) protocol data unit of a plurality of PDCP protocol data units, and an indication of the sequence numbers of PDCP protocol data units from the plurality of PDCP protocol data units whose reception is not to be expected; and

transmitting an acknowledgment or negative acknowledgement for the PDCP protocol data units whose reception is to be expected based on the indication.

11. The method of claim 10, wherein the indication of the sequence numbers of PDCP protocol data units from the plurality of PDCP protocol data units whose reception is not to be expected comprises at least one of:

a field in a header of each of the plurality of RLC protocol data units indicating how many PDCP protocol data units are missing between a current RLC protocol data unit and a previous RLC protocol data unit; and

one or more of the RLC protocol data units being empty RLC protocol data units corresponding to one or more missing PDCP protocol data units from the plurality of PDCP protocol data units.

12. The method of claims 11, the method further comprising:

discarding the one or more empty RLC protocol data units corresponding to the one or more missing PDCP protocol data units from the plurality of PDCP protocol data units.

13. The method of any one of the claims 10 to 12, the method further comprising:

transmitting a request for re-transmission for one of the plurality of PDCP protocol data units that was not received by the receiver and whose reception was expected; and

receiving, in response to the request, a RLC protocol data unit corresponding to the one PDCP protocol data unit, wherein the RLC protocol data unit comprises a request to acknowledge that the one PDCP protocol data unit was received.

14. An apparatus comprising:

at least one processor; and

at least one memory including computer program code;

the at least one memory and the computer program code configured, with the at least one processor, to cause the apparatus at least to:

determine a sequence number associated with each of a plurality of packet data convergence protocol (PDCP) protocol data units;

generate, based at least on the determined sequence numbers, a plurality of radio link control (RLC) protocol data units corresponding to the plurality of PDCP protocol data units, wherein each of the plurality of RLC protocol data units includes at least:

the sequence number of the corresponding PDCP protocol data unit, and an indication of PDCP protocol data units whose reception is not to be expected; and

transmit, by a transmitting entity, the plurality of RLC protocol data units.

15. The apparatus of claim 14, wherein the indication of PDCP protocol data units whose reception is not to be expected comprises at least one of:

a field in a header of each of the plurality of RLC protocol data units indicating how many PDCP protocol data units are missing between a current RLC protocol data unit and a previous RLC protocol data unit; and

one or more of the RLC protocol data units being empty RLC protocol data units corresponding to one or more missing PDCP protocol data units from the plurality of PDCP protocol data units.

16. The apparatus of any one of claims 14 and 15, wherein a size of the field is based at least partially upon a number of communication links between the transmitting entity and a receiving entity.

17. The apparatus of any one of claims 14 and 15, wherein a size of the field is dynamically changed based on the number of consecutive one or more missing PDCP protocol data units between the current RLC protocol data unit and the previous RLC protocol data unit.

18. The apparatus of any one of claims 14 to 17, wherein the at least one memory and the computer program code are configured, with the at least one processor, to cause the apparatus at least to:

determine that the size of the field is not capable of indicating the number of consecutive one or more missing PDCP protocol data units between the current RLC protocol data unit and the previous RLC protocol data unit, wherein the one or more empty RLC protocol data units corresponding to one or more missing PDCP protocol

data units from the plurality of PDCP protocol data units are generated such that the remaining gaps can be indicated by the field.

19. The apparatus of any one of claims 15 to 18, wherein the generated empty RLC protocol data units include a sequence number that corresponds with the sequence number of the respective one or more missing PDCP protocol data units.

20. The apparatus of any one of claims 14 to 19, wherein the at least one memory and the computer program code are configured, with the at least one processor, to cause the apparatus at least to:

determine that the sequence number of one of the plurality of PDCP protocol data units is lower than a previous one of the plurality of PDCP protocol data units; and

transmit an RLC protocol data unit corresponding to the one PDCP protocol data unit, wherein the RLC comprises a request to acknowledge that the one PDCP protocol data unit was received.

21. The apparatus of any one of the claims 14 to 20, wherein the at least one memory and the computer program code are configured, with the at least one processor, to cause the apparatus at least to:

discard at least one of the plurality of PDCP protocol data units based on a discard timer;

means for receive a request for re-transmission for the discarded PDCP protocol data unit from the receiving entity;

in response to receipt of the request, generate an empty PDCP protocol data unit having a same sequence number as the discarded PDCP protocol data unit; and

transmit the empty PDCP protocol data unit to the receiving entity.

22. The apparatus of any one of the claims 14 to 21, further comprising:

receive, from the receiving entity, an acknowledgment or negative acknowledgement for only the plurality of PDCP protocol data units that are not missing.

23. An apparatus comprising:

at least one processor; and

at least one memory including computer program code;

the at least one memory and the computer program code are configured, with the at least one processor, to cause the apparatus at least to:

receive a plurality of radio link control (RLC) protocol data units at a receiver, wherein each of the plurality of RLC protocol data units comprises at least a sequence number corresponding to a packet data convergence protocol (PDCP) protocol data unit of a plurality of PDCP protocol data units, and an indication of the sequence numbers of PDCP protocol data units from the plurality of PDCP protocol data units whose reception is not to be expected; and

transmit an acknowledgment or negative acknowledgement for each of the PDCP protocol data units whose reception is to be expected based on the indication.

24. The apparatus of claim 23, wherein the indication of the sequence numbers of the PDCP protocol data units from the plurality of PDCP protocol data units whose reception is not to be expected comprises at least one of:

a field in a header of each of the plurality of RLC protocol data units indicating how many PDCP protocol data units are missing between a current RLC protocol data unit and a previous RLC protocol data unit; and

one or more of the RLC protocol data units being empty RLC protocol data units corresponding to one or more missing PDCP protocol data units from the plurality of PDCP protocol data units.

25. The apparatus of any one of claim 24, wherein the at least one memory and the computer program code are configured, with the at least one processor, to cause the apparatus at least to:

discard the one or more empty RLC protocol data units corresponding to the one or more missing PDCP protocol data units from the plurality of PDCP protocol data units.

26. The apparatus of any one of claims 23 to 25, wherein the at least one memory and the computer program code are configured, with the at least one processor, to cause the apparatus at least to:

transmit a request for re-transmission for one of the plurality of PDCP protocol data units that was not received by the receiver and whose reception was expected; and

receive, in response to the request, a RLC protocol data unit corresponding to the one PDCP protocol data unit, wherein the RLC protocol data unit comprises a request to acknowledge that the one PDCP protocol data unit was received.

27. An apparatus comprising:

means for determining a sequence number associated with each of a plurality of packet data convergence protocol (PDCP) protocol data units;

means for generating, based at least on the determined sequence numbers, a plurality of radio link control (RLC) protocol data units corresponding to the plurality of PDCP protocol data units, wherein each of the plurality of RLC protocol data units includes at least: the sequence number of the corresponding PDCP protocol data unit, and an indication of PDCP protocol data units whose reception is not to be expected; and

means for transmitting, by a transmitting entity, the plurality of RLC protocol data units.

28. An apparatus comprising:

means for receiving a plurality of radio link control (RLC) protocol data units at a receiver, wherein each of the plurality of RLC protocol data units comprises at least a sequence number corresponding to a packet data convergence protocol (PDCP) protocol data unit of a plurality of PDCP protocol data units, and an indication of the sequence numbers of PDCP protocol data units from the plurality of PDCP protocol data units whose reception is not to be expected; and

means for transmitting an acknowledgment or negative acknowledgement for each of the PDCP protocol data units whose reception is to be expected based on the indication.

29. A user equipment comprising an apparatus according to any one of claims 14 to 22 or 23 to 26.

30. A base station comprising an apparatus according to any one of claims 14 to 22 or 23 to 26.

31. A communication system comprising an apparatus in accordance with any one of claims 14 to 22 and an apparatus in accordance with any one of claims 23 to 26.

32. A computer program comprising program code for executing the method according to any of claims 1 to 9 or 10 to 13.

33. The computer program according to claim 32, wherein the computer program is a computer program product comprising a computer-readable medium bearing computer program code embodied therein for use with a computer.

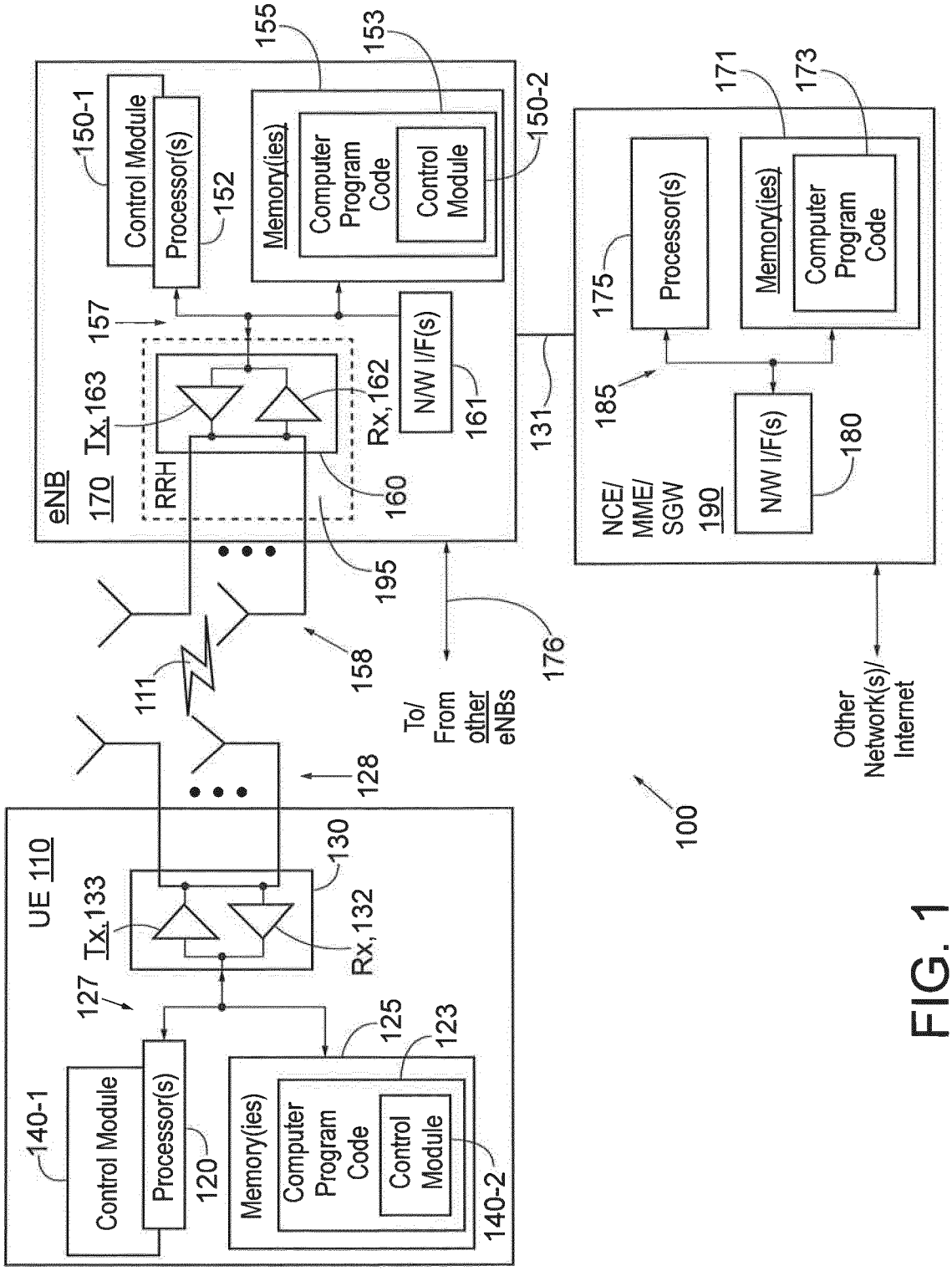

eNB
170
RRH
Tx, 163
Rx, 162
160
157
N/W I/F(s)
161
150-1
Control Module
Processor(s)
152
Memory(ies)
Computer Program Code
Control Module
155
153
150-2
131
NCE/ MME/ SGW 190
185
Processor(s)
175
Memory(ies)
Computer Program Code
171
173
N/W I/F(s)
180
Other Network(s)/ Internet
176
To/ From other eNBs
195
158
111
128
UE 110
Tx, 133
Rx, 132
130
127
125
123
140-1
Control Module
Processor(s)
120
Memory(ies)
Computer Program Code
Control Module
140-2
100

FIG. 1

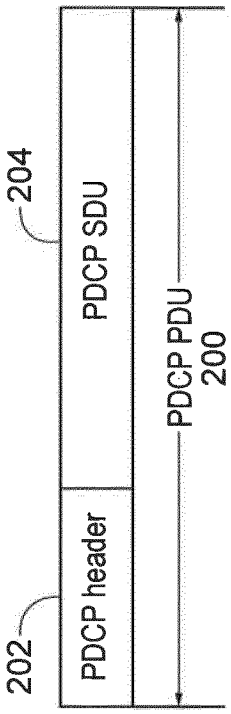

204
PDCP SDU
PDCP header
202
PDCP PDU
200

FIG. 2

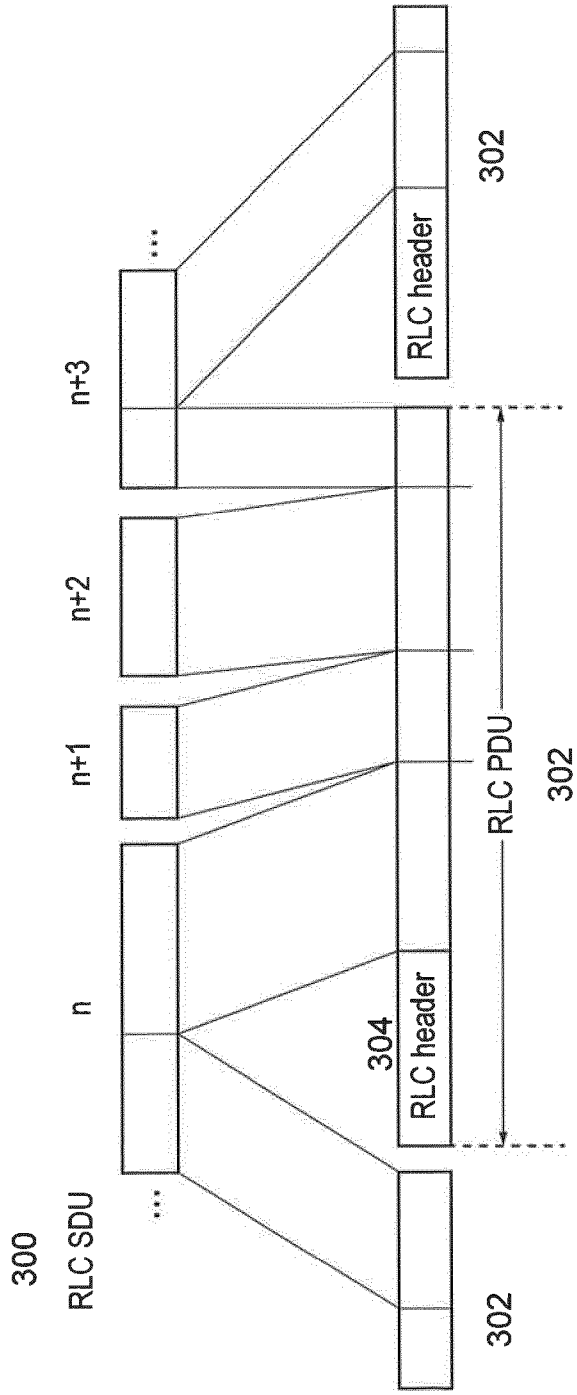

300
RLC SDU
n
n+1
n+2
n+3
...
RLC header
304
RLC header
302
302
RLC PDU
302

FIG. 3

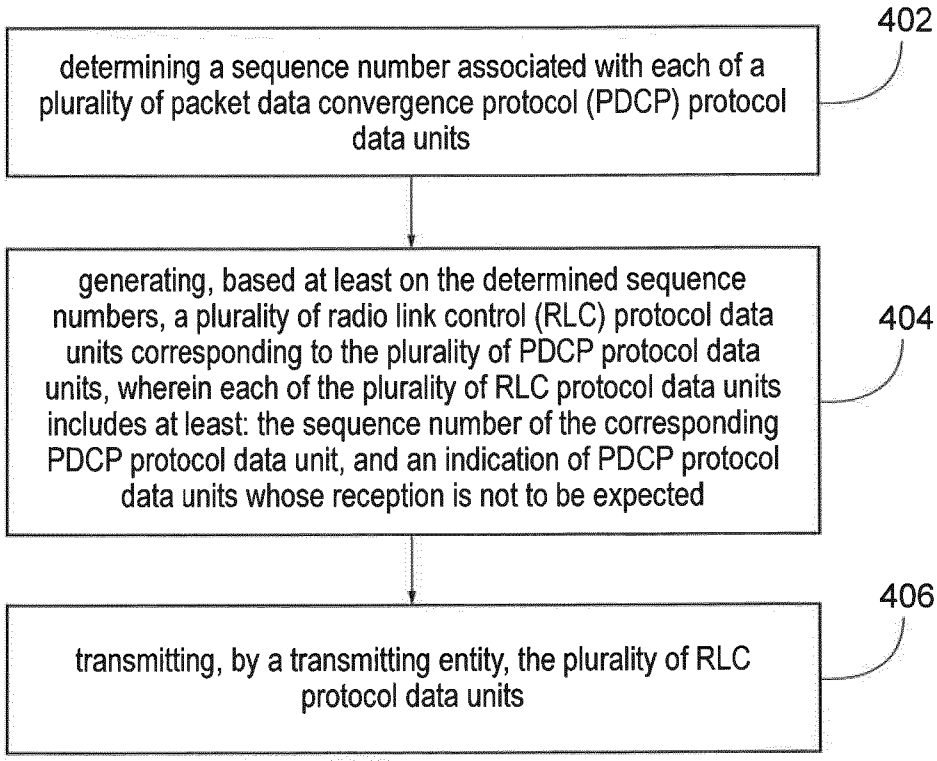

402
determining a sequence number associated with each of a plurality of packet data convergence protocol (PDCP) protocol data units
404
generating, based at least on the determined sequence numbers, a plurality of radio link control (RLC) protocol data units corresponding to the plurality of PDCP protocol data units, wherein each of the plurality of RLC protocol data units includes at least: the sequence number of the corresponding PDCP protocol data unit, and an indication of PDCP protocol data units whose reception is not to be expected
406
transmitting, by a transmitting entity, the plurality of RLC protocol data units

FIG. 4

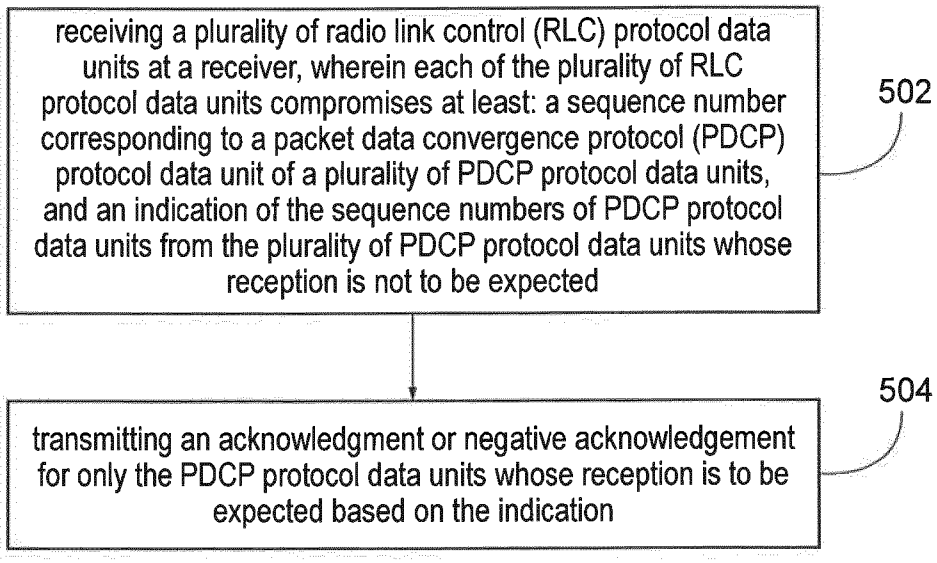

receiving a plurality of radio link control (RLC) protocol data units at a receiver, wherein each of the plurality of RLC protocol data units compromises at least: a sequence number corresponding to a packet data convergence protocol (PDCP) protocol data unit of a plurality of PDCP protocol data units, and an indication of the sequence numbers of PDCP protocol data units from the plurality of PDCP protocol data units whose reception is not to be expected
502
transmitting an acknowledgment or negative acknowledgement for only the PDCP protocol data units whose reception is to be expected based on the indication
504

FIG. 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/FI2017/050278

A. **CLASSIFICATION OF SUBJECT MATTER**

See extra sheet

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)

IPC:H04W, H04L

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

FI, SE, NO, DK

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

EPODOC, EPO-Internal full-text databases

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 7403528 B2 (HU TECK H [US] et al.) 22 July 2008 (22.07.2008)	1-2, 6-15, 19-33
A	abstract, col. 3 lines 3-15, col. 6 lines 59-64, claims 1-6	3-5, 16-18
Y	US 2007293173 A1 (JIANG SAM SHIAW-SHIANG [US]) 20 December 2007 (20.12.2007)	1-2, 6-15, 19-33
A	abstract, paragraph [0007], fig. 2	3-5, 16-18
A	US 2015326456 A1 (DUDDA TORSTEN [DE] et al.) 12 November 2015 (12.11.2015) abstract	1-33
A	US 8228917 B2 (VAYANOS ALKINOOS H [US] et al.) 24 July 2012 (24.07.2012) abstract	1-33

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

* Special categories of cited documents:

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"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
29 June 2017 (29.06.2017)	03 July 2017 (03.07.2017)

Name and mailing address of the ISA/FI
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INTERNATIONAL SEARCH REPORT

International application No.
PCT/FI2017/050278

CLASSIFICATION OF SUBJECT MATTER

IPC
H04L 12/801 (2013.01)
H04L 1/00 (2006.01)
H04L 1/16 (2006.01)
H04L 1/18 (2006.01)
H04W 80/02 (2009.01)
H04L 29/06 (2006.01)

INTERNATIONAL SEARCH REPORT
Information on Patent Family Members

International application No.
PCT/FI2017/050278

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		TW 200803569 A	01/01/2008
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