

Provisional Application for Patent Cover Sheet

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c)

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Add

Title of Invention

METHOD AND APPARATUS FOR ENHANCING COVERAGE OF MACHINE-TYPE-COMMUNICATION (MTC) DEVICES

Attorney Docket Number (if applicable)

IDC-11593US01

Correspondence Address

Direct all correspondence to (select one):

☒ The address corresponding to Customer Number

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24374

The invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.

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Entity Status

Applicant claims small entity status under 37 CFR 1.27

- ☐ Yes, applicant qualifies for small entity status under 37 CFR 1.27
- ☒ No

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Signature	/Scott Wolinsky/			Date (YYYY-MM-DD)	Oct 5, 2012
First Name	Scott	Last Name	Wolinsky	Registration Number (If appropriate)	46413

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100

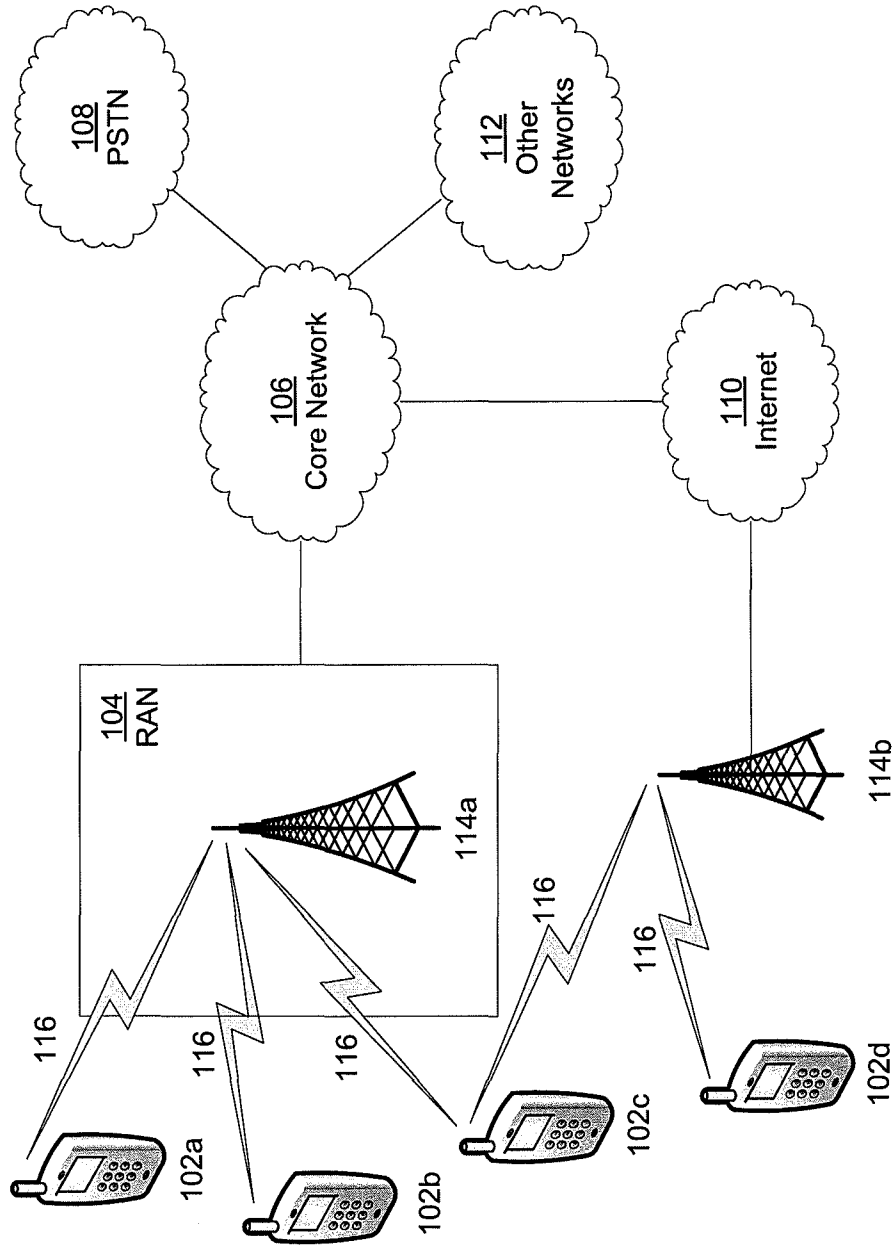
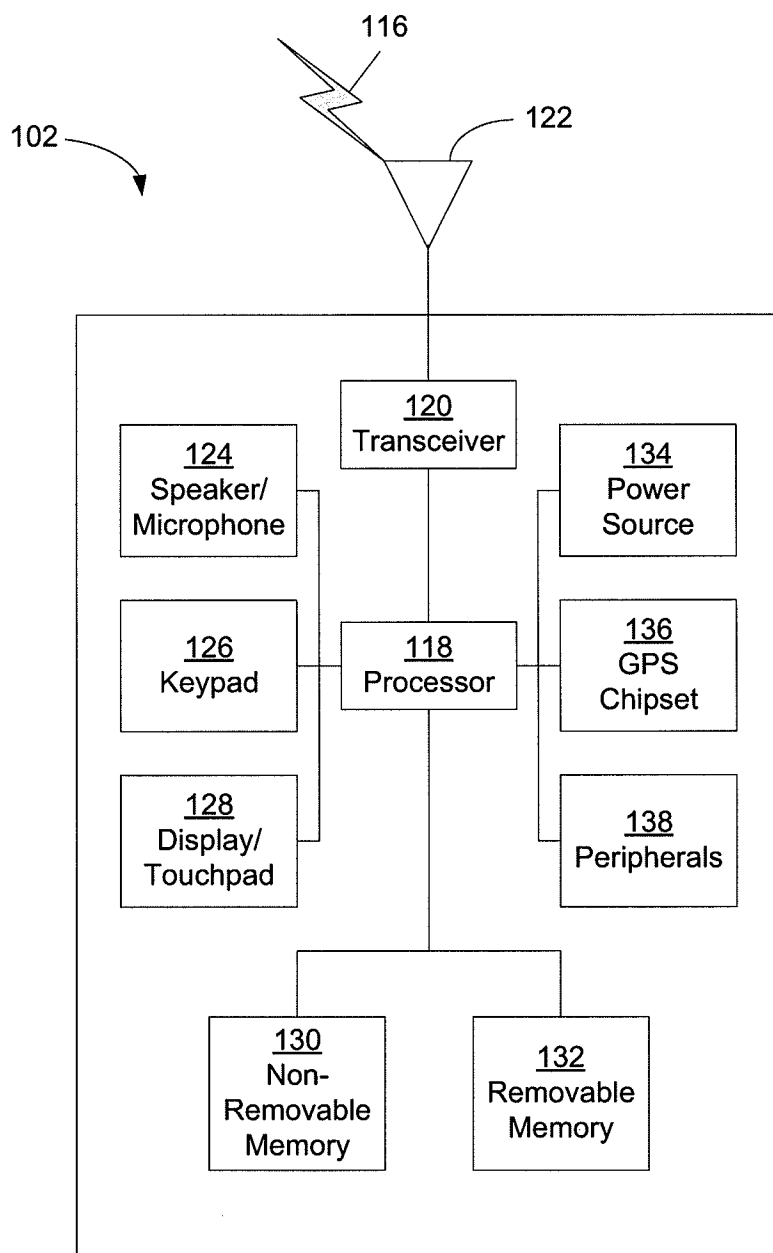


FIG. 1A

**FIG. 1B**

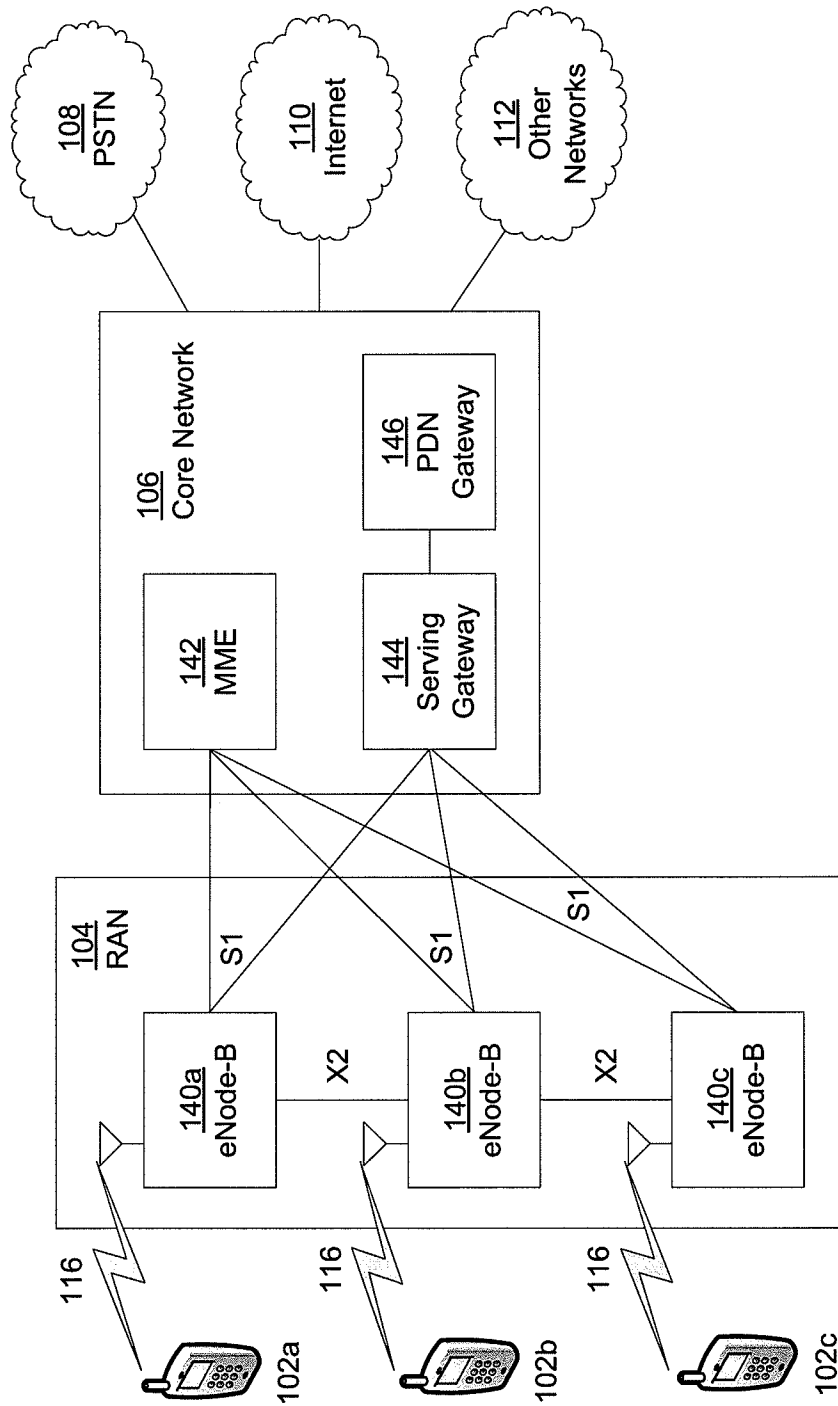


FIG. 1C

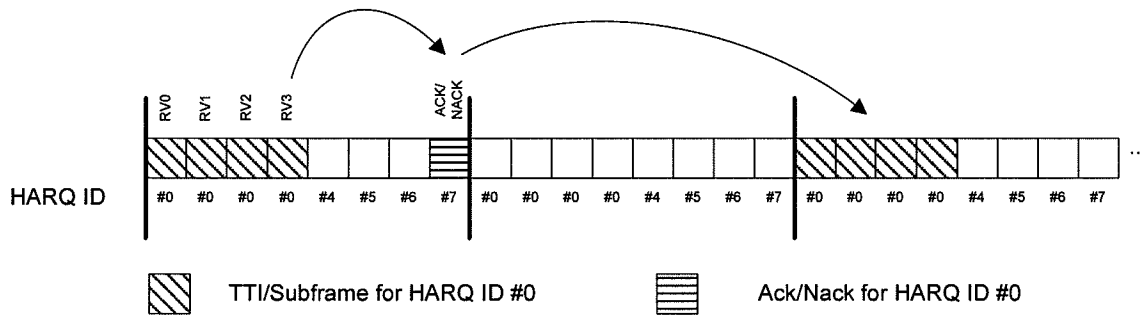


FIG. 2

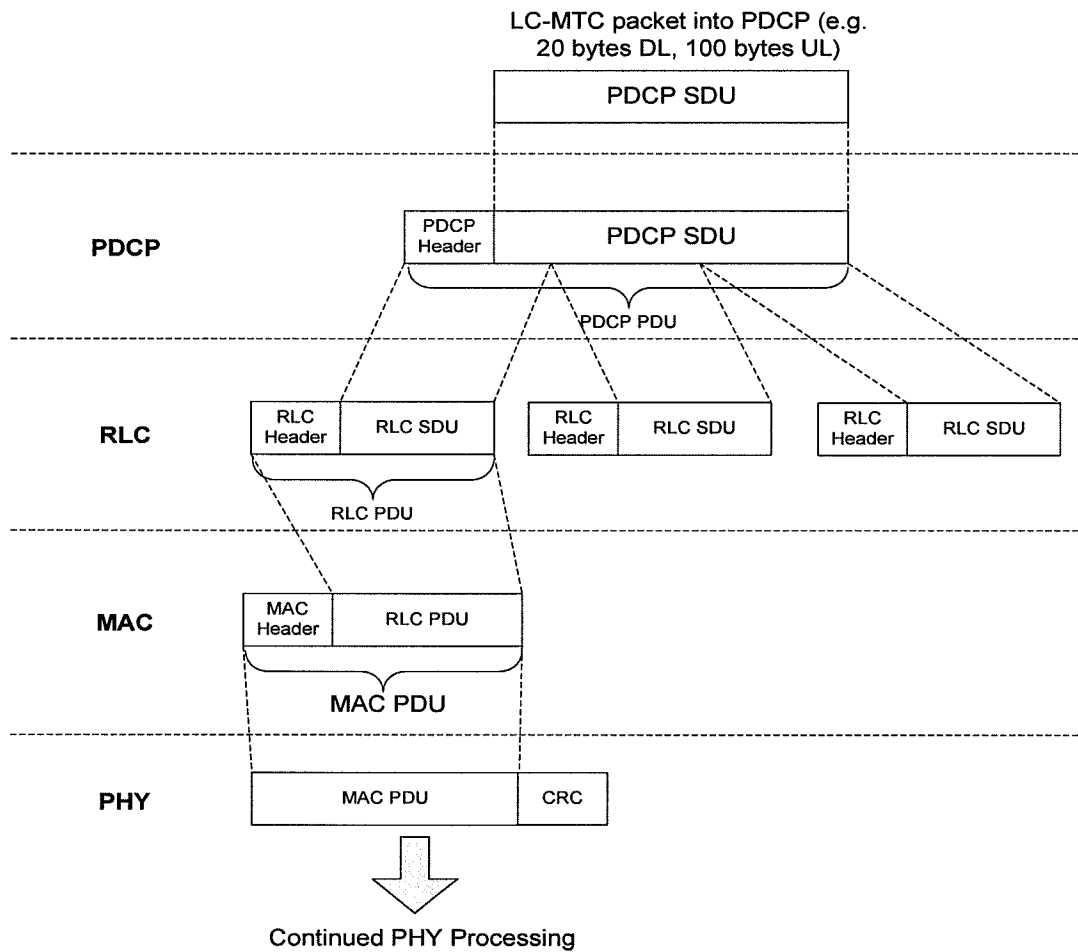


FIG. 3

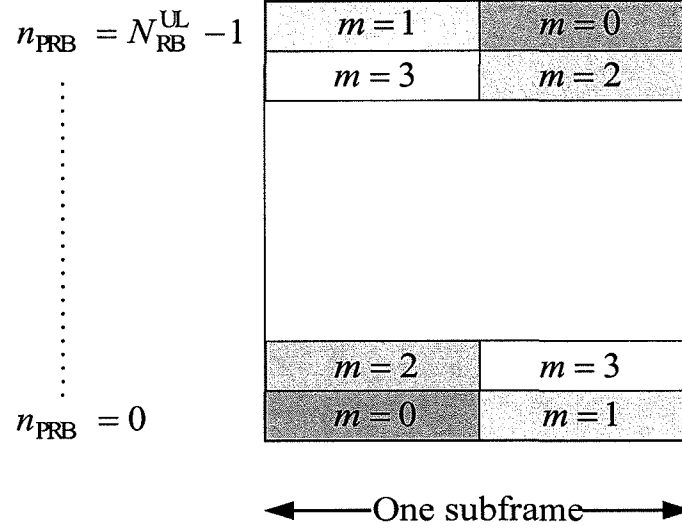


FIG. 4

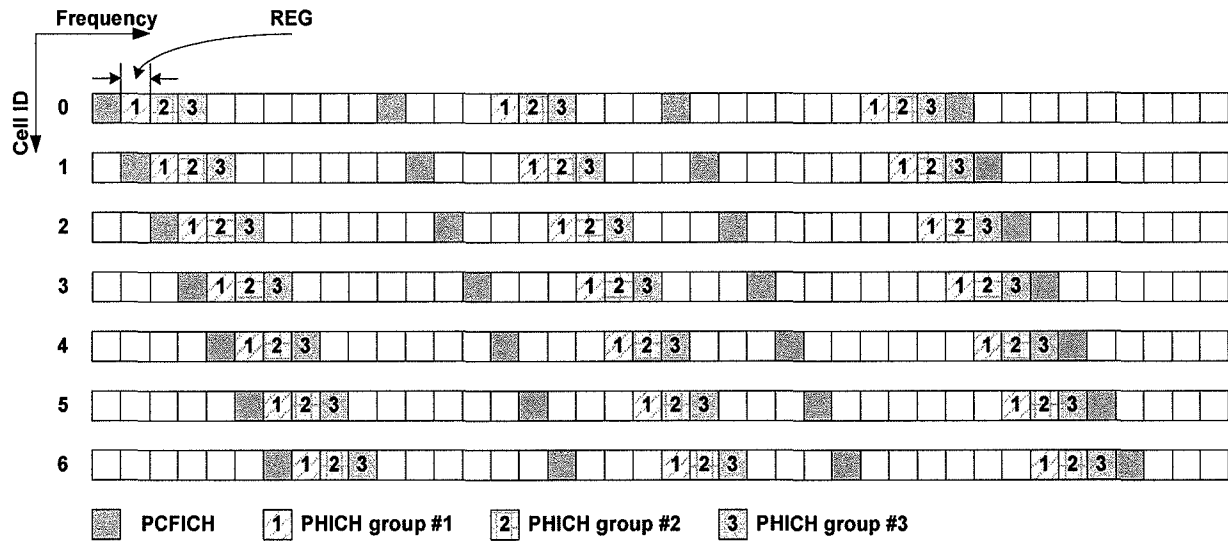


FIG. 5

Sequence index $n_{\text{PHICH}}^{\text{seq}}$	Orthogonal sequence	
	Normal cyclic prefix $N_{\text{SF}}^{\text{PHICH}} = 4$	Extended cyclic prefix $N_{\text{SF}}^{\text{PHICH}} = 2$
0	[+1 +1 +1 +1]	[+1 +1]
1	[+1 -1 +1 -1]	[+1 -1]
2	[+1 +1 -1 -1]	[+j +j]
3	[+1 -1 -1 +1]	[+j -j]
4	[+j +j +j +j]	-
5	[+j -j +j -j]	-
6	[+j +j -j -j]	-
7	[+j -j -j +j]	-

FIG. 6

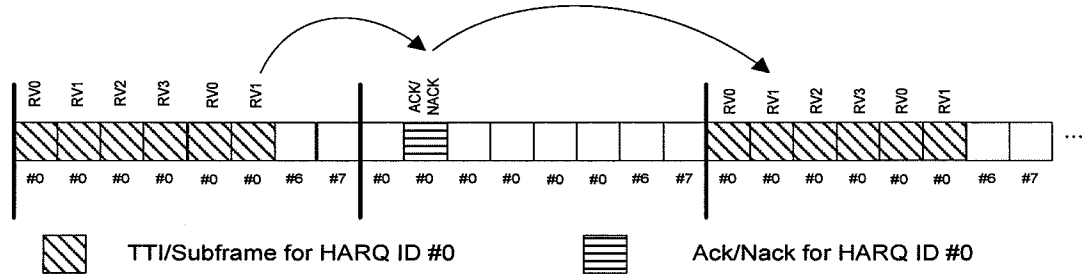


FIG. 7

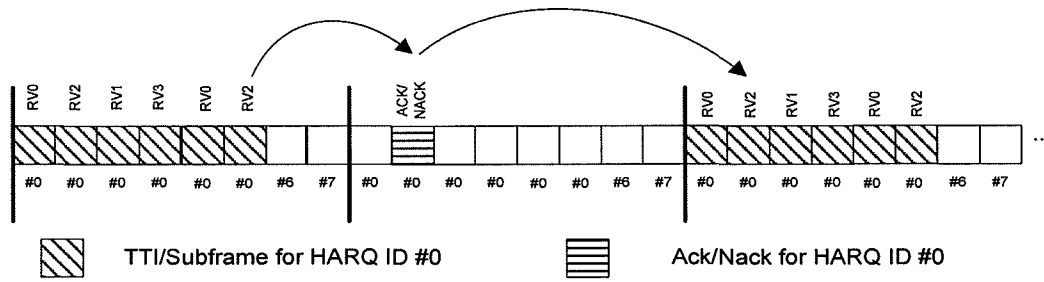


FIG. 8

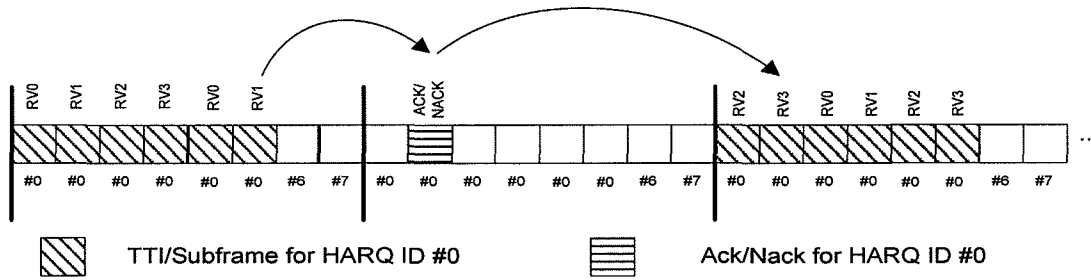


FIG. 9

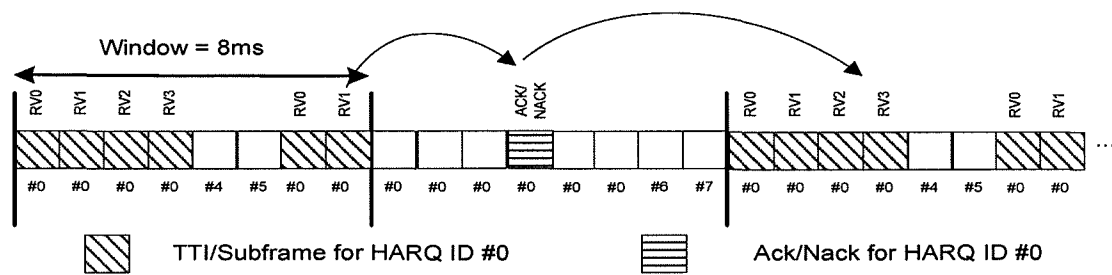


FIG. 10

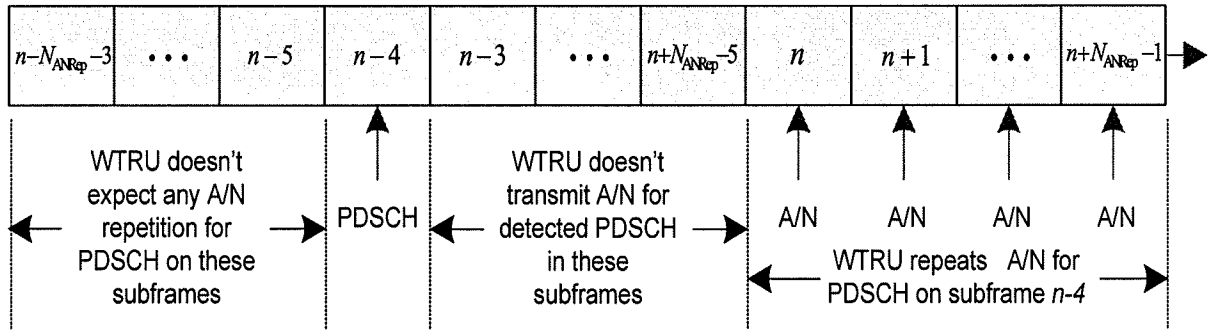


FIG. 11

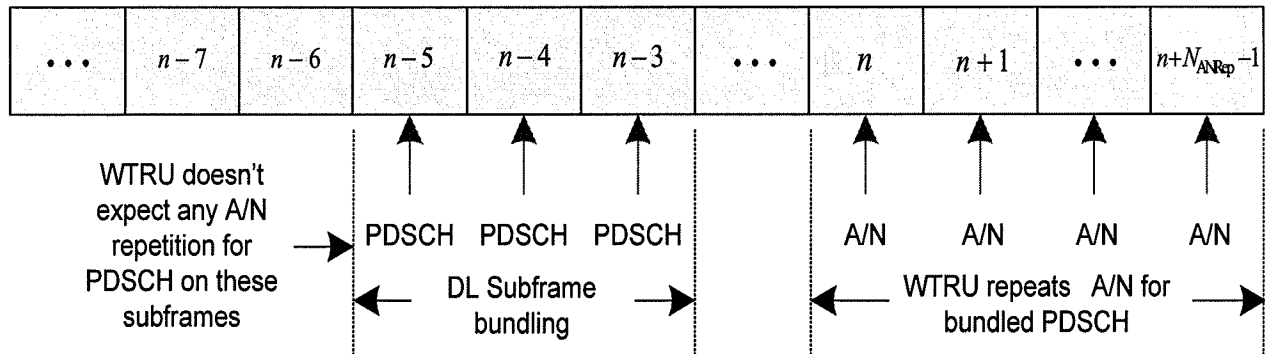


FIG. 12

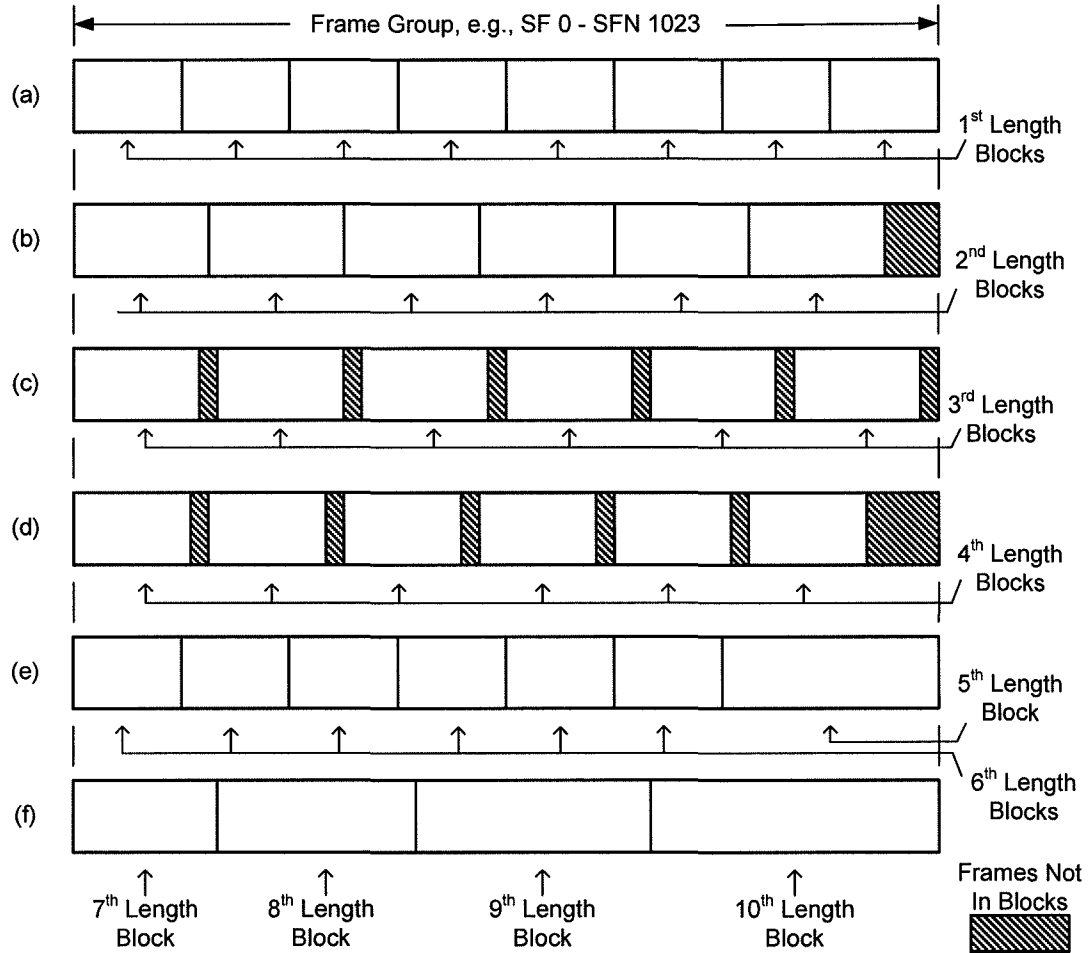


FIG. 13

METHOD AND APPARATUS FOR ENHANCING COVERAGE OF MACHINE-TYPE-COMMUNICATION (MTC) DEVICES

BACKGROUND

[0001] It may be desirable to increase (e.g., by 20 dB) the service coverage of a specific long term evolution (LTE) device or advanced LTE (LTE-A) device, (e.g., low-cost machine-type-communication (LC-MTC) device), as compared with the LTE cell coverage defined for normal LTE wireless transmit/receive units (WTRUs). In this case, the requirements for the throughput and latency may be relaxed, (e.g., a size on the order of 100 bytes/message in the uplink (UL) and 20 bytes/message in the downlink (DL)), and allowing latency of up to 10 seconds for the DL and up to 1 hour for the UL, (i.e., not voice).

[0002] For an UL shared data channel, transmission time interval (TTI) bundling may be supported for up to four (4) consecutive subframes, (i.e., 4 ms). Thus, maximum coverage enhancement may be limited to a 6 dB enhancement in the UL. Therefore, further coverage enhancement may be supported for the physical UL shared channel (PUSCH) in order to achieve as much as a 20 dB coverage enhancement. In addition, the coverage of the physical DL shared channel (PDSCH) may also be improved, since the TTI bundling has not even been supported thus far.

SUMMARY

[0003] A method and apparatus are described for a low cost machine-type-communication (LC-MTC) wireless transmit/receive unit (WTRU) to enhance coverage. The WTRU may bundle a predetermined number of consecutive subframes to enhance coverage by coding data in each of the subframes with a different redundancy version (RV), and then transmitting the plurality of subframes. The data may be coded with different RVs according to a subframe index or the location of each subframe among the bundled subframes. The subframes may be configured by an evolved Node-B (eNB) in a semi-static manner. Further, the WTRU may reduce overhead of layer 2 (L2)

protocol layers by coordinating the size of a radio link control (RLC) layer and packet data convergence protocol (PDCP) protocol data units (PDUs) such that the resultant data PDU with a header part and a data part maintain byte alignment.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] A more detailed understanding may be had from the following description, given by way of example in conjunction with the accompanying drawings wherein:

[0005] Figure 1A shows an example communications system in which one or more disclosed embodiments may be implemented;

[0006] Figure 1B shows an example wireless transmit/receive unit (WTRU) that may be used within the communications system shown in Figure 1A;

[0007] Figure 1C shows an example radio access network and an example core network that may be used within the communications system shown in Figure 1A;

[0008] Figure 2 shows an example of transmission time interval (TTI) bundling with a TTI bundle of four (4) consecutive TTIs;

[0009] Figure 3 shows an example of layer 2 (L2) processing an incoming data packet;

[0010] Figure 4 shows mapping of physical resource blocks for a physical uplink control channel (PUCCH);

[0011] Figure 5 shows physical control format indicator channel (PCFICH) and physical hybrid automatic repeat request (HARQ) indicator channel (PHICH) resource element group (REG) allocation according to a physical cell identifier (PCI);

[0012] Figure 6 shows an orthogonal sequence according to a sequence index and a spreading factor;

[0013] Figure 7 shows a cyclic redundancy version (RV) assignment with RV order {0, 1, 2, 3};

[0014] Figure 8 shows a cyclic RV assignment with RV order {0, 2, 1, 3};

[0015] Figure 9 shows a cyclic RV assignment without a window;

[0016] Figure 10 shows an example TTI bundling with a bitmap indication;

[0017] Figure 11 shows the behavior of a legacy wireless transmit/receive unit (WTRU) in case of a positive acknowledgement (ACK)/negative acknowledgement (NACK) repetition;

[0018] Figure 12 shows ACK/NACK repetition in the case of downlink (DL) subframe bundling; and

[0019] Figure 13 shows identification of frames and blocks of a preamble for a random access channel (RACH) procedure.

DETAILED DESCRIPTION

[0020] Figure 1A shows an example communications system 100 in which one or more disclosed embodiments may be implemented. The communications system 100 may be a multiple access system that provides content, such as voice, data, video, messaging, broadcast, and the like, to multiple wireless users. The communications system 100 may enable multiple wireless users to access such content through the sharing of system resources, including wireless bandwidth. For example, the communications systems 100 may employ one or more channel access methods, such as code division multiple access (CDMA), time division multiple access (TDMA), frequency division multiple access (FDMA), orthogonal FDMA (OFDMA), single-carrier FDMA (SC-FDMA), and the like.

[0021] As shown in Figure 1A, the communications system 100 may include wireless transmit/receive units (WTRUs) 102a, 102b, 102c, 102d, a radio access network (RAN) 104, a core network 106, a public switched telephone network (PSTN) 108, the Internet 110, and other networks 112, though it will be appreciated that the disclosed embodiments contemplate any number of WTRUs, base stations, networks, and/or network elements. Each of the WTRUs 102a, 102b, 102c, 102d may be any type of device configured to operate and/or communicate in a wireless environment. By way of example, the WTRUs 102a, 102b, 102c, 102d may be configured to transmit and/or receive wireless signals and may include user equipment (UE), a mobile station, a fixed or mobile subscriber unit, a pager, a cellular telephone, a personal digital

assistant (PDA), a smartphone, a laptop, a netbook, a personal computer, a wireless sensor, consumer electronics, and the like.

[0022] The communications systems 100 may also include a base station 114a and a base station 114b. Each of the base stations 114a, 114b may be any type of device configured to wirelessly interface with at least one of the WTRUs 102a, 102b, 102c, 102d to facilitate access to one or more communication networks, such as the core network 106, the Internet 110, and/or the other networks 112. By way of example, the base stations 114a, 114b may be a base transceiver station (BTS), a Node-B, an evolved Node-B (eNB), a Home Node-B (HNB), a Home eNB (HeNB), a site controller, an access point (AP), a wireless router, and the like. While the base stations 114a, 114b are each depicted as a single element, it will be appreciated that the base stations 114a, 114b may include any number of interconnected base stations and/or network elements.

[0023] The base station 114a may be part of the RAN 104, which may also include other base stations and/or network elements (not shown), such as a base station controller (BSC), a radio network controller (RNC), relay nodes, and the like. The base station 114a and/or the base station 114b may be configured to transmit and/or receive wireless signals within a particular geographic region, which may be referred to as a cell (not shown). The cell may further be divided into cell sectors. For example, the cell associated with the base station 114a may be divided into three sectors. Thus, in one embodiment, the base station 114a may include three transceivers, i.e., one for each sector of the cell. In another embodiment, the base station 114a may employ multiple-input multiple-output (MIMO) technology and, therefore, may utilize multiple transceivers for each sector of the cell.

[0024] The base stations 114a, 114b may communicate with one or more of the WTRUs 102a, 102b, 102c, 102d over an air interface 116, which may be any suitable wireless communication link, (e.g., radio frequency (RF), microwave, infrared (IR), ultraviolet (UV), visible light, and the like). The air interface 116 may be established using any suitable radio access technology (RAT).

[0025] More specifically, as noted above, the communications system 100 may be a multiple access system and may employ one or more channel access schemes, such as CDMA, TDMA, FDMA, OFDMA, SC-FDMA, and the like. For example, the base station 114a in the RAN 104 and the WTRUs 102a, 102b, 102c may implement a radio technology such as universal mobile telecommunications system (UMTS) terrestrial radio access (UTRA), which may establish the air interface 116 using wideband CDMA (WCDMA). WCDMA may include communication protocols such as high-speed packet access (HSPA) and/or evolved HSPA (HSPA+). HSPA may include high-speed downlink packet access (HSDPA) and/or high-speed uplink packet access (HSUPA).

[0026] In another embodiment, the base station 114a and the WTRUs 102a, 102b, 102c may implement a radio technology such as evolved UTRA (E-UTRA), which may establish the air interface 116 using long term evolution (LTE) and/or LTE-Advanced (LTE-A).

[0027] In other embodiments, the base station 114a and the WTRUs 102a, 102b, 102c may implement radio technologies such as IEEE 802.16 (i.e., worldwide interoperability for microwave access (WiMAX)), CDMA2000, CDMA2000 1X, CDMA2000 evolution-data optimized (EV-DO), Interim Standard 2000 (IS-2000), Interim Standard 95 (IS-95), Interim Standard 856 (IS-856), global system for mobile communications (GSM), enhanced data rates for GSM evolution (EDGE), GSM/EDGE RAN (GERAN), and the like.

[0028] The base station 114b in Figure 1A may be a wireless router, HNB, HeNB, or AP, for example, and may utilize any suitable RAT for facilitating wireless connectivity in a localized area, such as a place of business, a home, a vehicle, a campus, and the like. In one embodiment, the base station 114b and the WTRUs 102c, 102d may implement a radio technology such as IEEE 802.11 to establish a wireless local area network (WLAN). In another embodiment, the base station 114b and the WTRUs 102c, 102d may implement a radio technology such as IEEE 802.15 to establish a wireless personal area network (WPAN). In yet another embodiment, the base station 114b and the WTRUs 102c, 102d may utilize a cellular-based RAT, (e.g.,

WCDMA, CDMA2000, GSM, LTE, LTE-A, and the like), to establish a picocell or femtocell. As shown in Figure 1A, the base station 114b may have a direct connection to the Internet 110. Thus, the base station 114b may not be required to access the Internet 110 via the core network 106.

[0029] The RAN 104 may be in communication with the core network 106, which may be any type of network configured to provide voice, data, applications, and/or voice over Internet protocol (VoIP) services to one or more of the WTRUs 102a, 102b, 102c, 102d. For example, the core network 106 may provide call control, billing services, mobile location-based services, pre-paid calling, Internet connectivity, video distribution, and the like, and/or perform high-level security functions, such as user authentication. Although not shown in Figure 1A, it will be appreciated that the RAN 104 and/or the core network 106 may be in direct or indirect communication with other RANs that employ the same RAT as the RAN 104 or a different RAT. For example, in addition to being connected to the RAN 104, which may be utilizing an E-UTRA radio technology, the core network 106 may also be in communication with another RAN (not shown) employing a GSM radio technology.

[0030] The core network 106 may also serve as a gateway for the WTRUs 102a, 102b, 102c, 102d to access the PSTN 108, the Internet 110, and/or other networks 112. The PSTN 108 may include circuit-switched telephone networks that provide plain old telephone service (POTS). The Internet 110 may include a global system of interconnected computer networks and devices that use common communication protocols, such as the transmission control protocol (TCP), user datagram protocol (UDP) and the Internet protocol (IP) in the TCP/IP suite. The networks 112 may include wired or wireless communications networks owned and/or operated by other service providers. For example, the networks 112 may include another core network connected to one or more RANs, which may employ the same RAT as the RAN 104 or a different RAT.

[0031] Some or all of the WTRUs 102a, 102b, 102c, 102d in the communications system 100 may include multi-mode capabilities, i.e., the WTRUs 102a, 102b, 102c,

102d may include multiple transceivers for communicating with different wireless networks over different wireless links. For example, the WTRU 102c shown in Figure 1A may be configured to communicate with the base station 114a, which may employ a cellular-based radio technology, and with the base station 114b, which may employ an IEEE 802 radio technology.

[0032] Figure 1B shows an example WTRU 102 that may be used within the communications system 100 shown in Figure 1A. As shown in Figure 1B, the WTRU 102 may include a processor 118, a transceiver 120, a transmit/receive element, (e.g., an antenna), 122, a speaker/microphone 124, a keypad 126, a display/touchpad 128, a non-removable memory 130, a removable memory 132, a power source 134, a global positioning system (GPS) chipset 136, and peripherals 138. It will be appreciated that the WTRU 102 may include any sub-combination of the foregoing elements while remaining consistent with an embodiment.

[0033] The processor 118 may be a general purpose processor, a special purpose processor, a conventional processor, a digital signal processor (DSP), a microprocessor, one or more microprocessors in association with a DSP core, a controller, a microcontroller, an application specific integrated circuit (ASIC), a field programmable gate array (FPGA) circuit, an integrated circuit (IC), a state machine, and the like. The processor 118 may perform signal coding, data processing, power control, input/output processing, and/or any other functionality that enables the WTRU 102 to operate in a wireless environment. The processor 118 may be coupled to the transceiver 120, which may be coupled to the transmit/receive element 122. While Figure 1B depicts the processor 118 and the transceiver 120 as separate components, the processor 118 and the transceiver 120 may be integrated together in an electronic package or chip.

[0034] The transmit/receive element 122 may be configured to transmit signals to, or receive signals from, a base station (e.g., the base station 114a) over the air interface 116. For example, in one embodiment, the transmit/receive element 122 may be an antenna configured to transmit and/or receive RF signals. In another

embodiment, the transmit/receive element 122 may be an emitter/detector configured to transmit and/or receive IR, UV, or visible light signals, for example. In yet another embodiment, the transmit/receive element 122 may be configured to transmit and receive both RF and light signals. The transmit/receive element 122 may be configured to transmit and/or receive any combination of wireless signals.

[0035] In addition, although the transmit/receive element 122 is depicted in Figure 1B as a single element, the WTRU 102 may include any number of transmit/receive elements 122. More specifically, the WTRU 102 may employ MIMO technology. Thus, in one embodiment, the WTRU 102 may include two or more transmit/receive elements 122, (e.g., multiple antennas), for transmitting and receiving wireless signals over the air interface 116.

[0036] The transceiver 120 may be configured to modulate the signals that are to be transmitted by the transmit/receive element 122 and to demodulate the signals that are received by the transmit/receive element 122. As noted above, the WTRU 102 may have multi-mode capabilities. Thus, the transceiver 120 may include multiple transceivers for enabling the WTRU 102 to communicate via multiple RATs, such as UTRA and IEEE 802.11, for example.

[0037] The processor 118 of the WTRU 102 may be coupled to, and may receive user input data from, the speaker/microphone 124, the keypad 126, and/or the display/touchpad 128 (e.g., a liquid crystal display (LCD) display unit or organic light-emitting diode (OLED) display unit). The processor 118 may also output user data to the speaker/microphone 124, the keypad 126, and/or the display/touchpad 128. In addition, the processor 118 may access information from, and store data in, any type of suitable memory, such as the non-removable memory 130 and/or the removable memory 132. The non-removable memory 130 may include random-access memory (RAM), read-only memory (ROM), a hard disk, or any other type of memory storage device. The removable memory 132 may include a subscriber identity module (SIM) card, a memory stick, a secure digital (SD) memory card, and the like. In other embodiments, the processor 118 may access information from, and store data in,

memory that is not physically located on the WTRU 102, such as on a server or a home computer (not shown).

[0038] The processor 118 may receive power from the power source 134, and may be configured to distribute and/or control the power to the other components in the WTRU 102. The power source 134 may be any suitable device for powering the WTRU 102. For example, the power source 134 may include one or more dry cell batteries (e.g., nickel-cadmium (NiCd), nickel-zinc (NiZn), nickel metal hydride (NiMH), lithium-ion (Li-ion), and the like), solar cells, fuel cells, and the like.

[0039] The processor 118 may also be coupled to the GPS chipset 136, which may be configured to provide location information (e.g., longitude and latitude) regarding the current location of the WTRU 102. In addition to, or in lieu of, the information from the GPS chipset 136, the WTRU 102 may receive location information over the air interface 116 from a base station, (e.g., base stations 114a, 114b), and/or determine its location based on the timing of the signals being received from two or more nearby base stations. The WTRU 102 may acquire location information by way of any suitable location-determination method while remaining consistent with an embodiment.

[0040] The processor 118 may further be coupled to other peripherals 138, which may include one or more software and/or hardware modules that provide additional features, functionality and/or wired or wireless connectivity. For example, the peripherals 138 may include an accelerometer, an e-compass, a satellite transceiver, a digital camera (for photographs or video), a universal serial bus (USB) port, a vibration device, a television transceiver, a hands free headset, a Bluetooth® module, a frequency modulated (FM) radio unit, a digital music player, a media player, a video game player module, an Internet browser, and the like.

[0041] Figure 1C shows an example RAN 104 and an example core network 106 that may be used within the communications system 100 shown in Figure 1A. As noted above, the RAN 104 may employ an E-UTRA radio technology to communicate with the WTRUs 102a, 102b, 102c over the air interface 116. The RAN 104 may also be in communication with the core network 106.

[0042] The RAN 104 may include eNBs 140a, 140b, 140c, though it will be appreciated that the RAN 104 may include any number of eNBs while remaining consistent with an embodiment. The eNBs 140a, 140b, 140c may each include one or more transceivers for communicating with the WTRUs 102a, 102b, 102c over the air interface 116. In one embodiment, the eNBs 140a, 140b, 140c may implement MIMO technology. Thus, the eNB 140a, for example, may use multiple antennas to transmit wireless signals to, and receive wireless signals from, the WTRU 102a.

[0043] Each of the eNBs 140a, 140b, 140c may be associated with a particular cell (not shown) and may be configured to handle radio resource management decisions, handover decisions, scheduling of users in the uplink and/or downlink, and the like. As shown in Figure 1C, the eNBs 140a, 140b, 140c may communicate with one another over an X2 interface.

[0044] The core network 106 shown in Figure 1C may include a mobility management entity (MME) 142, a serving gateway 144, and a packet data network (PDN) gateway 146. While each of the foregoing elements are depicted as part of the core network 106, it will be appreciated that any one of these elements may be owned and/or operated by an entity other than the core network operator.

[0045] The MME 142 may be connected to each of the eNBs 140a, 140b, 140c in the RAN 104 via an S1 interface and may serve as a control node. For example, the MME 142 may be responsible for authenticating users of the WTRUs 102a, 102b, 102c, bearer activation/deactivation, selecting a particular serving gateway during an initial attach of the WTRUs 102a, 102b, 102c, and the like. The MME 142 may also provide a control plane function for switching between the RAN 104 and other RANs (not shown) that employ other radio technologies, such as GSM or WCDMA.

[0046] The serving gateway 144 may be connected to each of the eNBs 140a, 140b, 140c in the RAN 104 via the S1 interface. The serving gateway 144 may generally route and forward user data packets to/from the WTRUs 102a, 102b, 102c. The serving gateway 144 may also perform other functions, such as anchoring user planes during inter-eNB handovers, triggering paging when downlink data is available

for the WTRUs 102a, 102b, 102c, managing and storing contexts of the WTRUs 102a, 102b, 102c, and the like.

[0047] The serving gateway 144 may also be connected to the PDN gateway 146, which may provide the WTRUs 102a, 102b, 102c with access to packet-switched networks, such as the Internet 110, to facilitate communications between the WTRUs 102a, 102b, 102c and IP-enabled devices.

[0048] The core network 106 may facilitate communications with other networks. For example, the core network 106 may provide the WTRUs 102a, 102b, 102c with access to circuit-switched networks, such as the PSTN 108, to facilitate communications between the WTRUs 102a, 102b, 102c and traditional land-line communications devices. For example, the core network 106 may include, or may communicate with, an IP gateway, (e.g., an IP multimedia subsystem (IMS) server), that serves as an interface between the core network 106 and the PSTN 108. In addition, the core network 106 may provide the WTRUs 102a, 102b, 102c with access to the networks 112, which may include other wired or wireless networks that are owned and/or operated by other service providers.

[0049] TTI bundling may enhance the UL coverage for a user of a WTRU that experiences limited UL coverage and its transmission power approaches the maximum. Figure 2 shows an example of transmission time interval (TTI) bundling with a TTI bundle of four (4) consecutive TTIs. By using TTI bundling in frequency division duplex (FDD), the same data may be transmitted in up to four (4) consecutive TTIs as shown in Figure 2, allowing the WTRU to extend the effective transmission time window by up to four (4) times, where a single transport block may be coded and transmitted with different redundancy versions (RVs) in those consecutive subframes. The same HARQ process number may be assigned to all TTIs in a TTI bundle. All TTIs within a TTI bundle may be treated as a single resource, where a single UL grant and a single ACK/NACK, (e.g., PHICH), may be associated with them. A TTI bundling mechanism may be configured by higher layer signaling per the WTRU. In FDD TTI bundling, the roundtrip time (RTT) for every re-transmission may be equal to 16ms.

When the FDD TTI bundling is activated, the WTRU may receive the UL grant for the first subframe in the TTI bundle according to the rules of a FDD UL grant, (e.g., R8), and once the UL data is transmitted in a TTI bundle, a PHICH, (or another UL grant), may be expected by the WTRU according to the PHICH rules, (e.g., R8), corresponding to the last subframe of that TTI bundle, (“TTI” and “subframe” may be used interchangeably). The consecutive TTIs in the same TTI bundle may be assigned to consecutive RVs.

[0050] Figure 3 shows an example of layer 2 (L2) processing an incoming data packet, where the HARQ ID #0 consists of 4 bundled TTIs, the ACK/NACK is received in 4 TTIs after the last TTI of the TTI bundle and the re-transmission happens in 16 TTIs after the first TTI of the initial transmission.

[0051] In R10, once FDD TTI bundling is activated, the WTRU may support up to 4 HARQ processes. In FDD operation, all TTI bundles of the same HARQ process may have the same number of UL subframes, have the same pattern, (e.g., include consecutive UL subframes), and may be uniformly distributed in the time domain.

[0052] Figure 4 shows mapping of physical resource blocks for a physical uplink control channel (PUCCH). Figure 4 indicates the header that is appended to the incoming packet to the packet data convergence protocol (PDCP) that is to be transmitted on the DL or UL direction. The processing example in Figure 4 is a simplified one for low data rates where the radio link control (RLC) segments, but does not concatenate PDCP protocol data units (PDUs), (into 3 RLC PDUs as shown in Figure 4), such that each medium access control (MAC) PDU may consist of a single segmented RLC PDU. This way, the protocol header overhead for each layer may include PDCP, RLC, MAC and physical (PHY) layers.

[0053] The PDCP layer may include an 8-bit PDCP header including 1 bit for a data or control PDU indication, and 7 bits for a sequence number (SN). The SN may be used for the purpose of in-sequence delivery of a PDCP service data unit (SDU) to higher layers, as well as used for hyper frame number (HFN) sequence management for ciphering.

[0054] In the RLC layer, the header size may be dependent on whether unacknowledged mode (UM) or acknowledged mode (AM) is configured. For AM, a 16 bit header is included, 10 bits of which is the SN. For UM, an 8 bit header is included, 5 bits of which is the SN. The header may be applicable to each segmented RLC SDU.

[0055] The MAC layer may include an 8-bit header, 5 bits of which may be used for the logical channel identification (ID) (LCID).

[0056] In the PHY layer, a 24-bit cyclic redundancy check (CRC) may be attached to the end of the MAC PDU prior to further processing in the physical layer.

[0057] Larger headers may be configured for each protocol layer when a high data rate data radio bearer (DRB) is configured. For example, the PDCP and RLC entities may allocate a larger SN bit size in the header. Further, the RLC layer may concatenate multiple RLC SDUs into a single PDU, which may increase the RLC header size further. Additionally, the MAC layer may also multiplex multiple MAC SDUs into a single MAC PDU as the allocated transport block size permits for the transmission opportunity, and the MAC header will increase accordingly to the number of MAC SDUs that are multiplexed into the MAC PDU.

[0058] The physical resources used for PUCCH may depend on two parameters, $N_{RB}^{(2)}$ and $N_{cs}^{(1)}$, given by higher layers. The variable $N_{RB}^{(2)} \geq 0$ may denote the bandwidth in terms of resource blocks that are available for use by PUCCH formats 2/2a/2b transmission in each slot. The variable $N_{cs}^{(1)}$ may denote the number of cyclic shifts used for PUCCH formats 1/1a/1b in a resource block used for a mix of formats 1/1a/1b and 2/2a/2b. The value of $N_{cs}^{(1)}$ is an integer multiple of Δ_{shift}^{PUCCH} within the range of $\{0, 1, \dots, 7\}$, where Δ_{shift}^{PUCCH} may be provided by higher layers. No mixed resource block may be present if $N_{cs}^{(1)} = 0$. At most, one resource block in each slot may support a mix of formats 1/1a/1b and 2/2a/2b. Resources used for transmission of PUCCH formats 1/1a/1b, 2/2a/2b and 3 may be represented by the non-negative indices $n_{PUCCH}^{(1, \tilde{p})}$,

$n_{PUCCH}^{(2, \tilde{p})} < N_{RB}^{(2)} N_{sc}^{RB} + \left\lceil \frac{N_{cs}^{(1)}}{8} \right\rceil \cdot (N_{sc}^{RB} - N_{cs}^{(1)} - 2)$, and $n_{PUCCH}^{(3, \tilde{p})}$, respectively.

[0059] The block of complex-valued symbols $z^{(\tilde{p})}(i)$ may be multiplied with the amplitude scaling factor β_{PUCCH} in order to conform to the transmit power P_{PUCCH} , and mapped in sequence starting with $z^{(\tilde{p})}(0)$ to resource elements. PUCCH may use one resource block in each of the two slots in a subframe. Within the physical resource block used for transmission, the mapping of $z^{(\tilde{p})}(i)$ to resource elements (k, l) on antenna port p and not used for transmission of reference signals may be in increasing order of first k , then l and finally the slot number, starting with the first slot in the subframe. The physical resource blocks to be used for transmission of PUCCH in slot n_s may be given by:

$$n_{\text{PRB}} = \begin{cases} \left\lfloor \frac{m}{2} \right\rfloor & \text{if } (m + n_s \bmod 2) \bmod 2 = 0 \\ N_{\text{RB}}^{\text{UL}} - 1 - \left\lfloor \frac{m}{2} \right\rfloor & \text{if } (m + n_s \bmod 2) \bmod 2 = 1 \end{cases}, \quad \text{Equation (1)}$$

where the variable m depends on the PUCCH format. For formats 1, 1a and 1b:

$$m = \begin{cases} N_{\text{RB}}^{(2)} & \text{if } n_{\text{PUCCH}}^{(1, \tilde{p})} < c \cdot N_{\text{cs}}^{(1)} / \Delta_{\text{shift}}^{\text{PUCCH}} \\ \left\lfloor \frac{n_{\text{PUCCH}}^{(1, \tilde{p})} - c \cdot N_{\text{cs}}^{(1)} / \Delta_{\text{shift}}^{\text{PUCCH}}}{c \cdot N_{\text{sc}}^{\text{RB}} / \Delta_{\text{shift}}^{\text{PUCCH}}} \right\rfloor + N_{\text{RB}}^{(2)} + \left\lfloor \frac{N_{\text{cs}}^{(1)}}{8} \right\rfloor & \text{otherwise} \end{cases}; \quad \text{Equation (2)}$$

$$c = \begin{cases} 3 & \text{normal cyclic prefix} \\ 2 & \text{extended cyclic prefix} \end{cases}$$

and for formats 2, 2a and 2b:

$$m = \left\lfloor n_{\text{PUCCH}}^{(2, \tilde{p})} / N_{\text{sc}}^{\text{RB}} \right\rfloor; \quad \text{Equation (3)}$$

and for format 3:

$$m = \left\lfloor n_{\text{PUCCH}}^{(3, \tilde{p})} / N_{\text{SF}, 0}^{\text{PUCCH}} \right\rfloor. \quad \text{Equation (4)}$$

[0060] Mapping of modulation symbols for the PUCCH is shown in Figure 4. In case of simultaneous transmission of sounding reference signal and PUCCH format 1, 1a, 1b or 3 when there is one serving cell configured, a shortened PUCCH format may

be used where the last single carrier frequency division multiple access (SC-FDMA) symbol in the second slot of a subframe may be left empty.

[0061] HARQ-ACK transmission on two antenna ports ($p \in [p_0, p_1]$) may be supported for PUCCH format 1a/1b. For FDD and one configured serving cell, the WTRU may use a PUCCH resource $n_{\text{PUCCH}}^{(1, \tilde{p})}$ for transmission of HARQ-ACK in subframe n for $\tilde{p}$ mapped to antenna port p for PUCCH format 1a/1b, where for a PDSCH transmission indicated by the detection of a corresponding PDCCH in subframe $n-4$, or for a PDCCH indicating downlink semi-persistent scheduling (SPS) release in subframe $n-4$, the WTRU may use $n_{\text{PUCCH}}^{(1, \tilde{p}_0)} = n_{\text{CCE}} + N_{\text{PUCCH}}^{(1)}$ for antenna port p_0 , where n_{CCE} is the number of the first control channel element (CCE), (i.e., lowest CCE index used to construct the PDCCH), used for transmission of the corresponding DL control information (DCI) assignment, and $N_{\text{PUCCH}}^{(1)}$ may be configured by higher layers. For two antenna port transmission, the PUCCH resource for antenna port p_1 may be given by $n_{\text{PUCCH}}^{(1, \tilde{p}_1)} = n_{\text{CCE}} + 1 + N_{\text{PUCCH}}^{(1)}$. For a PDSCH transmission on the primary cell where there is not a corresponding PDCCH detected in subframe $n-4$, the value of $n_{\text{PUCCH}}^{(1, \tilde{p})}$ may be determined according to higher layer configuration. For a WTRU configured for two antenna port transmission, a PUCCH resource value may map to two PUCCH resources with the first PUCCH resource $n_{\text{PUCCH}}^{(1, \tilde{p}_0)}$ for antenna port p_0 and the second PUCCH resource $n_{\text{PUCCH}}^{(1, \tilde{p}_1)}$ for antenna port p_1 . Otherwise, the PUCCH resource value may map to a single PUCCH resource $n_{\text{PUCCH}}^{(1, \tilde{p}_0)}$ for antenna port p_0 .

[0062] A PHICH may be used to transmit an ACK or NACK corresponding to the PUSCH transmitted in a UL subframe. A PHICH may also be transmitted in distributed manner across system bandwidth and orthogonal frequency division multiplexing (OFDM) symbols within a DL control channel. The number of OFDM symbol may be defined as PHICH duration and configurable via higher layer signaling. As different from the PCFICH, the PHICH resource position may vary according to PHICH duration.

[0063] Figure 5 shows physical control format indicator channel (PCFICH) and physical hybrid automatic repeat request (HARQ) indicator channel (PHICH) resource element group (REG) allocation according to a physical cell identifier (PCI). As seen in Figure 5, multiple PHICH groups may be defined in a cell, and a PHICH group may contain multiple PHICHs with orthogonal sequences, and the PHICH for a WTRU may be defined dynamically with resource information in a UL grant such as lowest physical resource block (PRB) index ($I_{\text{PRB}_{\text{RA}}}^{\text{lowest_index}}$) and demodulation reference signal (DM-RS) cyclic shift (n_{DMRS}). Therefore, two index pair (PHICH group index: $n_{\text{PHICH}}^{\text{group}}$, PHICH sequence index: $n_{\text{PHICH}}^{\text{seq}}$) may indicate the PHICH resource for a specific WTRU. In the PHICH index pair ($n_{\text{PHICH}}^{\text{group}}$, $n_{\text{PHICH}}^{\text{seq}}$), each index may be defined as follows:

$$n_{\text{PHICH}}^{\text{group}} = (I_{\text{PRB}_{\text{RA}}}^{\text{lowest_index}} + n_{\text{DMRS}}) \bmod N_{\text{PHICH}}^{\text{group}} ; \quad \text{Equation (5)}$$

$$n_{\text{PHICH}}^{\text{seq}} = \left(\left\lfloor \frac{I_{\text{PRB}_{\text{RA}}}^{\text{lowest_index}}}{N_{\text{PHICH}}^{\text{group}}} \right\rfloor + n_{\text{DMRS}} \right) \bmod 2 N_{\text{SF}}^{\text{PHICH}} , \quad \text{Equation (6)}$$

where the $N_{\text{PHICH}}^{\text{group}}$ may denotes the number of PHICH group available in the system with following definition:

$$N_{\text{PHICH}}^{\text{group}} = \left\{ \begin{array}{l} \left\lceil N_g \left(\frac{N_{\text{RB}}^{\text{DL}}}{8} \right) \right\rceil \\ 2 \cdot \left\lceil N_g \left(\frac{N_{\text{RB}}^{\text{DL}}}{8} \right) \right\rceil \end{array} \right\} , \quad \text{Equation (7)}$$

where N_g is 2-bit information transmitted via a physical broadcasting channel (PBCH) and the information is within $N_g \in \{1/6, 1/2, 1, 2\}$. The orthogonal sequence according to the spreading factor is shown in Figure 6.

[0064] The eNB and the WTRU may use the random access procedure for the WTRU to obtain initial access, reset UL timing, and to reset timing during handover. Part of the procedure is that the WTRU transmits a certain physical RACH (PRACH)

preamble sequence at a certain power P_{PRACH} (based on configured `preambleInitialReceivedTargetPower`, `deltaPreamble` and measured pathloss, and limited by `Pcmax` or `Pcmax,c` and using a certain time and frequency resource. If the eNB detects the preamble, it may respond with a random access response (RAR) and the procedure may continue. If the WTRU does not receive an RAR for the transmitted preamble, (correct preamble index and time and frequency resource), within an allotted time (`ra-ResponseWindowSize`), the WTRU may send another preamble at a later time, at a higher power (higher than the previous preamble transmission, by `powerRampingStep`) limited by `Pcmax` or `Pcmax,c`, and may again wait for receipt of an RAR from the eNB. This pair of transmitting/waiting may continue until the eNB finally responds with an RAR, or until the maximum number of RACH preamble transmissions (`preambleTransMax`) has been reached. The eNB may send the RAR in response to a single preamble transmission.

[0065] A particular instance of a RACH procedure may be either contention-based or contention-free. A contention-free procedure may be initiated by PDCCH order or by an RRC connection reconfiguration message with mobility control information, i.e., a handover request. For a contention-free procedure initiated by PDCCH order in subframe n , the PRACH preamble may be transmitted in the first subframe $n+k_2$, $k_2 \geq 6$, where a PRACH resource is available, and when initiated by RRC command, other delays may be specified. The WTRU may autonomously initiate a contention-based procedure for a number of reasons, e.g., initial access, restoration of UL synchronization, recovering from radio link failure. Other than for recovery from radio link failure, it may not be specified as to how long after such event the WTRU may send the PRACH preamble.

[0066] For a contention-free RACH procedure, the network-signaled PRACH preamble is used, whereas for contention-based RACH, the WTRU may autonomously choose a preamble. The preamble format to be used and the time/frequency resource(s) available for preamble transmissions may be based on `prach-configIndex` and a specified procedure.

[0067] Inherent in the LTE system design is that eventually one of the preambles transmitted at the progressively higher transmit powers may be detected by the eNB. An RAR may be sent by the eNB in response to that one detected preamble.

[0068] Segmentation functionality in an RLC layer may allow for smaller segmented data to be transmitted with increased energy per bit. However, the layer 2 (L2) header overhead added to each segmented data may limit gains to coverage enhancements provided by segmentation. The overhead added by L2 protocol headers may be reduced to further these gains.

[0069] As the coverage of the shared channels in both UL and DL are improved, the coverage of its associated HARQ ACK channels may need to be improved as well in order to support the H-ARQ process.

[0070] Inherent in the LTE system design is that the evolved Node-B may eventually detect and respond to one power-ramped preamble transmission from the WTRU. A machine-type-communication (LC-MTC) may experience much higher pathloss, up to 20 dB, than was anticipated in the LTE system design. For an LC-MTC experiencing such high pathloss, it may be possible that none of the ramped preambles, including those transmitted with the maximum transmission power, may be detected and responded to by the eNB. As such, methods and procedures are needed for a RACH procedure for the LC-MTC when experiencing very high pathloss.

[0071] Given that an LC-MTC WTRU may support very low data rates with high delay tolerance in terms of quality of service, the WTRU may possibly reduce the size of each protocol layer header for each transport block that the WTRU may receive and/or transmit.

[0072] The PDCP and RLC may allocate a smaller SN size in its headers. In the PDCP, the WTRU may allocate a SN size of smaller than 7 bits. In the RLC, the WTRU may allocate a SN size of smaller than 5 bits for UM or 10 bits for AM. The WTRU may coordinate the sizes of the RLC and PDCP PDUs such that the resultant data PDU with the header and data part may maintain octet (byte) alignment. The WTRU may

have a PDCP PDU that is not byte aligned, but the RLC header and PDUs may be processed such that the resulting RLC PDU byte alignment may be maintained.

[0073] The WTRU may not include the extension (“E”) fields in MAC and RLC, thus further reducing the header sizes. For example, a WTRU may be configured for a data radio bearer (DRB) with very low data rate such that small data packets, (e.g., 100 bytes in UL), may arrive into PDCP infrequently, (e.g., once every hour). The WTRU may then be configured with a small SN size, for example 2 bits, in PDCP such that the sequence numbers range from 0 to 3. In RLC, the WTRU may be configured for UM and the RLC SDU may be segmented into 8 smaller RLC PDUs, and relatively, the RLC SN size may be specified for 3 bits. Further, the WTRU may not include RLC or MAC “E” bit into the header since RLC SDUs and MAC SDUs may not be concatenated into the RLC and MAC PDU, (e.g., 1 PDU per SDU). The WTRU may then perform L1 processing of the resultant MAC PDU for UL transmission. Given the reduced header size, the PDPC may have its header size to 3 bits, RLC to 6 bits and MAC to 7 bits. The WTRU and eNB may apply the same reduction of protocol headers in the DL also.

[0074] The WTRU/eNB may reduce RLC header size by scrambling the CRC bits, which may be appended to the MAC PDU, with the SN of the RLC PDU included in the MAC PDU. The WTRU may then remove SN from the RLC header. For example, independently or in combination with RLC SN size reduction, the WTRU, may upon receiving a MAC PDU, descramble the CRC parity bits with possible SN values prior to performing the CRC check. The WTRU may perform the descrambling based on the entire possible SN range or based on the current RLC receiver window, excluding for SNs that have already been received. Once the correct SN has been identified and the MAC PDU has been correctly received, the WTRU may pass the determined SN value to RLC for proper PDU processing.

[0075] The WTRU may scramble the CRC parity bits with MAC LCID information. For example, the WTRU may use the 5 bit LCID information of the DRB

to scramble to the CRC parity bits, as long as there is a single LCID associated with the MAC SDUs that are multiplexed into the MAC PDU.

[0076] The WTRU may transmit and receive data on the data radio bearer on a single HARQ process for UL and/or DL direction. For example, given that the LC-MTC WTRU may transmit and receive data at very low data rates with high tolerance for delay, the WTRU may utilize a single HARQ process in each of the UL and/or DL direction. Since the WTRU may only receive a single MAC PDU at a time, the sequence numbering maintenance burden in both RLC and PDCP layers may be reduced, further supporting the SN size reduction as proposed above.

[0077] The WTRU may use a multi-step CRC attachment and computation procedure. The WTRU may reduce the overhead from CRC parity bit attachment to the data. For transmitting data, the WTRU may, in RLC layer, calculate and attach long CRC parity bits to the RLC SDU prior to segmentation/concatenation procedure. The WTRU may then segment the RLC SDU with CRC parity bits attached to the end of the RLC SDU. The WTRU may, in PHY layer, calculate and attach a shorter set of CRC parity bits to each MAC PDU prior to transmission. For receiving data, the WTRU may, in MAC layer, upon reception of the MAC PDU and correct calculation of CRC, consider the reception successful, and deliver the corresponding MAC SDU to RLC. The WTRU may, in RLC, upon receiving RLC PDUs, and successfully reconstructing a RLC SDU, perform CRC check based on the long CRC calculation and parity bits applied to the RLC SDU.

[0078] Based on the outcome of the CRC check, if the CRC check passes, the WTRU may deliver the RLC SDU to PDCP. If the CRC check fails, the WTRU may discard the SDU and associated PDUs, for example, if the WTRU has been configured for RLC UM, or may discard the SDU and provide an indication to the transmitter side for re-transmission of the associated PDUs. For example, if the WTRU has been configured for RLC AM, the WTRU may provide RLC STATUS PDU indicating the SNs of the RLC PDUs that may be part of the discarded RLC SDU.

[0079] For example, the WTRU may attach a 24-bit CRC to the RLC SDU prior to segmentation in RLC. For the purpose of this example, the RLC SDU has been segmented into 8 RLC PDUs. Subsequently, the WTRU may attach an 8-bit CRC to the MAC PDU which contains the previously segmented RLC SDU. In relative comparison to attaching 24-bit CRC to each MAC PDU, where the CRC overhead is $24 \times 8 = 192$ bits, the above CRC attachment procedure may yield $24 + 8 \times 8 = 88$ bit CRC overhead. The CRC overhead may be further reduced, for example, if the number of segmented RLC PDU is increased.

[0080] A WTRU may apply the proposed solutions herein individually or in combination as part of “coverage enhancement” mode of operation. A WTRU may operate in “coverage enhancement” mode from power on, possibly as indicated in its capabilities. For example, a WTRU may be pre-configured to start operation in “coverage enhancement” mode and accordingly may perform cell search, network access (e.g. PRACH process) and other connected mode procedures based on the procedures as proposed, instead of the normal procedures. A WTRU may switch between a normal (e.g., Rel-11) operation and “coverage enhancement” mode, and may indicate support for “coverage enhancement” mode to the network as part of its WTRU capabilities indication, for example via RRC signaling.

[0081] The WTRU may switch from normal to “coverage enhancement” mode in the one or more of the following ways. The WTRU may receive an indication to operate in “coverage enhancement” mode from network. For example, the WTRU may receive RRC reconfiguration message with PDCP, RLC, and MAC parameters with reduced SN sizes and other changes to the header configuration as described above. The WTRU may measure and/or detect changes in environment such that WTRU may no longer operate in normal mode and may begin operation in “coverage enhancement” mode.

[0082] The WTRU may switch under the following example conditions: during cell selection/reselection, WTRU may find a suitable cell under “coverage enhancements” conditions but not in normal operation conditions, when network access attempts and PRACH procedure fails in normal mode, and the WTRU switches to

“coverage enhancements” mode PRACH procedure, upon radio link failure detection and subsequent re-establishment to the serving cell, or based on connected mode or IDLE mode measurements, the current serving cell RSRP/RSRQ falls below a certain threshold, and possibly, there are no neighbor cells whose measurements meet the criteria for handover or cell re-selection.

[0083] The WTRU may indicate the change to “coverage enhancements” mode and/or request to change to “coverage enhancements” mode to the network by sending a measurement report that may include a request indication to change operation modes. This measurement report may be periodic or may be event triggered, as configured for example in the measurement object from the network. PRACH preambles may indicate to network that mode of operation by WTRU has changed. The WTRU may transition from “coverage enhancement” to normal operation mode with similar procedures as described above.

[0084] TTI bundling may be supported up to N_{TTI} subframes, where the N_{TTI} subframes may be configured by an eNB in a semi-static manner. Hereafter, the subframe, TTI and ms may be used interchangeably. One or more of following may apply for a WTRU configured with TTI bundling with N_{TTI} subframes. A WTRU may transmit/receive the same data in consecutive N_{TTI} subframes, and the data may be coded with different RVs according to the subframe index or the location of the subframe among the bundled subframes. The RV may be changed with the order {0, 1, 2, 3} cyclically within a window so that RV-{0, 1, 2, 3, 0, 1} may be used in order, assuming that an 8-TTI window size is used if 6 subframes are bundled as shown in Figure 7. The 8ms window size may be used, assuming that 8 HARQ processes are used for other WTRUs not configured with TTI bundling. The window may not be defined if the maximum N_{TTI} is equal to or smaller than 8.

[0085] The redundancy version may be changed with the order {0, 2, 1, 3} cyclically within a window so that RV-{0, 2, 1, 3, 0, 2} is used in order, assuming that 8 TTI window size is used if 6 subframes are bundled, as shown in Figure 8. In this case, the RV order {0, 2, 1, 3} may be used only for downlink TTI bundling, the RV order {0,

2, 1, 3} may be used if the N_{TTI} is larger than a threshold value, (e.g., the threshold value may be 4, otherwise, the RV order {0, 1, 2, 3} may be used), the RV order {0, 2, 1, 3} may be replaced with another order such as {1, 3, 0, 2}, and/or the RV orders {0, 1, 2, 3} and {0, 2, 1, 3} may be used interchangeably, (e.g., the RV order {0, 1, 2, 3} may be used in an initial transmission and the RV order {0, 2, 1, 3} may be used for a retransmission).

[0086] The RV may be changed with a RV order cyclically without window size for the retransmission case. For example, if the RV order {0, 1, 2, 3} is used and 6 subframes are bundled, the RV-{0, 1, 2, 3, 0, 1} may be used for the initial transmission and the RV-{2, 3, 0, 1, 2, 3} may be used for the first retransmission. Figure 9 shows an example of the cyclic RV assignment without the window. The window may not be defined if the maximum N_{TTI} is equal to or smaller than 8. A WTRU may not transmit/receive any shared data within the subframes not configured for the TTI bundling.

[0087] A WTRU may transmit/receive the same data in N_{TTI} subframes within a window and the data may be coded with different RVs according to the subframe index or the location of the subframe among the bundled subframes. The bundled N_{TTI} subframes may be defined as any subset of subframes within the window. In this case, the window size (N_{window}) may be defined. A fixed positive integer number may be used as the window size such as 8. A positive integer number may be configured via higher layer signaling. A positive integer number may be defined as a function of at least one of the system parameters and WTRU identity number.

[0088] The subset of subframes for TTI bundling may be indicated by using bitmap within the window and the bitmap may be informed via higher layer signaling. Figure 10 shows an example of the TTI bundling with bitmap indication.

[0089] The TTI bundling may be supported up to N_{TTI} subframes, where the N_{TTI} may be configured by eNB in a dynamic manner. In this case, a WTRU may be configured with a specific transmission mode supporting TTI bundling dynamically. For example, a new transmission mode (e.g., TM-x) and its associated new DCI (e.g.,

DCI format 1E) may be defined. In the DCI format 1E, indication bits for TTI bundling may be included so that for each DL/UL data transmission, the N_{TTI} may be defined so that a WTRU may transmit/receive data N_{TTI} times according to the indication.

[0090] A set of TTI bundling cases may be defined via higher layer signaling and the indication bits in the DCI format indicate one of the bundling size within the set. For example, if four TTI bundling cases are defined as $\{N_{\text{TTI},1}=1, N_{\text{TTI},2}=4, N_{\text{TTI},3}=6, N_{\text{TTI},4}=8\}$, two bits for the indication may be used in the DCI format to inform which TTI bundling case is used for the UL and/or DL grant. A set of TTI bundling cases may be predefined and fixed for all WTRUs so that no higher layer signaling is used to define the set of TTI bundling cases. However, the indication bits may still be used to indicate which TTI bundling case is used for the UL and/or DL grant. A WTRU may be configured with a TTI bundling dynamically, regardless of the transmission mode configured for PUSCH/PDSCH transmission.

[0091] The bundled TTIs may have a single HARQ_ACK so that a WTRU may transmit/receive a HARQ_ACK after receiving/transmitting bundled TTIs for a PDSCH/PUSCH. A WTRU may transmit a HARQ_ACK when a TTI bundling is used. A WTRU may transmit HARQ_ACK in the uplink subframe $n+k$ if the downlink subframe n satisfies the last subframe within a bundled subframe associated with the PDSCH. In this case, the k may be defined as a fixed positive integer number such as $k=4$. A WTRU may transmit HARQ_ACK in the uplink subframe $n+k$ if the downlink subframe n satisfies a subframe containing the PDCCH associated with the PDSCH. In this case, the k may be defined as a function of N_{TTI} . For instance, $k = N_{\text{TTI}}+4$.

[0092] A WTRU may transmit HARQ_ACK in the uplink subframe m if the WTRU received a PDSCH within a time window (e.g., 8 ms). A single PDSCH may be transmitted within a time window. The subframe m may be a predefined subframe which may be located in the next radio frame right after the window in which corresponding PDSCH is transmitted. The PUCCH resource for HARQ_ACK transmission may be defined as a function of the first CCE/eCCE index of the

PDCCH/ePDCCH associated PDSCH. Alternatively, the PUCCH resource may be defined via higher layer signaling.

[0093] A WTRU may receive a HARQ_ACK when a TTI bundling is used. A WTRU receives a HARQ_ACI in the downlink subframe $n+k$, if the uplink subframe n is the latest subframe within the bundled subframes associated for the PUSCH transmission, and/or the downlink subframe n is the subframe a WTRU receives uplink grant for the associated PUSCH.

[0094] The bundled TTIs may have two or more HARQ_ACKs so that a WTRU may accumulate the multiple HARQ_ACK in order to improve the coverage. A WTRU may assume that all individual subframes within the bundled subframes may have associated HARQ_ACK in the subframe $n+k$ and the multiple HARQ_ARQ will have the same HI code so that the WTRU may add multiple HARQ_ARQ to improve the coverage. The multiple HARQ_ACKs for the bundled subframes may be used when the N_{TTI} is larger than a threshold. For example, if N_{TTI} is larger than 4, then a WTRU may assume that multiple HARQ_ACKs are transmitted.

[0095] A WTRU may assume that a subset of subframes within the bundled subframes may have associated HARQ_ACKs in the subframe corresponding subframes. The WTRU may assume that the subset of subframes have the same HI code. The multiple HARQ_ACKs for the bundled subframes may be used when the N_{TTI} is larger than a threshold. For example, if N_{TTI} is larger than 4, then a WTRU may assume that multiple HARQ_ACKs are transmitted.

[0096] ACK/NACK repetition has been introduced in LTE to enhance coverage for cell edge WTRUs that are typically prone to power limitation and/or inter-cell interference. More specifically, if configured, the legacy WTRU may repeatedly transmit ACK/NACK information in the $N_{ANRep} - 1$ consecutive subframes following the initial HARQ-ACK transmission. In terms of the HARQ time line when ACK/NAK repetition is enabled, upon detection of a PDSCH transmission in subframe $n-4$, the legacy WTRU may transmit the HARQ-ACK response in N_{ANRep} consecutive subframes

starting from subframe n , unless the WTRU is repeating the transmission of an HARQ-ACK in subframe n corresponding to a PDSCH transmission in subframes $n - N_{\text{ANRep}} - 3, \dots, n - 5$. Besides, the legacy WTRU may not transmit any HARQ-ACK response corresponding to any detected PDSCH transmission in subframes $n - 3, \dots, n + N_{\text{ANRep}} - 5$. Figure 11 shows the behavior of a legacy WTRU in case of ACK/NACK repetition.

[0097] In case of subframe bundling in the DL which may be introduced to improve DL coverage, the WTRU may repeat the transmission of a single HARQ-ACK response corresponding to the whole PDSCH transmissions within the bundle on the uplink. ACK/NACK repetition in case of DL subframe bundling according to this method is shown in Figure 12.

[0098] For a PDSCH transmission with a corresponding PDCCH detected in subframes within the DL subframe bundle, the WTRU may repeat the transmission of the corresponding ACK/NACK response for the entire DL transmission on subframes $n + 1, \dots, n + N_{\text{ANRep}} - 1$ using the PUCCH resources derived from the corresponding PDCCH CCE index detected in the bundled subframes. According to this approach, for every subframe within the DL subframe bundle, the WTRU may first detect the PDCCH in that subframe, and then derive the PUCCH index for ACK/NACK repetition in the corresponding UL subframe based on the lowest CCE index used to construct the corresponding DCI assignment.

[0099] The WTRU may repeat the transmission of the corresponding ACK/NACK response for the entire DL transmission on subframes $n + 1, \dots, n + N_{\text{ANRep}} - 1$ using the PUCCH resource derived from the PDCCH CCE index detected in the last subframe of the bundle, the PUCCH resource derived from the PDCCH CCE index detected in the first subframe of the bundle, or the PUCCH resource configured by higher layers.

[0100] For a PDSCH transmission without a corresponding PDCCH detected in the bundled subframes, the WTRU may repeat the transmission of corresponding ACK/NAK response for the whole transmission on subframes $n + 1, \dots, n + N_{\text{ANRep}} - 1$ using

the PUCCH resource derived from the PDCCH CCE index detected in the most recent DL scheduling assignment, or the PUCCH resource configured by higher layers.

[0101] In LTE, ACK/NACK repetition may be limited to a repetition factor of four, in order to enhance the UL coverage. The WTRU may need to retransmit the ACK/NACK response using a higher repetition factor. The enhanced repetition factor used by the WTRU may be signaled to the WTRU through higher layer, or implicitly derived based on the subframe bundling parameters used in the DL such as the number of DL subframes within a bundle, or a function of the number of DL subframes within a bundle.

[0102] In order to improve PHICH coverage in the DL, the WTRU may employ one or a combination of the following methods.

[0103] In a PHICH repetition method, the WTRU may receive and detect the ACK/NACK information associated with the uplink PUSCH transmission using multiple PHICH resources. In this method, the ACK/NACK information transmitted on PHICH may be associated with the uplink PUSCH transmission over a single subframe, or in the case of subframe bundling operation, the ACK/NACK feedback may be associated with the bundled PUSCH transmission over multiple subframes. Besides multiple PHICH resources over which the WTRU receives its HARQ, ACK/NACK feedback may be distributed over multiple subframes or within a single subframe. This may be different from the legacy WTRU operation wherein the WTRU may only processes a single PHICH resource for a given subframe corresponding to a single UL transport block.

[0104] In terms of PHICH resources, a WTRU may determine the corresponding PHICH resources from PRB indices of the uplink resource allocation. PRB indices may be associated with the PRBs used for PUSCH transmission within a single subframe. In this case, for a given subframe, the WTRU may use the lowest index PRB to determine its first PHICH resource and then determine its other assigned PHICH resources within that subframe by sequentially increasing the PRB index that constitutes its UL resource allocation based on its configured PHICH repetition factor.

[0105] Thus, the PHICH resources may be identified by the index pair $(n_{PHICH,i}^{group}, n_{PHICH,i}^{seq})$ where $n_{PHICH,i}^{group}$ is the PHICH group number and $n_{PHICH,i}^{seq}$ is the orthogonal sequence index within the group for the i th PHICH resource as defined by:

$$\begin{aligned} n_{PHICH,i}^{group} &= (I_{PRB_RA,i} + n_{DMRS}) \bmod N_{PHICH,i}^{group} + I_{PHICH} N_{PHICH,i}^{group} \\ n_{PHICH,i}^{seq} &= \left(\left\lfloor I_{PRB_RA,i} / N_{PHICH,i}^{group} \right\rfloor + n_{DMRS} \right) \bmod 2N_{SF}^{PHICH} \end{aligned}, \quad \text{Equation (8)}$$

where

$$I_{PRB_RA,i} = \begin{cases} I_{PRB_RA}^{lowest_index} + i \\ i = 0, \dots, N_{PHICHRep} - 1 \end{cases}, \quad \text{Equation (9)}$$

with $N_{PHICHRep}$ as the PHICH repetition factor.

[0106] In case of subframe bundling operation, PHICH resources could be derived from the PRB indices associated with uplink transmissions over multiple uplink subframes in the bundle. This approach would be different from that of the legacy WTRU behavior wherein the corresponding PHICH resource is exclusively associated with the last subframe in the bundle.

[0107] In terms of PHICH resources, a WTRU may determine the corresponding PHICH resources from uplink demodulation reference symbol (DMRS) cyclic shift associated with the PUSCH transmission(s). DMRS cyclic shifts may be associated with the PUSCH transmission within a single subframe. In this case, for a given subframe, the WTRU may use the cyclic shift from DMRS field in the most recent PDCCH to determine its first PHICH resource, and then determine its other assigned PHICH resources within that subframe by sequentially increasing the cyclic shifts. Note that there is a limit of maximum eight cyclic shifts that may be used by the WTRU. Thus, the PHICH resources may be identified by the index pair $(n_{PHICH,i}^{group}, n_{PHICH,i}^{seq})$ where $n_{PHICH,i}^{group}$ is the PHICH group number and $n_{PHICH,i}^{seq}$ is the orthogonal sequence index within the group for the i th PHICH resource as defined by:

$$\begin{aligned} n_{PHICH,i}^{group} &= (I_{PRB_RA} + n_{DMRS,i}) \bmod N_{PHICH,i}^{group} + I_{PHICH} N_{PHICH,i}^{group} \\ n_{PHICH,i}^{seq} &= \left(\left\lfloor I_{PRB_RA} / N_{PHICH,i}^{group} \right\rfloor + n_{DMRS,i} \right) \bmod 2N_{SF}^{PHICH} \end{aligned}, \quad \text{Equation (10)}$$

where

$$n_{DMRS,i} = \begin{cases} n_{DMRS} + i \\ i = 0, \dots, N_{PHICH Rep} - 1 \end{cases}, \quad \text{Equation (11)}$$

with $N_{PHICH Rep}$ as the PHICH repetition factor.

[0108] In a PHICH Power boosting method, depending on the WTRU's channel conditions, power control may be applied on the PHICH. Power boosting, together with ACK/NACK repetition using multiple PHICH resources, may considerably enhance the coverage of PHICH.

[0109] In a PHICH without code-division multiplexing method, a legacy PHICH group may consist of multiple PHICH resources that are code-division multiplexed (CDM) and mapped to the same set of resource elements. This may result in power splitting across multiple PHICH resources at the transmitter. Besides, due to the channel estimation error at the WTRU, orthogonality among the PHICH resources that are code-division multiplexed within the PHICH group may be lost, which in turn, may result in loss of coverage.

[0110] The WTRU may assume that there is only one PHICH resource utilized within the PHICH group without any code-division multiplexing.

[0111] To increase PRACH coverage, and for example with the intent of some form of preamble integration at the eNB, for each instance of RACH procedure, the WTRU may send many preambles, termed "repeated preambles," which elicit only one RAR from eNB. The repeated preambles may use the same preamble sequence as the first preamble, and may use the same transmit power, P_{PRACH} .

[0112] Following the first preamble for a RACH procedure, the repeated preambles may be transmitted at later times, for example, using the same resource but in later allowed frames. For example, for a first preamble using the resource "any SFN subframe 4", the repeated preambles may be transmitted in subsequent frames in subframe 4. As another example, for a first preamble using the resource "even SFN

subframe 4”, the repeated preambles may be transmitted in subsequent even frames in subframe 4.

[0113] The first preamble to be followed by repeated preambles may be in any frame, or if limited to certain frames, for example to even frames, to any such limited, for example even, frame. Alternatively, the first such preamble may be further limited to only certain frames. The first frame with that first preamble and the subsequent frames with the repeated preambles may be termed as a block of frames. The WTRU may, for example, only transmit the first preamble in the first frame of a block.

[0114] A way that the blocks may be identified is that such blocks may be within groups of frames, in which any frame may be identified as being at a specific position within a specific block, and each block may be identified as being at a specific position within a group, may be known at the eNB and WTRU. For example, a frame group may be a series of 1024 contiguous frames starting with SFN 0 and ending with SFN 1023. The identification of frames within blocks may be, for example, as depicted in Figure 13 (a), the length of a series of equal-length blocks, denoted as “1st length, 2nd length, and the like, for different block lengths, equals the length of the frame group, or, as depicted in Figure 13 (b), (c), and (d), the length of a series of equal-length blocks may not equal the length of the frame group and some frames in a frame group are not in a block, or as depicted in Figure 13 (e) and (f), the length of a series of equal and unequal-length blocks may be equal to the length of a frame group, or some combination of all methods shown in Figure 13.

[0115] An alternative method may be that the frames within blocks, and the blocks within groups, may be scattered, for example, not contiguous, or intermixed, in some deterministic manner known to the eNB and the WTRU, either specified or configured.

[0116] An example of determining the frames within a block is as follows. Let a group of frames be frames numbered as SFN 0 through SFN 1023. Let N_{pre} be the number, or the maximum number, of preambles transmitted in a block, where N_{pre} is a power of two, e.g., 64, 128, and the like, such that an integer number of blocks is

configured first within a group, as depicted in Figure 13 (a). For preambles that may be transmitted in any frame, the frames in the first block may be frames with SFN 0 through $(N_{pre}-1)$, the second block may be frames with SFN N_{pre} through $2N_{pre}-1$, and so forth, with the last block consisting of frames with SFN $1023-(N_{pre}-1)$ through 1023. For preambles that may be transmitted in only even numbered frames, the frames in the first block would be frames with SFN 0 through $2N_{pre}-1$ (although that last frame itself may not be used to transmit a preamble as its SFN is odd), the second block may be frames with SFN $2N_{pre}$ through $4N_{pre}-1$ (although that last frame itself may not be used to transmit a preamble as its SFN is odd), and so forth, with the last block consisting of frames with SFN $1024-2N_{pre}$ through 1023 (although that last frame itself may not be used to transmit a preamble as its SFN is odd).

[0117] One way that the eNB may respond to the block of preambles is that the RAR may be sent after the last preamble in the block. The WTRU may look for the RAR after the last preamble during the configured response window for that preamble. Another way that the eNB may respond to the block of preambles is that the RAR may be sent after any preamble in a block, for example during the response window for any such preamble. If the WTRU receives the RAR before having transmitted the last preamble in a block, the WTRU may, for example, not transmit any more preambles in the block.

[0118] If the WTRU does not receive the RAR in the response window of the last preamble of the block, the WTRU may initiate the transmission of another block of preambles. For the contention-based RACH procedure, the WTRU may pick another specific preamble sequence for the subsequent block, and also apply the same time backoff rules, (as is done for R11).

[0119] The number of preambles transmitted in a block, or the maximum number of preambles transmitted in a block, or alternatively the length of a block, may be configured or specified. The value may indicate the total number to send, or the length, for example in frames, or how many additional to send, in such case, e.g., zero means no repeated preambles may be sent.

[0120] The eNB may directly indicate its capability to detect repeated preambles, or may indicate it by broadcasting a related quantity, for example, the number of preambles transmitted in a block, and/or by indicating separate PRACH resources for repeated preambles. Such resources may use various indices or tables. Alternatively, there may be no special resources for repeated preambles.

[0121] For the case of the eNB capable of detecting repeated preambles, the maximum number of RACH preamble transmissions, preambleTransMax, may refer to the maximum number of preamble blocks. Alternatively, the network may configure separately the maximum number of preamble blocks.

[0122] The WTRU may autonomously decide to transmit repeated preambles, if allowed by the network, based on various conditions. For example, if $P_{\text{cmx}} < \text{preambleInitialReceivedTargetPower} + \text{deltaPreamble} + \text{pathloss}$, or if $(P_{\text{cmx}} \pm \text{some amount}) < \text{preambleInitialReceivedTargetPower} - \text{deltaPreamble} + \text{pathloss}$, or if previous RACH procedure failed due to reaching max number of PRACH transmissions (preambleTransMax), or always if a device is so configured or is hard wired to do it. Repeated preambles may be sent at the same power using the same preamble using certain resources.

[0123] Although features and elements are described above in particular combinations, one of ordinary skill in the art will appreciate that each feature or element may be used alone or in combination with any of the other features and elements. In addition, the embodiments described herein may be implemented in a computer program, software, or firmware incorporated in a computer-readable medium for execution by a computer or processor. Examples of computer-readable media include electronic signals, (transmitted over wired or wireless connections), and computer-readable storage media. Examples of computer-readable storage media include, but are not limited to, a read only memory (ROM), a random access memory (RAM), a register, a cache memory, a semiconductor memory device, a magnetic media, (e.g., an internal hard disc or a removable disc), a magneto-optical media, and an optical media such as a compact disc (CD) or a digital versatile disc (DVD). A processor

in association with software may be used to implement a radio frequency transceiver for use in a WTRU, UE, terminal, base station, Node-B, eNB, HNB, HeNB, AP, RNC, wireless router or any host computer.

CLAIMS

What is claimed:

1. A method of a wireless transmit/receive unit (WTRU) bundling a predetermined number of consecutive subframes to enhance coverage, the method comprising:

the WTRU coding data in each of the subframes with a different redundancy version (RV); and

the WTRU transmitting the plurality of subframes.

2. The method of claim 1 wherein the data is coded with different RVs according to a subframe index.

3. The method of claim 1 wherein the data is coded with different RVs according to the location of each subframe among the bundled subframes.

4. The method as in any one of claims 1-3 wherein the subframes are configured by an evolved Node-B (eNB) in a semi-static manner.

5. A method of a wireless transmit/receive unit (WTRU) reducing overhead of layer 2 (L2) protocol layers, the method comprising:

the WTRU coordinating the size of a radio link control (RLC) layer and packet data convergence protocol (PDCP) protocol data units (PDUs) such that the resultant data PDU with a header part and a data part maintain byte alignment.

6. The method of claim 5 wherein the WTRU allocates a sequence number (SN) smaller than 7 bits.

7. The method of claim 5 wherein the WTRU allocates a sequence number (SN) smaller than 5 bits for unacknowledged mode (UM).

8. The method of claim 5 wherein the WTRU allocates a sequence number (SN) smaller than 10 bits for acknowledged mode (UM).

9. A method of a wireless transmit/receive unit (WTRU) reducing overhead of layer 2 (L2) protocol layers, the method comprising:

the WTRU scrambling cyclic redundancy check (CRC) bits appended to a medium access control (MAC) protocol data unit (PDU) with sequence number (SN) bits of a radio link control (RLC) PDU included in the MAC PDU.

10. The method of claim 9 further comprising:
the WTRU removing the SN bits from an RLC header.

11. The method of claim 9 further comprising:
the WTRU receiving a MAC PDU;
the WTRU descrambling CRC parity bits with possible SN values; and
performing a CRC check.

12. A method of a wireless transmit/receive unit (WTRU) reducing overhead of layer 2 (L2) protocol layers, the method comprising:

the WTRU receiving bundled transmission time intervals (TTIs) for a physical downlink shared channel (PDSCH); and

the WTRU transmitting a hybrid automatic repeat request (HARQ) acknowledgement (ACK) in an uplink subframe $n+k$ on a condition that a downlink subframe n is the last subframe within a bundled subframe associated with the PDSCH, wherein k is a fixed positive integer number.

13. A method of a wireless transmit/receive unit (WTRU) reducing overhead of layer 2 (L2) protocol layers, the method comprising:

the WTRU receiving bundled transmission time intervals (TTIs) for a physical downlink shared channel (PDSCH); and

the WTRU transmitting a hybrid automatic repeat request (HARQ) acknowledgement (ACK) in an uplink subframe $n+k$ on a condition that a downlink subframe n is a subframe containing a physical downlink control channel (PDCCH) associated with the PDSCH.

14. The method of claim 13 wherein k is a function of the number of TTIs.

15. A method of a wireless transmit/receive unit (WTRU) enhancing physical hybrid automatic repeat request (HARQ) indicator channel (PHICH) coverage in the downlink, the method comprising:

the WTRU receiving positive acknowledgement (ACK)/negative acknowledgement (NACK) information associated with an uplink physical uplink shared channel (PUSCH) transmission using multiple PHICH resources; and

the WTRU determining the PHICH resources based on physical resource block (PRB) indices of an uplink resource allocation.

16. The method of claim 15 wherein the PRB indices are associated with PRBs used for PUSCH transmission within a single subframe.

17. A method of a wireless transmit/receive unit (WTRU) enhancing physical random access channel (PRACH) coverage, the method comprising:

the WTRU transmitting a first preamble for a random access channel (RACH) procedure; and

the WTRU transmitting repeated preambles.

18. The method of claim 17 wherein the first preamble and the repeated preambles are transmitted using the same resource.

19. A wireless transmit/receive unit (WTRU) comprising:
a processor configured to code data in each of a plurality of consecutive subframes with a different redundancy version (RV) to enhance coverage; and
a transmitter configured to transmit the plurality of subframes.

20. The WTRU of claim 19 wherein the data is coded with different RVs according to a subframe index.

21. The WTRU of claim 19 wherein the data is coded with different RVs according to the location of each subframe among the bundled subframes.

22. The WTRU as in any one of claims 19-21 wherein the plurality of consecutive subframes may be configured by an evolved Node-B (eNB) in a semi-static manner.

ABSTRACT

A method and apparatus are described for a low cost machine-type-communication (LC-MTC) wireless transmit/receive unit (WTRU) to enhance coverage. The WTRU may bundle a predetermined number of consecutive subframes to enhance coverage by coding data in each of the subframes with a different redundancy version (RV), and then transmitting the plurality of subframes. The data may be coded with different RVs according to a subframe index or the location of each subframe among the bundled subframes. The subframes may be configured by an evolved Node-B (eNB) in a semi-static manner. Further, the WTRU may reduce overhead of layer 2 (L2) protocol layers by coordinating the size of a radio link control (RLC) layer and packet data convergence protocol (PDCP) protocol data units (PDUs) such that the resultant data PDU with a header part and a data part maintain byte alignment.