

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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Title of Invention	METHOD AND APPARATUS FOR ENHANCING COVERAGE OF MACHINE-TYPE-COMMUNICATION (MTC) DEVICES
Attorney Docket Number (if applicable)	IDC-11767US01
Correspondence Address Direct all correspondence to (select one):	
☒ The address corresponding to Customer Number	☐ Firm or Individual Name
Customer Number	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.	
☒ No.	
☐ Yes, the name of the U.S. Government agency and the Government contract number are:	

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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Please see 37 CFR 1.4(d) for the form of the signature.

Signature	/Scott Wolinsky/			Date (YYYY-MM-DD)	2013-04-03
First Name	Scott	Last Name	Wolinsky	Registration Number (If appropriate)	46413

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100

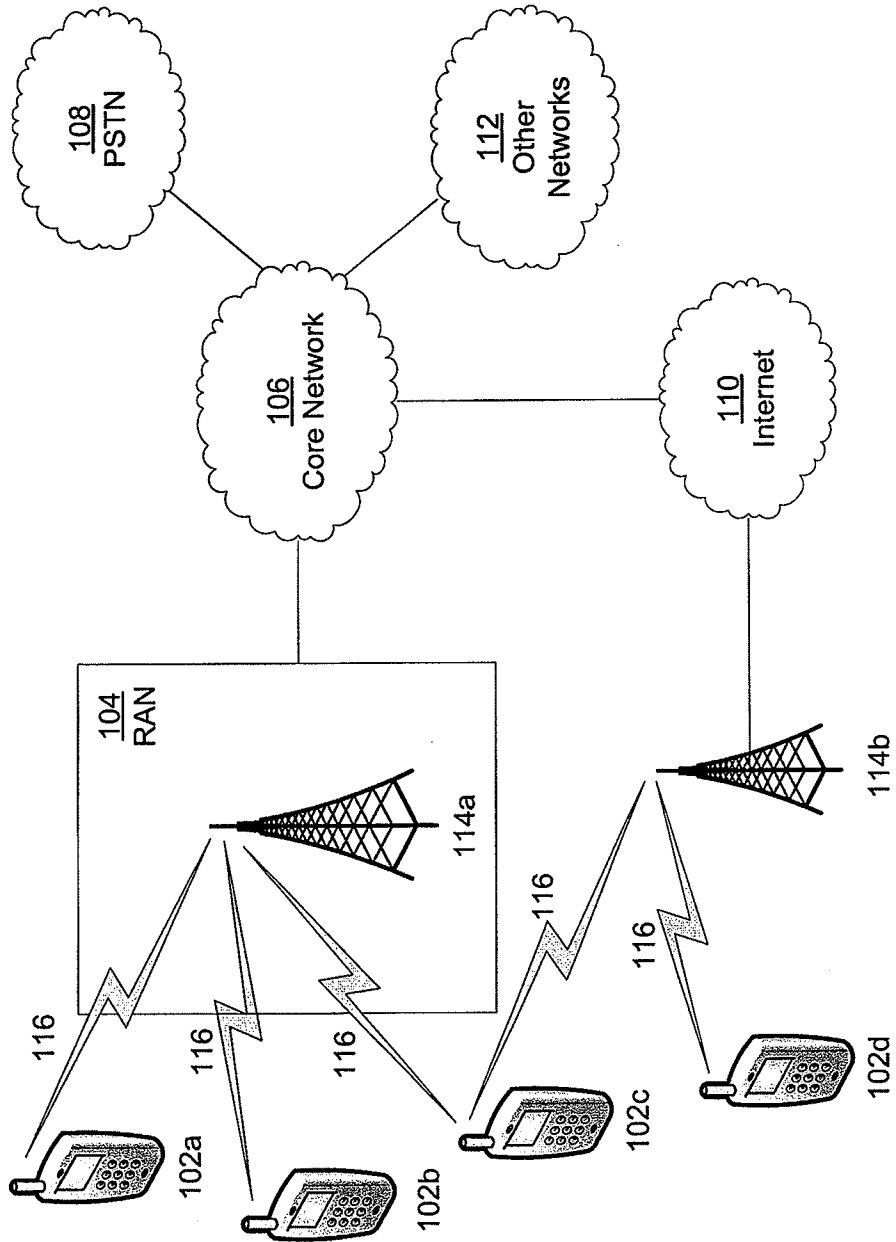


FIG. 1A

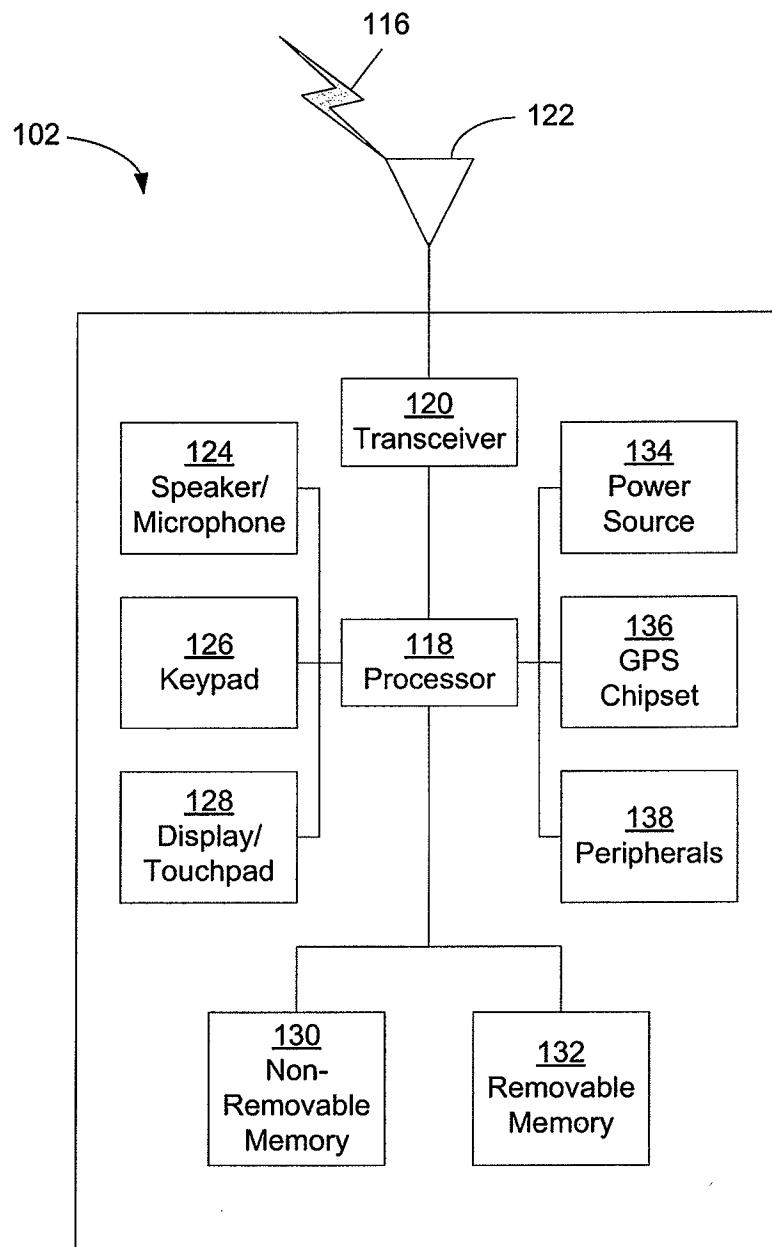


FIG. 1B

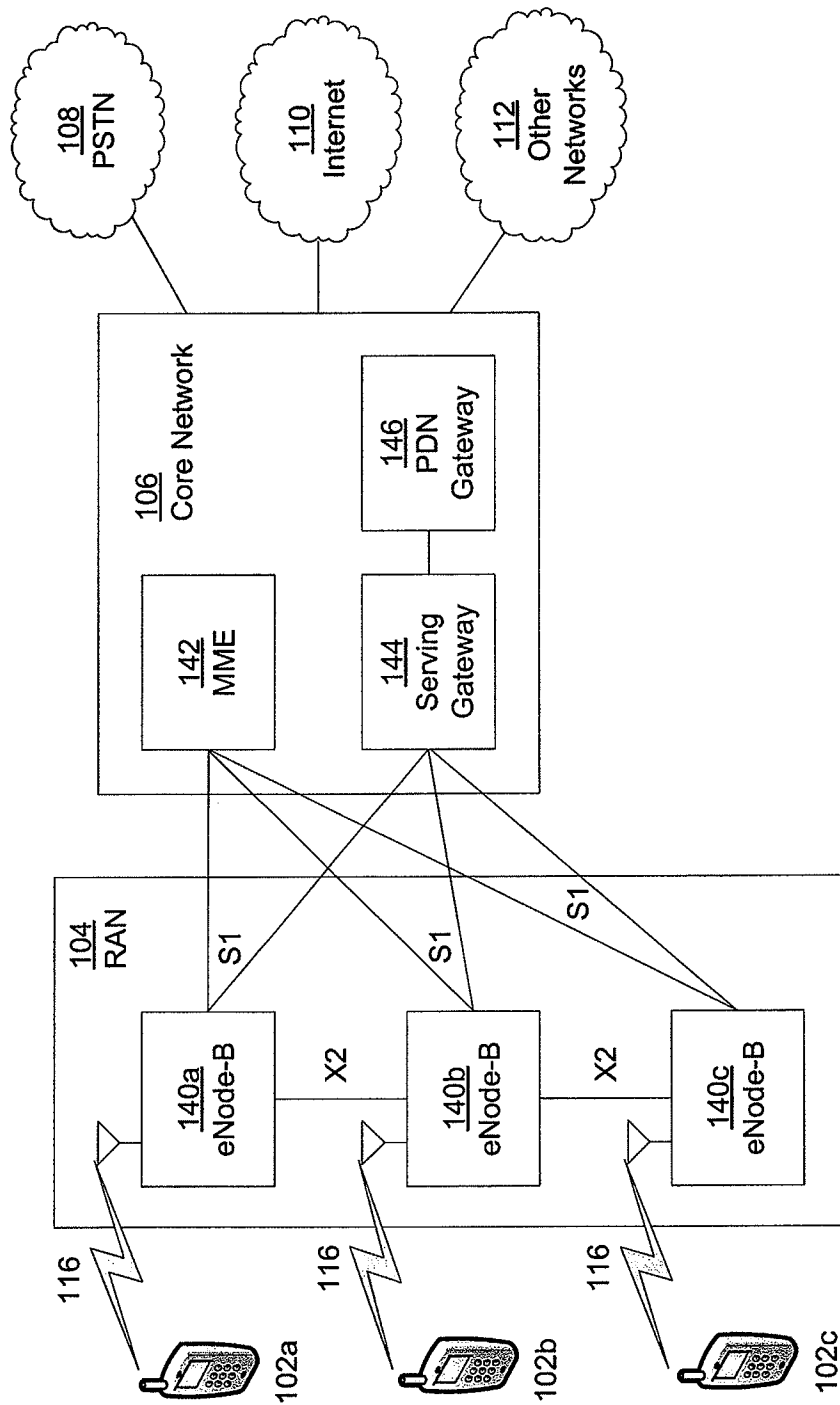


FIG. 1C

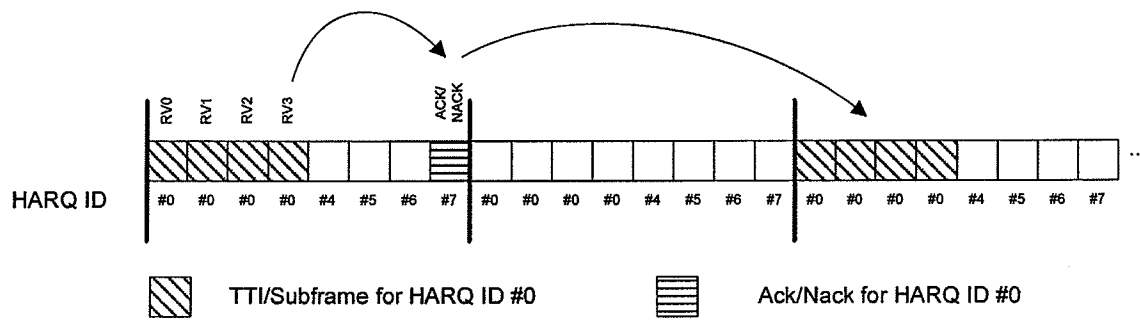


FIG. 2

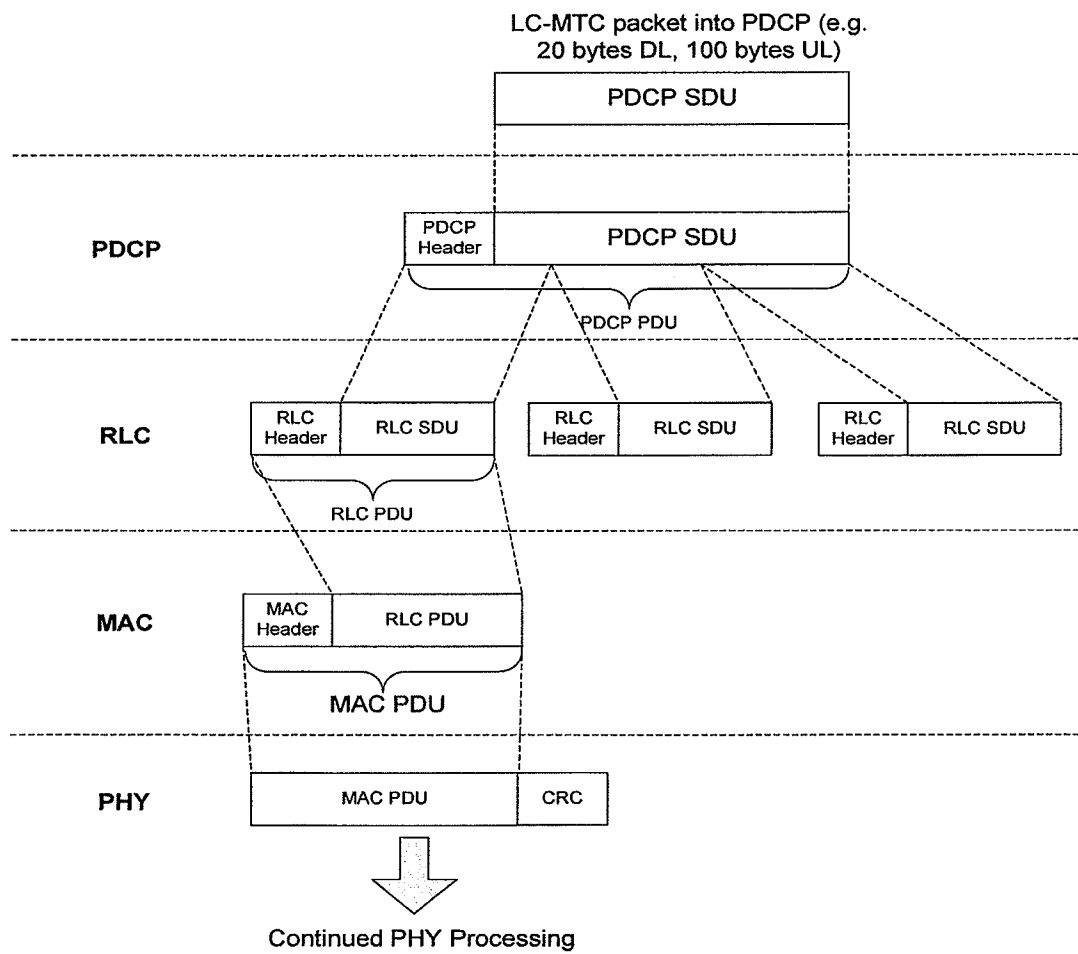


FIG. 3

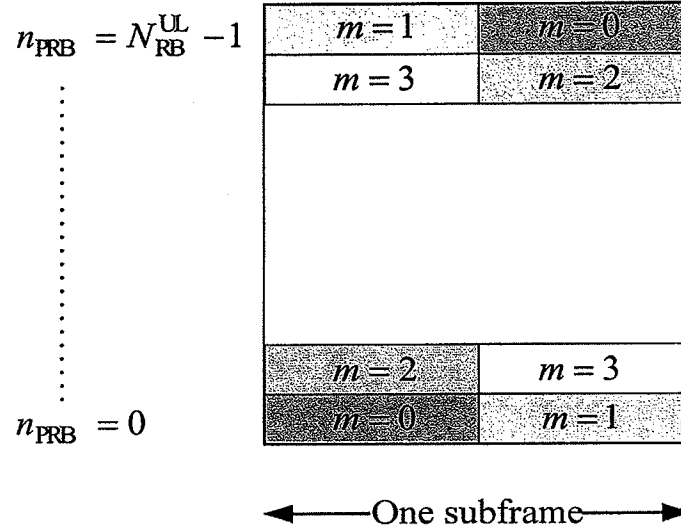


FIG. 4

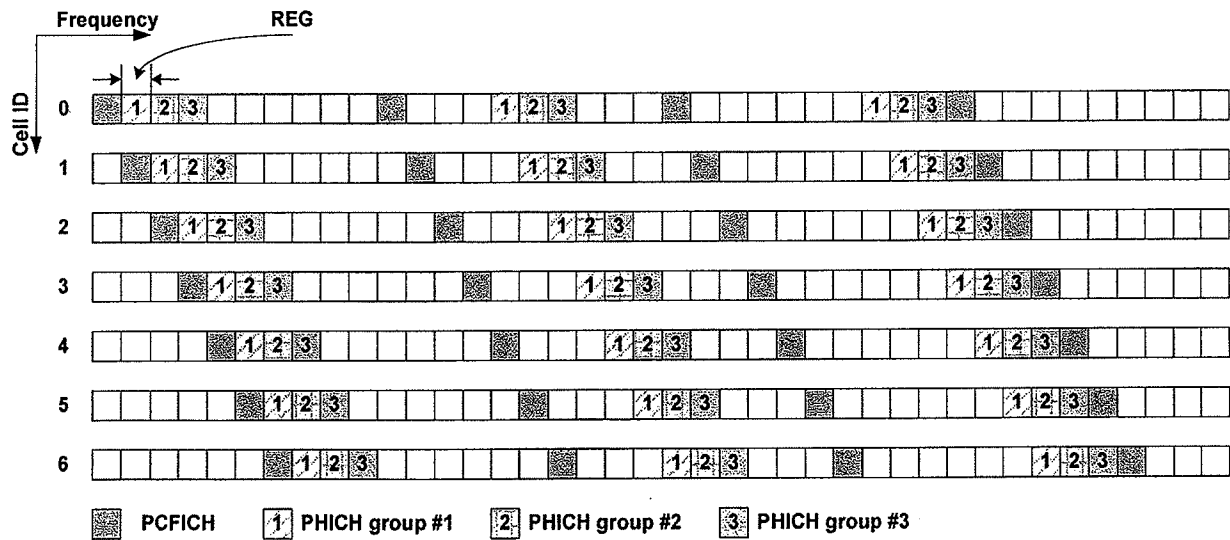


FIG. 5

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

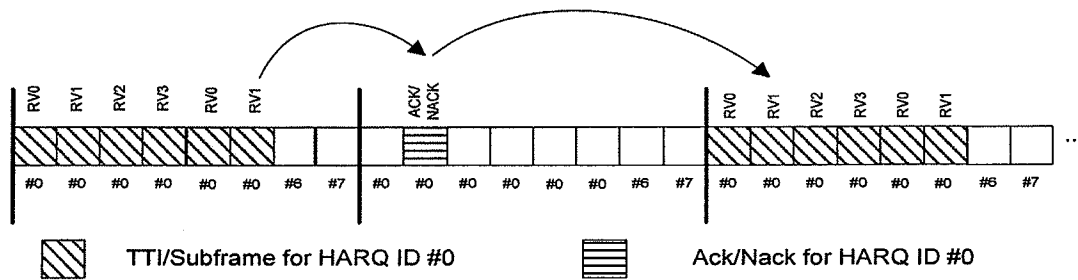


FIG. 7

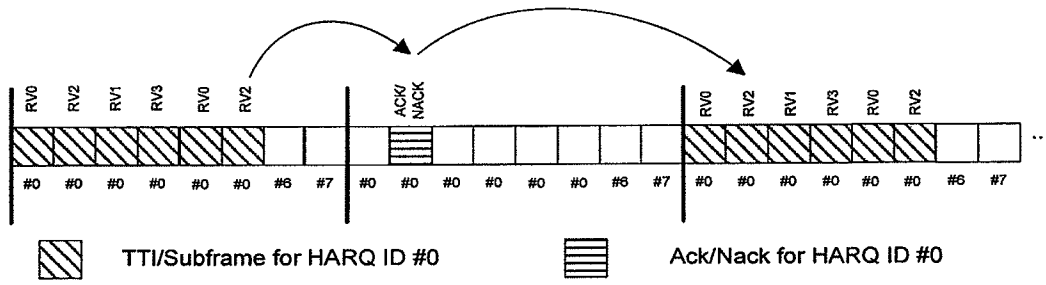


FIG. 8

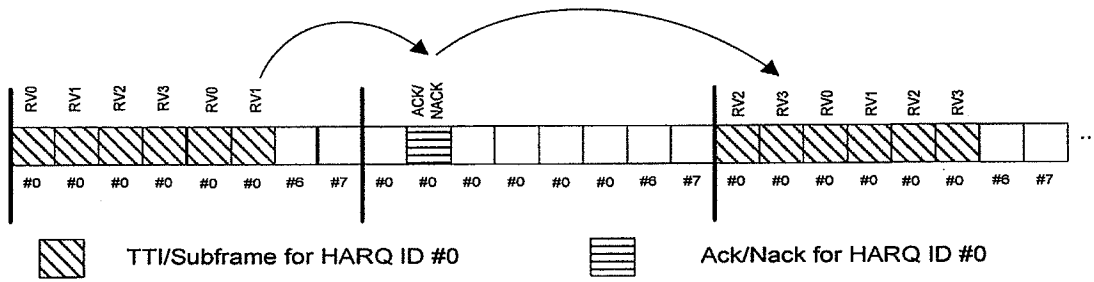


FIG. 9

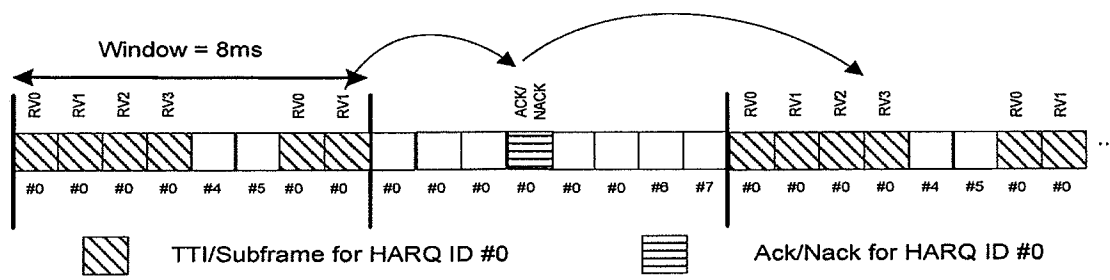


FIG. 10

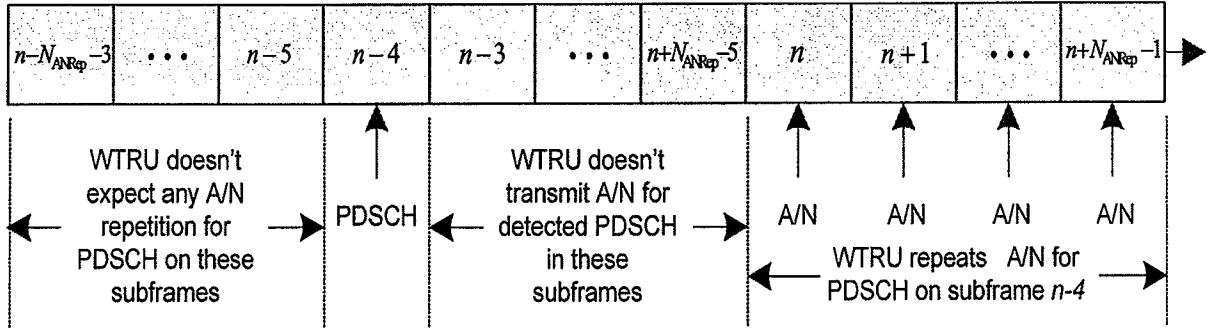


FIG. 11

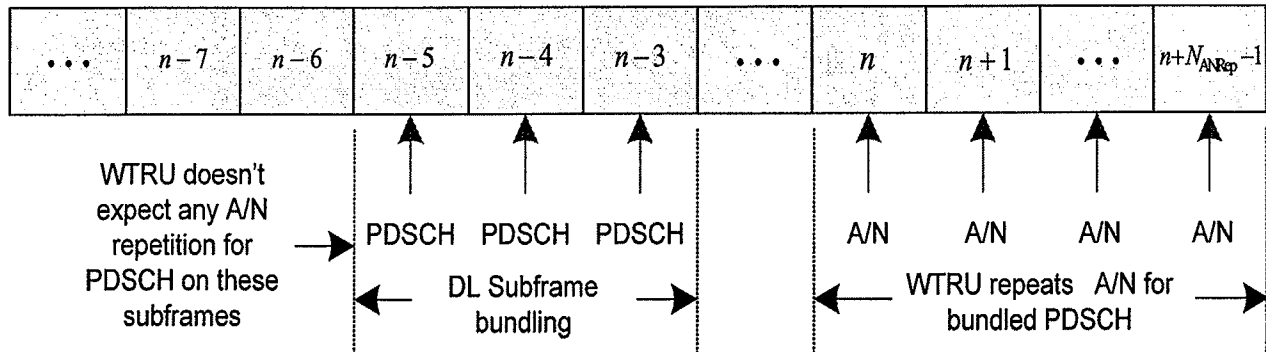


FIG. 12

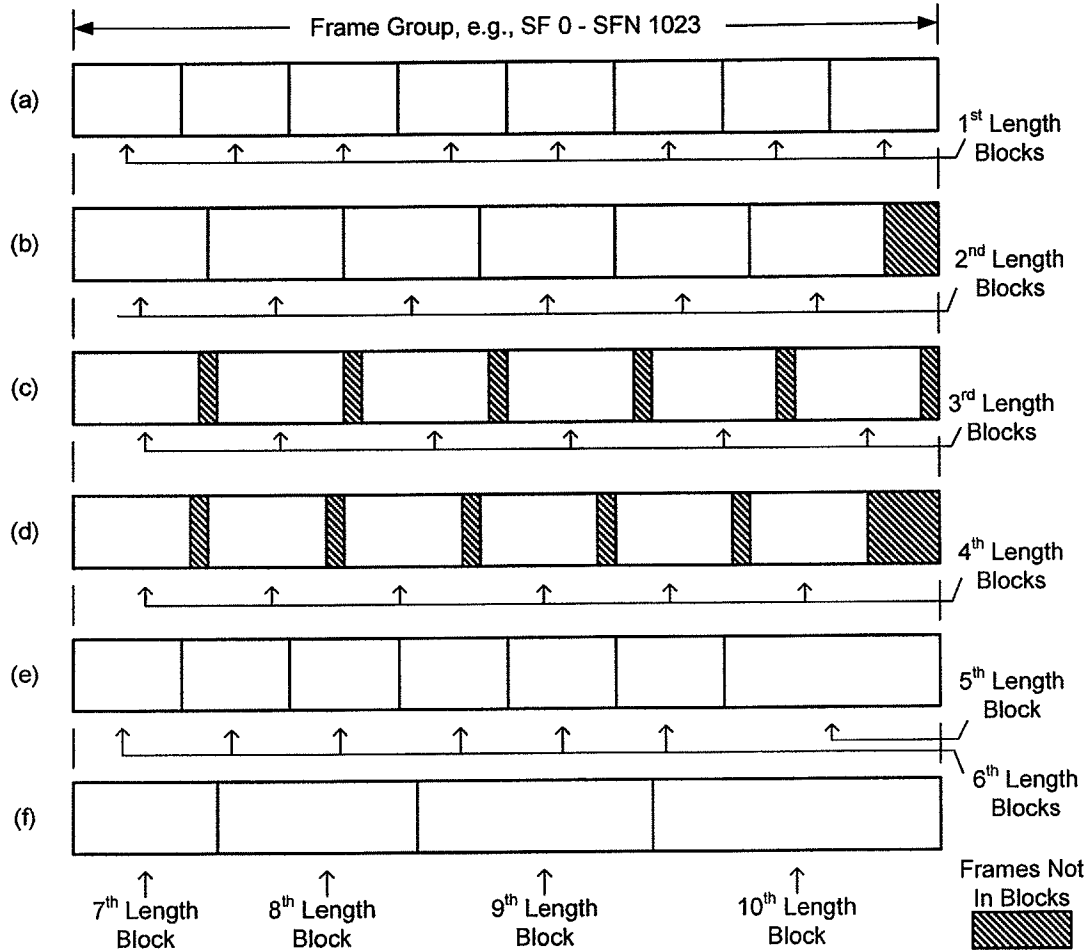


FIG. 13

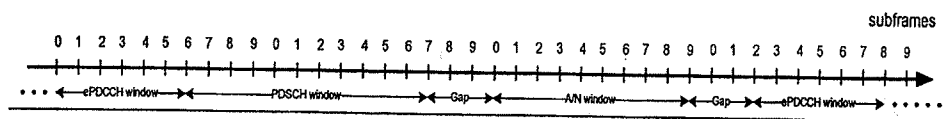


FIG. 14

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

BACKGROUND

[0001] It may be desirable to enhance, (e.g., increase by as much as 20 dB), the service coverage of a long term evolution (LTE) or advanced LTE (LTE-A) device, (e.g., a low-cost machine-type-communication (LC-MTC) device), as compared with the conventional LTE cell coverage defined for typical LTE wireless transmit/receive units (WTRUs). In this case, the requirements for the throughput and latency may be relaxed, (e.g., message size may be limited to 100 bytes/message in the uplink (UL) and/or 20 bytes/message in the downlink (DL)), and may allow latency of up to 10 seconds for the DL and/or of up to 1 hour for the UL.

[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 TTI bundling has not received much support 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 modulation symbols 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;

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

[0020] Figure 14 shows a window-based downlink transmission.

DETAILED DESCRIPTION

[0021] 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.

[0022] 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.

[0023] 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.

[0024] 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.

[0025] 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).

[0026] 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 DL packet access (HSDPA) and/or high-speed uplink packet access (HSUPA).

[0027] 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).

[0028] 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.

[0029] 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.

[0030] 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.

[0031] 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.

[0032] 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.

[0033] 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.

[0034] 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.

[0035] 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.

[0036] 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.

[0037] 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.

[0038] 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).

[0039] 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.

[0040] 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.

[0041] 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.

[0042] 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.

[0043] 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.

[0044] 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.

[0045] 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.

[0046] 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.

[0047] 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.

[0048] 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.

[0049] 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.

[0050] 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 hybrid automatic repeat request (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 16 ms. 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 an 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.

[0051] As shown in Figure 2, layer 2 (L2) processing is performed on 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.

[0052] 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.

[0053] Figure 3 shows an example of layer 2 (L2) processing an incoming data packet. As shown in Figure 3, a packet data convergence protocol (PDCP) header is appended to the incoming packet that is to be transmitted in the DL or UL direction. The processing example in Figure 3 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 3), such that each medium access control (MAC) PDU may consist of a single segmented RLC PDU. In this manner, the protocol header overhead for each layer may include PDCP, RLC, MAC and physical (PHY) layers.

[0054] 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.

[0055] 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.

[0056] The MAC layer may include an 8-bit header, 5 bits of which may be used for the logical channel identification (ID) (LCID).

[0057] 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.

[0058] 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 may increase according to the number of MAC SDUs that are multiplexed into the MAC PDU.

[0059] 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 $n_{\text{PUCCH}}^{(1,\tilde{p})}$,

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

[0060] 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:

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

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

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:

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

[0061] Figure 4 shows mapping of modulation symbols for a physical uplink control channel (PUCCH). 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.

[0062] 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 physical DL shared channel (PDSCH) transmission indicated by the detection of a corresponding physical downlink control channel (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 a 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 .

[0063] 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 symbols may be defined as PHICH duration and may be configurable via higher layer signaling. As different from the physical control format indicator channel (PCFICH), the physical hybrid automatic repeat request (HARQ) indicator channel (PHICH) resource position may vary according to PHICH duration.

[0064] Figure 5 shows the PCFICH and PHICH resource element group (REG) allocation according to a physical cell identifier (PCI). As shown 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 $(I_{PRB_{RA}}^{\text{lowest\_index}})$ and demodulation reference signal (DM-RS) cyclic shift (n_{DMRS}) . Therefore, two index pair (PHICH group index: n_{PHICH}^{group} , PHICH sequence index: n_{PHICH}^{seq}) may indicate the PHICH resource for a specific WTRU. In the PHICH index pair $(n_{PHICH}^{\text{group}}, n_{PHICH}^{\text{seq}})$, each index may be defined as follows:

$$n_{PHICH}^{\text{group}} = (I_{PRB_{RA}}^{\text{lowest\_index}} + n_{DMRS}) \bmod N_{PHICH}^{\text{group}} ; \quad \text{Equation (5)}$$

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

where the N_{PHICH}^{group} may denote the number of PHICH groups available in the system with following definition:

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

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.

[0065] 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 random access channel (PRACH) preamble sequence at a certain power P_{PRACH} (based on configured `preambleInitialReceivedTargetPower`, `deltaPreamble` and measured pathloss, and limited by P_{cmx} or $P_{\text{cmx,c}}$ 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 P_{cmx} or $P_{\text{cmx,c}}$, 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 random access channel (RACH) preamble transmissions (`preambleTransMax`) has been reached. The eNB may send the RAR in response to a single preamble transmission.

[0066] 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 a radio resource control (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 an event the WTRU may send the PRACH preamble.

[0067] For a contention-free RACH procedure, the network-sigaled 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.

[0068] 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.

[0069] The preamble formats for PRACH may be defined as three parts: cyclic prefix (T_{CP}), preamble (T_{PRE}), and guard time (T_{GT}). The total time including these three parts may be considered as time for RA (T_{RA}). For FDD system, four preamble formats may be supported as shown in Table 1 below, which includes preamble formats for PRACH.

Table 1

Preamble format	T_{CP}	T_{SEQ}
0	$3168 \cdot T_s$	$24576 \cdot T_s$
1	$21024 \cdot T_s$	$24576 \cdot T_s$
2	$6240 \cdot T_s$	$2 \cdot 24576 \cdot T_s$
3	$21024 \cdot T_s$	$2 \cdot 24576 \cdot T_s$

[0070] In Table 1, the T_{SEQ} is $T_{PRE} + T_{GT}$ and T_s denotes basic time unit, (e.g., sample time). As shown in Table 1, the preamble format 2 and 3 may have twice the T_{SEQ} length as compared with the other two formats, whereby signal power may be increase by repeating the preamble two times.

[0071] Paging may be used for network initiated connection setup of a WTRU, primarily in IDLE mode. At the physical layer, paging may be sent using PDCCH and PDSCH. A single paging radio network temporary identity (P-RNTI) may be allocated for the paging channel (PCH). In the MAC, no HARQ process may be used for PCH, and RLC transparent mode (TM) may be applied to the paging control channel (PCCH). The RRC paging message may contain precise WTRU identities for specific WTRUs being paged for connection initiation, as well as common indications for changes to certain system information, including changes to system information block (SIB) and information related to earthquake and tsunami warning system (ETWS), commercial mobile alert system (CMAS) and enhanced access barring (EAB).

[0072] For energy efficiency purposes, a discontinuous reception (DRX) mechanism may be used along with paging to allow for the WTRU to save energy in between receiving paging messages, which is allocated on a single subframe per paging (DRX) cycle per WTRU. The parameters for the DRX cycle may be configured via SIB or higher layers, (e.g., the non-access stratum (NAS) layer).

[0073] The paging occasion to a given WTRU may be defined by its WTRU identity, e.g., international mobile subscriber identity (IMSI), DRX cycle length, and

parameter “nB” set in the RRC layer. The value of nB may define the density of the paging occasions in a given cell, ranging from a paging frame and occasion occurring every 32 frames ($nB = T/32$) to 4 paging occasions in a subframe $s\{0,1,5,6\}$ for TDD or $s\{0,4,5,9\}$ for FDD per paging frame ($nB = 4T$). The WTRU may receive the WTRU specific paging record only during its allocated paging occasion, and may read the indication for changes to broadcast information in other paging occasions.

[0074] The WTRU may acquire cell and network related system information, which it may use for cell selection, access, and/or connection establishment. The system information may be broadcast by the cell in blocks. One or more of the following information blocks may be needed by a WTRU for cell access.

[0075] A master information block (MIB) may be transmitted on the PBCH in subframe #0 with TTI of 40 ms and may be repeated every 10 ms. The physical resource of PBCH may be fixed and may be located within the 72 center subcarriers of the transmission band. The PBCH resource may be in the first 4 symbols of the second timeslot. The information contained in this block may include at least part of the system frame number (SFN), (e.g., the 8 most significant bits of the SFN), configured DL bandwidth of the cell and PHICH configuration for the cell. By acquiring 1 of the 4 repeated MIBs in the 40 ms TTI, the WTRU may be able to derive the 2 least significant bits of the SFN for the full SFN value.

[0076] System information block type 1 (SIB1) may be transmitted on a PDSCH in subframe 5. SIB1 may have a TTI of 80 ms, and may be repeated every 20 ms. The resource location of SIB1 may be indicated by a PDCCH scrambled with SI-RNTI. SIB1 may provide information a WTRU may use for access to the cell and network, and scheduling information for the other SIBs.

[0077] System information block type 2 (SIB2) may be transmitted on a PDSCH based on the scheduling information contained in SIB1. The resource location may be indicated by PDCCH scrambled by SI-RNTI. SIB2 may provide information a WTRU may use to access and initiate connectivity with the cell and network. The information

in SIB2 may include a channel common configuration such as for PRACH/RACH, MBSFN subframe configuration, UL information.

[0078] A scheduling information list for system information (SI) may be used. Each listed SI in the scheduling information list may contain one or more SIBs, with the exception of SIB2 which may be included by itself in an SI-2. Scheduling of SIs may be based on periodicity of the system information and SI window length. The eNB may have some flexibility in the time and frequency resource for sending other SIBs

[0079] Other SIB information may be related to cell reselection information, multimedia broadcast multicast service (MBMS), emergency and warning system related information that the WTRU may need. Some of the SIBs may be optional based on the configuration of the cell and network, and may not be transmitted by the cell.

[0080] 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.

[0081] 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.

[0082] As the control channel coverage is degraded for the LC-MTC device, as well as data channel channels, if data channel coverage is only improved, there may be a coverage imbalance between control and data channels. Since control channel may be received for the data channel reception, the control channel coverage may be improved at the same time.

[0083] A PBCH may be transmitted over 40 ms and repeated four times so that a WTRU may integrate signals in a 40 ms window size if a WTRU suffers from low received signal to interference plus noise ratio (SINR) as the integration of signals may increase received SINR. However, a PBCH signal integration more than 40 ms may not be possible as the system frame number (SFN) may keep changing in the PBCH in

every 40 ms. Therefore, the coverage of PBCH may also be improved for the low coverage WTRUs.

[0084] PBCH coverage may also affect SFN acquisition for an LC-MTC device to perform cell access and other procedures that depend on frame level timing. Improvements for an LC-MTC device to determine SFN may be considered. Additionally, LC-MTC specific system information acquisition may also be considered for further coverage enhancements.

[0085] The evolved Node-B may eventually detect and respond to a power-ramped preamble transmission from the WTRU. A machine-type-communication (LC-MTC) may experience much higher pathloss, (e.g., 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.

[0086] The configuration of a paging channel may not include an HARQ process, and as such may not benefit from re-transmissions. Additionally, the PCCH may operate in an RLC TM, and may benefit from additional gains from an RLC segmentation process. Methods are needed for the PCH to benefit from signaling accumulation for coverage enhancement gains.

[0087] In order to improve the coverage of ePDCCH, PDSCH, and PUCCH, repetitive transmission may be considered as a coverage enhancement technology. In this case, the current HARQ process such as $n+4$ timing relationship may not be used anymore since the reference subframe may be redefined among the repetitively transmitted subframes. In addition, the timing relationship between uplink grant and PUSCH transmission also may be redefined with a new reference subframe n .

[0088] 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.

[0089] The PDCP and RLC may allocate a smaller sequence number (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.

[0090] 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 reduced to 3 bits, RLC reduced to 6 bits and MAC reduced to 7 bits. The WTRU and eNB may apply the same reduction of protocol headers in the DL also.

[0091] For coverage enhancement purposes, the WTRU may be configured with reduced PDCP, RLC, and MAC header configuration as part of data radio bearer setup procedure, and may be signaled by RRC. For example, as part of the RRC procedure, WTRU may be signaled to apply 2 bit SN length in PDCP, possibly apply 3 bit SN length in RLC with UM mode, and possibly apply a bit to indicate the exclusion of “E”

bit in the MAC header. The WTRU may use a default or pre-defined set of MAC, RLC, and PDCP configuration, including possibly the example header configuration, which may be defined in RRC. The WTRU may be explicitly indicated by the network to use the coverage enhancement mode protocol layer parameters, or the WTRU may autonomously use the coverage enhancement mode parameters, and signal its use to the network.

[0092] 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.

[0093] 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 the CRC parity bits, as long as there is a single LCID associated with the MAC SDUs that are multiplexed into the MAC PDU.

[0094] 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.

[0095] 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 the 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 the 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 the 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 the RLC layer, 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.

[0096] 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.

[0097] 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.

[0098] If a WTRU is under a “coverage enhancement” mode of operation, TTI bundling may be used, where the number of subframes for TTI bundling may be predefined or configured. In addition, the bundled subframes may be repetitively transmitted in time. For instance, N_{TTI} subframes may be bundled, and the bundled

subframes may be repetitively transmitted, whereby N_{rep} , then, $N_{\text{TTI}} \times N_{\text{rep}}$ subframes are used in total. In a broadcasting signal, an indication related to the capability of “coverage enhancement” mode of operation may be included, so that a WTRU capable of the “coverage enhancement” mode may select coverage enhancement mode according to the conditions.

[0099] One or more of following may apply for a bundling size (N_{TTI}) and/or a repetition rate (N_{rep}) for the “coverage enhancement” mode. The bundling size and/or repetition rate may be configured via higher layers together with the transmission mode configuration. A default value of bundling size and/or repetition rate for “coverage enhancement” mode may be defined and the default value may be used if a UE is configured to or falls under “coverage enhancement” mode until the UE receives UE-specific configuration of a bundling size and/or a repetition rate. In this case, the default value may be the largest value among the candidate values, or a WTRU may start to receive PDSCH with the default value and perform a certain number of trials of PDSCH reception. If a WTRU fails to receive PDSCH, the WTRU may increase the bundling size and/or repetition rate with a specific step size. The step size may be predefined and may be the same irrespective of the number of failures or different according to the number of failures.

[0100] TTI bundling and repetition may be used together. HARQ_ACK may not be reported until the last bundled TTI is received within the number of repetitions.

[0101] TTI bundling may be supported for up to N_{TTI} subframes, where the N_{TTI} subframes may be configured by an eNB in a semi-static manner. Hereafter, subframe, TTI and ms may be used interchangeably. One or more of the 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 a different redundancy version (RV) 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, for example, RV-{0, 1, 2, 3, 0, 1} may be used in order, using an 8-TTI window size if 6 subframes are bundled as shown

in Figure 7. The 8ms window size may be used when 8 HARQ processes are used for other WTRUs not configured with TTI bundling. The window size may not be defined, thus allowing bundling any subframes while the maximum N_{TTI} may be equal to or smaller than 8.

[0102] The RV may be changed with the order {0, 2, 1, 3} cyclically within a window so that, for example, RV-{0, 2, 1, 3, 0, 2} may be used in order when an 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 RV order such as {1, 3, 0, 2}. More than one RV order, (e.g., RV orders {0, 1, 2, 3} and {0, 2, 1, 3}, may be used for transmission and/or reception to or from one or more WTRUs. For example, one RV order, (e.g., the RV order {0, 1, 2, 3}), may be used in an initial transmission and the other RV order, (e.g., the RV order {0, 2, 1, 3}), may be used for a retransmission.

[0103] 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.

[0104] 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 and/or the subset of subframes for TTI

bundling may be indicated by using a bitmap within the window and the bitmap may be informed via higher layer signaling.

[0105] The window size (N_{window}) may be defined as at least one of a positive integer number which may have a fixed value such as 8, a positive integer number which may be configured via higher layer signaling, a positive integer number which may be defined as a function of at least one of the system parameters, or a WTRU identity number, which may be a C-RNTI or IMSI.

[0106] The subset of subframes for TTI bundling may be indicated by using a 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.

[0107] The TTI bundling may be supported for 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 new DCI format, 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.

[0108] A set of TTI bundling cases may be defined via higher layer signaling and the indication bits in the DCI format may indicate one of the bundling size within the set. For example, if four TTI bundling cases are defined as $\{N_{\text{TTI},1}=1, N_{\text{TTI},2}=4, N_{\text{TTI},3}=6, N_{\text{TTI},4}=8\}$, then two bits, for example, 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 higher layer signaling may not be needed to define the set of TTI bundling cases. 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.

[0109] 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 TTI bundling is used in the DL. A WTRU may transmit HARQ_ACK in the uplink subframe $n+k$ if the downlink subframe n is the last subframe within the bundled subframes 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 contains the PDCCH or ePDCCH associated with the grant for the PDSCH. In this case, the k may be defined as a function of N_{TTI} , (e.g., $k = N_{TTI}+4$).

[0110] The subframe n may be the subframe containing the PDCCH or ePDCCH associated with the grant for the PDSCH. In this case, the k may be defined as a function of the bundling window N_{window} . For instance, $k = N_{window} + 4$.

[0111] A WTRU may transmit HARQ_ACK corresponding to the bundled DL transmission if the WTRU successfully received the PDSCH of the bundled DL transmission.

[0112] A WTRU may transmit HARQ_ACK in the uplink subframe m if the WTRU received a PDSCH within a time window of x ms, (e.g., 8 ms). A single PDSCH may be transmitted over one or more subframes within a time window of x ms. The subframe m may be a predefined subframe which may be located in the next radio frame of the last subframe of the window located in which the 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 with the PDSCH. Alternatively, the PUCCH resource may be defined via higher layer signaling.

[0113] A WTRU may receive a HARQ_ACK when TTI bundling is used in the UL. A WTRU may receive HARQ_ACK in the downlink subframe $n+k$. Uplink subframe n may be the latest subframe within the bundled subframes associated with the PUSCH transmission. In this case, k may be a fixed number such as 4. Downlink subframe n may be the subframe in which a WTRU receives an uplink grant for the

associated PUSCH. In this case, k may be a function of the bundling size or the bundling window, e.g., $k = N_{\text{TTI}} + 4$ or $k = N_{\text{Window}} + 4$.

[0114] 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 may 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.

[0115] A WTRU may assume that a subset of subframes within the bundled subframes may have associated HARQ_ACK. 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.

[0116] 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 $N_{\text{ANRep}} - 1$ 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.

[0117] 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. Thus, the WTRU first collects and decodes all PDSCH transmissions within the DL subframe bundle and then generates a single HARQ-ACK response for transmission on the UL. ACK/NAK repetition in case of DL subframe bundling according to this method is shown in the Figure 12. As for the UL ACK/NACK timing, according to one exemplary method, the WTRU may, upon detection of a PDSCH transmission within subframe(s) $n-l$ (where l is the index of the subframe within the DL subframe bundle) intended for the WTRU, transmit the initial HARQ-ACK response in UL subframe n and then repeat the HARQ-ACK response in $n+1, \dots, n + N_{\text{ANRep}} - 1$ subframes. As shown in Figure 12, the index l is 3, 4 or 5, and the size of the DL subframe bundle is three.

[0118] For a PDSCH transmission with a corresponding (E)PDCCH detected in subframes within the DL subframe bundle, the WTRU may transmit the initial ACK/NACK response corresponding to the entire DL bundle transmission in UL subframe n and then may repeat the transmission of the corresponding ACK/NACK response for the entire DL bundle transmission on subframes $n+1, \dots, n + N_{\text{ANRep}} - 1$ using the PUCCH resources derived from the corresponding (E)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 (E)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.

[0119] 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 (E)PDCCH CCE index detected in the last subframe of the bundle, the PUCCH resource derived from the (E)PDCCH CCE index detected in the first subframe of the bundle, or the PUCCH resource configured by higher layer signaling.

[0120] For a PDSCH transmission without a corresponding PDCCH detected in the bundled subframes, the WTRU may transmit the initial ACK/NACK response corresponding to the entire DL bundle transmission in UL subframe n and then 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 layer signaling.

[0121] 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.

[0122] In order to improve PHICH coverage in the DL, the WTRU may employ one or a combination of the following methods.

[0123] 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 process a single PHICH resource for a given subframe corresponding to a single UL transport block.

[0124] 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.

[0125] Thus, the PHICH resources may be identified by the index pair $(n_{PHICH,i}^{group}, n_{PHICH,i}^{seq})$ where $n_{PHICH,i}^{group}$ may be the PHICH group number and $n_{PHICH,i}^{seq}$ may be the orthogonal sequence index within the group for the i th PHICH resource which may be 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.

[0126] 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.

[0127] 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

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

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

[0128] 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.

[0129] 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.

[0130] The WTRU may assume that there is only one PHICH resource utilized within the PHICH group without any code-division multiplexing.

[0131] PDCCH has been used for downlink/uplink grant and broadcasting channel transmission, paging, RACH response, group power control and the like. DCI formats have been introduced to support various downlink/uplink transmission modes, such as DCI formats 0 and 4 for uplink grant, DCI formats 1A, 1B, 1C, 2, 2A, 2B, 2C for downlink transmission, and DCI formats 3 and 3A for group power control. The solutions herein may be applied for both PDCCH and EPDCCH, or may only be applicable for either PDCCH or EPDCCH. The terminologies of PDCCHs, such as CCE, REG, PDCCH candidates, and search space, may be used interchangeably with ECCE, EREG and EPDCCH candidates and search space.

[0132] In a first solution, the DCI contents may be downsized for better coverage. Since the (E)PDCCH link adaptation may be based on the number of CCEs, the number of CCEs may be closely related to the coverage of the PDCCH. For instance, 1 CCE may be equivalent to the coding rate $\frac{1}{2}$. Thus, the 2 CCEs may be equivalent to the coding rate $\frac{1}{4}$ as the double number of PDCCH resources are used for a DCI transmission. Since there are four CCE aggregation levels available, such as {1, 2, 4, 8}, the reduction of DCI contents may increase the coverage of the PDCCH in a given CCE aggregation level. For the downsized DCI contents, one or more of following may apply.

[0133] A new DCI format associated with downlink transmission and/or uplink grant may be defined, for example, for this category of WTRUs. Two or less bits may be used for H-ARQ process number indication, which implies that the number of H-ARQ processes is reduced from 8 H-ARQ processes. No H-ARQ process number field may be included in the DCI so that a single H-ARQ process is used or synchronous H-ARQ process is used. Four or less bits may be used for a modulation and coding scheme (MCS) indication. Assuming that N-bit ($N < 5$) may be used for the MCS, the most significant bit (MSB) of the 5-bit MCS table may be assumed at the receiver and the least significant bit (LSB) may be assumed as a predefined bit. For example, a 3-bit MCS field ($N=3$) may be used in a new DCI format, the three bits corresponding to the

first three bits of the MCS table, and the two bit LSB may be predefined as '00'. Therefore, the three bits of the MCS table may be used with the 3-bit MCS field, and a WTRU may interpret the 3-bit MCS field as xxx00, where xxx is MSB of the 5-bit MCS field and '00' is the 2-bit LSB. Alternatively, a 3-bit MCS field may be considered as a part of the LSB, and the MSB may be predefined. For both alternatives, the LSB part or MSB part of the 5-bit MCS field which is not indicated by 3-bit MCS field in the new DCI format may be either predefined or configured by higher layer signaling and/or broadcasting.

[0134] A new MCS table may be defined with an N-bit MCS field, and the new MCS table may be defined with a subset of a previous release 5-bit MCS table.

[0135] The resource allocation bits according to the resource allocation type, (0, 1, and/or 2), may be reduced by limiting the maximum number of PRBs used for PDSCH transmission. For example, assuming that 25 PRB-pairs are available in downlink bandwidth, the maximum number of PRBs allocated in a subframe may be limited to 5 PRB pairs so that the number of bits for resource allocation may be reduced. Alternatively, the resource allocation field may not be used in a new DCI format while using higher layer signaling instead. Therefore, a downlink resource allocation in frequency domain may be a semi-static allocation, while the time allocation may be based on PDCCH. In this case, a WTRU may receive PDCCH in given PRB-pairs configured by higher layers, while the PDCCH may indicate whether the PDSCH for the WTRU may be transmitted in the subframe or not.

[0136] The redundancy version may be removed or downsized in a new DCI format. For example, the redundancy version may be fixed as '0' and no bit field for redundancy version may be used. Assuming that lower coding rate may be used for a new DCI format to support better coverage, the other redundancy versions {i.e., 1, 2, and 3} may not be needed and a single redundancy version may be sufficient. Therefore, a single redundancy version among {0, 1, 2, or 3} may be used as a fixed manner. As an alternative, a 1-bit redundancy version may be used so that two out of four redundancy versions may be used.

[0137] In a second solution, a repetition or extension of the (E)PDCCH format may be used in order to improve the (E)PDCCH coverage. The repetition of (E)PDCCH may be applied in a subframe or over multiple subframes. Hereafter, (E)PDCCH coverage enhancement mode, (E)PDCCH coverage extension mode, coverage enhancement mode, and coverage enhanced mode may be used interchangeably.

[0138] The (E)CCE aggregation levels may be different so that the (E)PDCCH candidates may have larger aggregation levels as compared with the legacy PDCCH. For instance, the aggregation levels {2, 4, 8, 16} or {4, 8, 16, 32} are used for the “coverage enhancement” mode for which the PDCCH coverage extension mode may be only applicable WTRU-specific search space, the PDCCH coverage extension mode may be used irrespective of the transmission, or the PDCCH coverage extension mode may be applicable for a specific DCI format and/or transmission mode.

[0139] A default WTRU-specific search space may be defined for the (E)PDCCH coverage extension mode, where a subset of aggregation levels may be used. For instance, if {1, 2, 4, 8, 16, 32, 64} is the set of aggregation levels used for (E)PDCCH coverage extension mode, a subset {2, 4, 8, 16} may be used in the default WTRU-specific search space. Therefore, a WTRU before a WTRU-specific configuration may monitors (E)PDCCH in a default WTRU-specific search space with the subset of aggregation levels {2, 4, 8, 16}. If a WTRU fails to decode (E)PDCCH within the default WTRU-specific search space for a certain number of trials or time, the WTRU may autonomously change the aggregation levels to a higher aggregation level set, (e.g., {4, 8, 16, 32}. Alternatively, a WTRU may monitor the default WTRU-specific search space until the WTRU receives a WTRU-specific configuration from higher layer.

[0140] Two or more of default WTRU-specific search spaces may be defined in different time/frequency resources, and the aggregation level set may be different according to the location of the default WTRU-specific search spaces. For instance, two default WTRU-specific search spaces may be defined such as default USS1 and default USS2, and the aggregation level set {1, 2, 4, 8} may be used for the default USS1 and the aggregation level set {16, 32, 64, 128} may be used for the default USS2. A UE may

be informed which default USS the WTRU may need to monitor implicitly during the PRACH procedure.

[0141] The subframes may be bundled for an (E)PDCCH transmission in the (E)PDCCH coverage extension mode. For instance, an (E)PDCCH may be transmitted for K-subframes (where $K > 1$). Within the bundled subframe, the starting (E)CCE number may be the same so that a WTRU may integrate the (E)CCEs over multiple subframes without demodulation. The (E)PDCCH coverage extension mode may be applicable WTRU-specific search space. The (E)PDCCH coverage extension mode may be used irrespective of the transmission. The (E)PDCCH coverage extension mode may be only applicable for a specific DCI format and/or transmission mode.

[0142] WTRU behavior may be defined by two control channel modes, (“mode-1” and “mode-2”) and configured by higher layer signaling. The “mode-1” may be called/defined but not limited to as “normal mode”, “legacy mode”, “normal coverage mode”, and/or “legacy coverage mode”. The “mode-2” may be called/defined but not limited to as “extended mode”, “coverage extension mode” “extend coverage mode”, and “larger coverage mode”. A WTRU may be configured with any type of transmission mode (TM-1~ TM-10) and control channel mode. A WTRU category may be defined with one or more control channel coverage extension schemes. Therefore, a WTRU that falls under this category may know which type of control channel mode needs to be used. This WTRU category using control channel coverage extension scheme may first work as the other category WTRUs until the WTRU transmits the WTRU category to the eNB.

[0143] Two modes of operation may be defined as “normal mode” and “coverage enhancement” mode. If a WTRU switches to or falls under “coverage enhancement” mode, the solutions for (E)PDCCH coverage enhancement mode may be used.

[0144] In a solution for EPDCCH coverage enhancement, closed-loop beamforming with large feedback overhead may be used. While the low cost MTC device may suffer from the short coverage, the channel status may be static since the low cost MTC device may be located in basement. Therefore, closed-loop beamforming

with the larger feedback overhead may be reported for better beamforming gain as the channel is not changing frequently. In this case, one or more of following may apply: on top of channel quality indicator (CQI)/precoder matrix indicator (PMI) and/or rank indicator (RI), a WTRU may report channel covariance matrix in long-term manner when a WTRU is configured with control channel coverage extension mode. If a WTRU is configured with control channel coverage extension mode, the WTRU may need to report explicit channel feedback, and one or more of following may apply: the explicit channel feedback may include wideband and/or subband channel covariance matrix, wideband and/or subband quantized channel matrix, and/or multi-rank PMIs, the explicit channel feedback may be reported via higher layer signaling, or whether the explicit channel feedback is reported or not may be based on eNB configuration.

[0145] The PBCH may include some important information for initial access in order to allow downlink signal reception at a WTRU receiver, for instance, downlink system bandwidth, SFN number information, (e.g., 8 MSBs of a 10 bit SFN), PHICH configuration, and number of common reference signal (CRS) ports. In order to provide robust system information for the WTRU suffering from low received SINR, the following solutions may be considered. One solution may be based on actual PBCH coverage enhancement and another solution may use another container for carrying the system information.

[0146] In one solution, the PBCH coverage may be improved by introducing a new PBCH structure for the WTRUs having short coverage. The new PBCH may be transmitted on top of the legacy PBCH for the backward compatibility in a legacy supportable carrier and the new PBCH may be transmitted in a non-backward compatible carrier, (e.g., new carrier type). The new PBCH may be different from legacy PBCH in terms of at least one of a transmission scheme, time/frequency position or repetition frequency. In this case, one or more of following may apply.

[0147] DM-RS based transmission may be used, thus using at least one of, but not limited to, antenna port {107, 108, 109, 110} or {7, 8, 9, 10}. Alternatively, a new antenna port may be defined.

- [0148] The DM-RS may be scrambled with a physical cell-ID.
- [0149] DM-RS based TxD may be used for the broadcasting channels. For instance, 2Tx or 4Tx transmit diversity (TxD) scheme.
- [0150] One of transmission scheme among single antenna port, 2Tx TxD, or 4Tx TxD may be used as a predefined manner.
- [0151] One of transmission scheme among single antenna port, 2Tx TxD, or 4Tx TxD may be used and a WTRU may need to blindly decode one of them.
- [0152] The antenna port number for the single antenna port, 2Tx TxD, and/or 4Tx TxD may be defined in at least one of following manners: a single antenna port may be predefined as a fixed antenna port number such as port-107 for instance, or a single antenna port may be configured as a function of PCI among the antenna ports {107, 108, 109, 110} or {107, 108} with modulo operation. For instance, modulo-4 operation is used with the PCI such as $n = (\text{PCI}) \bmod 4$ and the n may indicate one of the antenna ports. Two or four antenna ports may be predefined such as {107, 109} for 2Tx and {107, 108, 109, 110}. For the simple system design, a single antenna port and 2Tx TxD may be used for the new PBCH transmission.
- [0153] The new PBCH may be located in a center 6 PRBs and may be in different subframes from the legacy PBCH. Since the legacy PBCH may always be transmitted in the first subframe in a radio frame, the new PBCH may be located in other subframes. The new PBCH may be located in one or more subframes in each frame or certain frames, (e.g., frames with certain SFN numbers or frames with SFNs with certain properties, such as SFNs, where $\text{SFN} \bmod \text{a certain number } X = 0$). The subframes and/or frames and/or frame properties may be fixed or may be a function of the cell's physical cell ID. The new PBCH may be located with a subframe offset so that a UE may be informed by the subframe offset for the new PBCH demodulation. Since a UE needs to synchronize with the cell, a UE may know which subframe contains legacy PBCH or the sync channels after finishing synchronization. Therefore, the UE may figure out the location of new PBCH with the subframe offset

which may be an offset from the subframe of the sync channels (PSS or SSS) or the subframe in which legacy PBCH may be found.

[0154] The subframe offset may be predefined as a fixed number such as $N_{\text{offset}} = 4$, or the subframe offset may be configured as a function of the physical cell ID (PCI) with modulo operation. For instance, $N_{\text{offset}} = (\text{PCI}) \text{ modulo-} K$, where the K could be a predefined number which may, for example, be larger than 2 and/or smaller than 10.

[0155] For TDD, the subframe offset may be a function of the TDD UL/DL configuration. Multiple subframe offsets may be used for the repetition. For instance, $N_{\text{offset},1}$ and $N_{\text{offset},2}$ may be used in order to transmit PBCH more frequently. The subframe offsets may be predefined as fixed numbers or configured as function of the physical cell-ID.

[0156] In a new PBCH, a smaller number of bits may be used for SFN indication. For instance, a 7-bit or less SFN number indicator may be used instead of 8bit SFN number so that the SFN number provided by PBCH may be the same in a longer time window. In this case of 7 bit SFN number indicator is used, the 7 bit SFN number may, for example, indicate the most significant 7 bits of 10 bit SFN numbers and a WTRU may implicitly detect the least significant 3 bit number “000”, “001”, “010”, “011”, “100”, “101”, “110”, and “111” in each radio frame from the scrambling code of coded bit, where a BCH transport block is coded/rate-matched and scrambled in bit level so that each radio frame may have a different part of scrambled coded bits. In the case of 7 bit SFN indication, the new PBCH time window is equivalent to 80 ms which is double of the legacy PBCH time window, where the PBCH time window may be considered as TTI for a PBCH transmission.

[0157] In the case that both legacy PBCH and new PBCH are transmitted in the same cell, a WTRU behavior for the PBCH reception may be defined as at least one of the following.

[0158] A WTRU may measure RSRP before the reception of the PBCH, if the measured RSRP is lower than a threshold, the WTRU may start to attempt to receive

and/or decode new PBCH. Otherwise, the WTRU start to attempt to receive and/or decode legacy PBCH.

[0159] A WTRU may start to attempt to receive and/or decode legacy PBCH at the beginning of initial access, if the WTRU fails to receive and/or decode the legacy PBCH with a predefined number of attempts, then the WTRU may stop attempting to receive and/or decode legacy PBCH and may start to attempt to receive and/or decode new PBCH.

[0160] If a WTRU falls under a specific WTRU category, the WTRU always start to attempt to receive and/or decode new PBCH.

[0161] Certain WTRUs such as WTRUs having low received SINR or falling under a certain WTRU category may not be able to successfully receive system information carried via legacy PBCH. Another channel may provide, and/or may be used by a WTRU such as the certain WTRU to receive, system information such one or more of the elements of system information typically provided by legacy PBCH.

[0162] EPDCCH common search space (or a newly defined search space) may be used to carry system information such as downlink system bandwidth, PHICH configuration, and SFN number. The EPDCCH common search space or subset of the EPDCCH common search space (or other search space, such as a system information search space e.g., SI-PDCCH) may be used for carrying system information.

[0163] A new DCI format may be defined for the system information. For instance, DCI format-x may be defined for the system information and may contain one or more of the following: DL system bandwidth (for example, dl-Bandwidth – ENUMERATED {n6, n15, n25, n50, n75, n100}, PHICH configuration (for example, phich-Config – PHICH-Config), SFN number (for example, systemFrameNumber – BIT STRING (Size(8)), or Spare (for example, spare – BIT STRING (Size (10))). The same coding chain with other DCI format may be used for the system information DCI format-x. Predefined eCCE numbers may be used for the DCI format-x. In this case, the aggregation level may be a predefined number (e.g. 8) or multiple aggregation levels may be used in a blind decoding manner.

[0164] The DCI format-x containing system information may be transmitted periodically in a predefined subframe. For instance, in every subframe 4 in a radio frame, the DCI format-x may be transmitted within the EPDCCH common search space (or other search space which may be used for system information).

[0165] The subframe location in a radio frame may be different such as 2, 3, 4, or 6 but not limited to. Therefore, a WTRU under “coverage enhancement” mode of operation may decode the DCI format-x containing system information rather than PBCH.

[0166] In TDD, the subframe location may be defined as a function of the TDD UL/DL subframe configuration. For instance, subframe 4 may be used in UL/DL subframe configuration 1, while subframe 3 may be used in UL/DL subframe configuration 2.

[0167] Consecutive subframes, or multiple subframes, which may be in a certain time window may contain the DCI format-x without changing SFN number. In order to improve the coverage, the DCI format-x may be transmitted repetitively for multiple subframes which may, for example, be consecutive or consecutive DL subframes. Since the SFN number is not changed in these multiple subframes, a WTRU may integrate the DCI format-x to improve the coverage. The time window may be a frame. The multiple subframes in which DCI format-x may be transmitted without changing SFN number may be in the same frame.

[0168] Two types of EPDCCH may be defined such as type-1 and type-2 EPDCCH common search space (CSS) and one of the EPDCCH common search space types may be used for system information. The type-1 EPDCCH CSS may be interchangeably used with “Cell-specific EPDCCH CSS”, “system EPDCCH CSS”, “predefined EPDCCH CSS”, “distributed EPDCCH CSS” and/or “broadcasting EPDCCH CSS”. The type-1 EPDCCH CSS location may be predefined within a center 6RBs and may not be transmitted in all subframes. For instance, in FDD, the type-1 EPDCCH CSS may be or may only be transmitted in all or a subset of the subframes {1, 2, 3, 4, 6, 7, 8, 9}. The type-1 EPDCCH CSS may be transmitted in a subset of the radio frames. The type-2

EPDCCH CSS may be interchangeably used with “WTRU-specific EPDCCH CSS”, “eNB configured EPDCCH CSS”, and/or “localized EPDCCH CSS”. The type-2 EPDCCH CSS location may be configured by higher layer signaling and/or broadcasting channel. The broadcasting channel may include the DCI format-x. The DCI format-x for the system information may be transmitted in the type-1 EPDCCH CSS.

[0169] A newly defined search space to use for system information ,e.g., SI-PDCCH, may have the properties as described above for type-1 EPDCCH. Based on the means in which an eNB (or cell) transmits certain system information such as the system information which may be included in the legacy PBCH, for example to a certain WTRU which may be part of a certain group of WTRUs, and/or based on the means in which a WTRU receives such information, one or more of the following may apply.

[0170] An eNB or cell communicating with a certain WTRU may not provide PHICH in response to an UL transmission from that WTRU which was granted or scheduled by that eNB or cell. The WTRU may understand that it is not expected to support PHICH. The WTRU may not look for, expect and/or act upon PHICH which may be provided by an eNB or cell in response to an UL transmission from the WTRU.

[0171] The WTRU may understand that it is not expected to support CRS based transmission. The WTRU may assume that CRS is not transmitted in a subframe in which the WTRU receives a DL grant and may assume that rate-matching around CRS for PDSCH reception is not required. An exception to this may be certain subframes in which CRS is known by the WTRU to be transmitted and the port number or numbers is/are a priori known (e.g., CRS may be transmitted in subframes 0 and 5 with port 0). The means may include the channel in which the certain system information is transmitted or received, for example, EPDCCH common search space or SI-PDCCH.

[0172] An eNB or cell may transmit and a WTRU may receive, for example in a channel other than PBCH such as EPDCCH CSS or SI-PDCCH, a subset of the system information which may be included in the legacy PBCH.

[0173] PHICH configuration may not be provided and/or CRS port number may not be provided. The system information which may be included the legacy PBCH may be grouped into multiple subsets which may be transmitted by an eNB or cell and/or received by a WTRU separately.

[0174] Each subset, for example system information subset-1 (SBS-1) and system information subset-2 (SBS-2) may be defined and transmitted or received separately.

[0175] The SBS-1 may contain downlink system bandwidth and SFN number and The SBS-2 may contain CRS port number and/or PHICH configuration.

[0176] The SBS-1 may contain a downlink system bandwidth and the SBS-2 may contain an SFN number and CRS port number.

[0177] The SBS-1 may contain downlink bandwidth and CRS-port number while SBS-2 may contain SFN number only.

[0178] Some of the system information which may be included in the legacy PBCH may not be included in any of the subsets, (e.g., PHICH configuration may not be included in any of the subsets). Each subset may have a different period or pattern for the transmission.

[0179] In one example, SBS-1 may be transmitted every 5 ms and SBS-2 may be transmitted every 10 ms. In another example, SBS-1 may be transmitted once every j-ms while SBS-2 may be transmitted over consecutive subframes in every k-ms.

[0180] Certain devices, such as LC-MTC or other devices in low SINR coverage areas, may acquire network and cell information for cell access and connection establishment from a certain system information block (here after LC-SIB) that is broadcasted by the eNB which may be supporting coverage enhancement such as LC-MTC coverage enhancement.

[0181] LC-SIB may be a signaling message (e.g. RRC) transmitted in a predefined frequency and time location.

[0182] LC-SIB may be semi-static, (e.g., may not change for long period of time, and may be repeated periodically in pre-defined frames and in one or more pre-defined subframes during that frame.

[0183] The WTRU may consider stored LC-SIB information as valid for a pre-defined window duration or possibly follow the legacy SIB modification procedure. The WTRU may receive a specific indication of LC-SIB change in paging information. Possibly, the WTRU may re-acquire LC-SIB upon each connection establishment for small data reception and/or reception.

[0184] LC-SIB may contain the *sysInfoValue Tag* to indicate whether the LC-SIB currently stored in WTRU is valid and up-to-date.

[0185] LC-SIB may not contain SFN, and LC-MTC device may acquire SFN through means other than LC-SIB or legacy MIB, for example as described elsewhere herein.

[0186] LC-SIB contents may be limited to one or more of the following information for the purpose of LC-MTC device connection establishment to the network.

[0187] The PLMN-IdentityList is a list that may be limited to a single PLMN ID as mobility of LC-MTC devices may be limited. Cell selection Information may include the RSRP/RSRQ threshold for suitable cell selection. LTC-MTC devices may operate under coverage enhancements may have no threshold for suitable cell selection criteria. The proper detection of LC-SIB may be selection criteria for suitable cell. For example, LC-MTC may consider cell selection with coverage enhancements operation once suitable cell selection by legacy criteria has failed.

[0188] RACH configuration: Both RACH and PRACH common configuration may be needed for LC-MTC device to initiate connection establishment with the network. Certain parameters, such as those related to power control and UL transmission power for RACH procedure may be pre-defined in the WTRU such that maximum transmission power is reached relatively quickly in the RACH process. For example, parameters such as number of preambles, maximum number of preamble transmissions and re-transmission power step may be pre-defined to the maximum allowable values as defined in RRC. The configuration for RACH and PRACH may

otherwise be specified in the LC-SIB if the parameters are different than those that are pre-defined.

[0189] PDSCH/PUSCH/PUCCH common configuration: These parameters may be included for WTRU operation of UL/DL signaling radio bearers upon initial connection establishment with the network.

[0190] UL Information: LC-SIB may contain this information. For example, the UL carrier information is specified in LC-SIB if UL is not configured with the default UL/DL separation or the UL bandwidth is not the same as the DL bandwidth.

[0191] Timers and Constants: RRC specific timers may be included. Possibly, LC-MTC devices may be pre-defined with different constant and timer values compared to normal WTRUs. For example, the default value of radio link failure detection timers and constants T310, N310, T311 may be set to different and longer values to allow for lower possibility of RLF detection by LC-MTC device in coverage enhancements scenario. Possibly, LC-MTC device may be configured not to perform radio link monitoring or indicate radio link failure.

[0192] Parameters in legacy SIBs needed for normal WTRU cell access may not be included in LC-SIB since some functionality may not be supported by LC-MTC devices in coverage enhancement operation. It may also be possible for LC-MTC devices to fallback to normal operation for legacy SIB acquisition by reading the normal cell system information and using that information. Once the WTRU has successfully read and maintained the validity of regular system information, the WTRU may use the information from normal SIBs over LC-SIB.

[0193] A WTRU or device, such as an LC-MTC device or other device in a low SINR coverage area, may acquire or otherwise determine the SFN of a cell where such acquisition or determination may be without obtaining it from a legacy PBCH.

[0194] In one solution, determination of SFN may be based on reception, e.g., successful reception or acquisition of a known signal and the timing of that signal.

[0195] The WTRU may determine the SFN to a certain resolution which may be full resolution, (e.g., 10-bit resolution for a SFN cycle of 1024), or less than full

resolution. Full resolution SFN may be referred to as full SFN. SFN with less than full resolution may be referred to as reduced resolution SFN, reduced SFN, or subset SFN.

[0196] The timing of the signal may include the subframe or subframes in which the signal may be transmitted, the frame or frames in which the signal may be transmitted, the subframe or subframes in which the WTRU receives or successfully receives the signal, the frame or frames in which the WTRU receives or successfully receives the signal, and/or the periodicity of the transmission of the signal.

[0197] The known signal may be transmitted by an eNB or cell. The signal may be transmitted in one or more predefined time/frequency resources. The signal may be transmitted periodically with a predefined period which may be a number of frames. The signal may be transmitted in a fixed or configured frame or frames within the period. The frame or frames in which the signal may be transmitted may be a function of a cell specific configuration, (e.g., physical cell ID). For example, a cell with PCI of 100 may transmit the known signal every SFN cycle (e.g., 1024) frames to indicate a certain SFN such as SFN 100 to the WTRU.

[0198] The signal may be repeated in two or more the subframes within a frame in which the signal is transmitted. The signal may be a predefined sequence. The signal may be a system information block such as a LC-SIB or SIB1. The signal may be a P-RNTI. The signal may be an SI.

[0199] A WTRU may receive or attempt to receive and/or decode the signal in one or more subframes of a frame in which the signal is transmitted. The WTRU may combine (e.g., integrate) signals from multiple such subframes within a frame in which the signal is transmitted and may use that combination to successfully receive and/or decode the signal, for example, in a single frame.

[0200] The frame or frames in which the signal may be transmitted and/or the periodicity of the transmission may indicate the SFN with full resolution. For example, the signal may be transmitted in a certain frame (e.g., frame 0) once every SFN cycle (e.g., 1024) frames, and may be used to indicate a certain SFN such as 0. Upon

successful reception of the signal, the WTRU may understand the frame of the reception to be the certain SFN (e.g., SFN 0). The WTRU may integrate the signal over multiple frames which may be separated by SFN cycle frames to achieve successful reception. The certain frame may be fixed or may be a function of physical cell ID.

[0201] In another example, the signal may be transmitted in multiple subframes, (e.g., certain subframes or all DL subframes), of a certain frame every SFN cycle, (e.g., 1024) frames, and may be used to indicate a certain SFN such as 0. Upon successful reception of the signal, the WTRU may understand the frame of the reception to be the certain SFN (e.g., SFN 0). The WTRU may integrate the signal over one or more of the multiple subframes to achieve successful reception. Successful reception by the WTRU may be accomplished in one frame. The certain frame and/or subframes may be fixed or may be a function of physical cell ID. The frame or frames in which the signal may be transmitted and/or the periodicity of the transmission may indicate the SFN with reduced resolution.

[0202] For example, the signal may be transmitted every N frames where (SFN cycle)/N may be an integer. The WTRU may integrate its reception in certain frame such as every Nth frame until the signal is successfully received. Since the signal may be transmitted every N frames, the resolution of the SFN may be reduced.

[0203] For example, once a WTRU successfully receives the signal which it may accomplish by integrating signals it receives every N frames (e.g., in certain one or more subframes every N frames), then the WTRU may understand which frames are the set of frames X, (X+N) modulo SFN cycle, (X+2*N) modulo SFN cycle, (X+3*N) modulo SFN cycle, ..., and the like, but may not know which frame is which X may be 0 or another known value, or X may be a function of physical cell Id. As an example, if X=0, N=8, and SFN cycle is 1024 the WTRU may determine which frames are the set of frames containing frames 0, 8, 16, ... 1016, but may not know which frame is which.

[0204] As another example, if X=0, N=512, and SFN cycle = 1024, the WTRU may determine which frames are the set of frames containing frames 0 and 512, but may not know which is frame 0 and which is frame 512.

[0205] X may be provided to the WTRU via signaling such as broadcast signaling which may, for example, be provided in the frames in which the signal used for SFN determination is transmitted. The WTRU may use the value of X to determine a revised set of frames beginning with 0, e.g., 0, N, 2N, and the like.

[0206] For example, if $X=3$, $N=8$, and SFN cycle = 1024, the WTRU may recognize the set of frames that are 3, 11, 19, etc. In those frames, the WTRU may receive signaling such as broadcast signaling which identifies X to be 3. The WTRU may then determine which frames are the set of frames 0, 8, 16, 24, and the like.

[0207] If an SIB or other control signaling is used as the signal for SFN determination, that SIB or control signaling may include the value of X.

[0208] When a WTRU understands the SFN with reduced resolution, e.g., the set of frames X, $(X+N)$ modulo SFN cycle, $(X+2*N)$ modulo SFN cycle, $(X+3*N)$ modulo SFN cycle, ..., etc., the WTRU may implicitly determine which frames are even and which are odd and the frames between the known frames. The WTRU and may use that information for certain procedures such as a random access procedure.

[0209] For example, if a WTRU knows the set of frames 0, 8, 16, ..., it may also know the set of frames 1, 9, 17, ... and 2, 10, 18, ... by shifting by one and two frames, respectively. The WTRU may, therefore, know which are the even and which are the odd subframes which may be needed for a random access procedure such as an initial random access procedure.

[0210] Acquisition or determination of subset SFN by a WTRU may mean or result in the WTRU distinguishing one or more sets of frames, which may consist of every Nth frame where N is the period in frames of the signal, which may be used by the WTRU to determine the subset SFN. The sets of frames may be unique. There may be up to N such sets of frames. The number of elements in each set may be $(\text{SFN cycle})/N$. This may be equivalent to the WTRU understanding for each frame the value of $(\text{SFN for that frame}) \bmod N$.

[0211] A WTRU may acquire or determine subset SFN based on acquisition of LC-SIB and pre-defined frame rules and periodicity of the LC-SIB transmission.

[0212] A WTRU may acquire or determine subset SFN based on properly decoding SIB1.

[0213] For example, SIB1 may be transmitted in SFN X where X may be 0 and may be repeated every 20 ms which may correspond to every 2 frames, e.g., even frames. The WTRU may understand that acquisition of SIB1 may correspond to finding the even frames which may enable the WTRU to determine which frames are even and which are odd.

[0214] A WTRU may acquire or determine a subset SFN based on P-RNTI detection in the common search space of PDCCH or EPDCCH given paging density of the cell, (e.g., n_B parameter in RRC) is greater than 1 frame, (e.g., $n_B = T/2, T/4, T/8, T/16, \text{or } T/32$).

[0215] A WTRU may acquire a subset SFN based on SI periodicity which may be indicated in the SI schedule. The configuration of certain SI allows for periodicity of up to 512 frames

[0216] In another solution, the determination of SFN may be based on reception, e.g., successful reception of a full resolution SFN and/or a subset SFN. Subset SFN may be sufficient for certain procedures such as system information acquisition and random access such as initial random access (e.g., RACH access).

[0217] The eNB or cell may transmit a signal which may include a full resolution SFN (e.g., 10-bit resolution for a SFN cycle of 1024) and/or or a subset SFN. The subset SFN may represent the least significant B bits of the full resolution SFN such as the least significant 3 bits. This may correspond to SFN modulo (2^B) which for the example of 3 bits may be SFN modulo 8.

[0218] Given successful reception of the subset SFN, the WTRU may acquire SFN modulo (2^B) for the frames in which the subset SFN may be received and may use that to understand SFN modulo (2^B) for other frames such as all frames.

[0219] The full resolution SFN may be transmitted periodically with a shorter duty cycle than the SFN cycle. For example, the signal with the full SFN may be transmitted every 8, 16, or 32, frames, among others. The subset SFN may be

transmitted once or multiple times during the duty cycle of the full SFN. The full SFN and/or the subset SFN may be transmitted in one or more, including possibly all or all DL, subframes in the frames in which they are each transmitted. The full SFN and the subset SFN may be transmitted in a different number of subframes in the frames in which they are transmitted

[0220] The definition of periodicity and length of signaled SFN for a cell may be a function of the acceptable tolerance to delay for the cell access procedure of the device such as a LC-MTC device as well as the cell specific configuration for certain SFN based procedures such as DRX and RACH access. The signaled SFN by a cell may be the full SFN and/or subset of SFN, based on the periodicity of the full SFN and/or subset of SFN.

[0221] A WTRU may acquire and decode a signal which may contain a full SFN or a subset SFN. A WTRU may understand which SFN to receive based on the schedule or schedules for the different SFNs.

[0222] A WTRU may integrate or otherwise combine same signals (full SFN with full SFN, subset SFN with subset SFN) from multiple subframes in a frame in order to successfully receive a signal.

[0223] A WTRU may integrate or otherwise combine identical signals, (full SFN with full SFN, subset SFN with subset SFN), from multiple frames, for example signals in frames that are separated by the periodicity of the transmission, in order to, for example, successfully receive the signal.

[0224] This may be applicable to a full SFN when the periodicity is equal to the SFN cycle. This may be applicable to the subset SFN when the periodicity is a multiple of the subset SFN cycle. For example, if the subset is 3 bits, then the subset cycle is 8. SFN subset signals in given frame may be combined with SFN subset signals that are 8 or a multiple of 8 frames away from that subframe

[0225] For the purpose of cell access, the WTRU may use one or more of the above methods of SFN acquisition to complete the establishment of connection with the cell. For example, the knowledge of odd/even SFNs may allow for the WTRU to initiate

the random access procedure, once the RACH/PRACH configuration has been acquired by LC-SIB and/or normal SIB.

[0226] 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, PPRACH.

[0227] 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.

[0228] 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.

[0229] 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.

[0230] 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.

[0231] 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).

[0232] 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.

[0233] 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).

[0234] 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.

[0235] 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.

[0236] 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.

[0237] The WTRU may autonomously decide to transmit repeated preambles, if allowed by the network, based on various conditions. For example, if $P_{\text{cmax}} < \text{preambleInitialReceivedTargetPower} + \text{deltaPreamble} + \text{pathloss}$, or if $(P_{\text{cmax}} \pm \text{some amount}) < \text{preambleInitialReceivedTargetPower} + \text{deltaPreamble} + \text{pathloss}$, 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.

[0238] In one solution, a new preamble format may be utilized which increases repetition number for the preamble, so that the energy for the PRACH preamble may be increased over more subframes. For instance, a new preamble format may be introduced as shown in Table 2 which may be used for coverage enhancement purposes. Table 2 below includes additional preamble formats for PRACH.

Table 2

Preamble format	T_{CP}	T_{SEQ}
5	$3168 \cdot T_s$	$n \cdot 24576 \cdot T_s$
6	$21024 \cdot T_s$	$n \cdot 24576 \cdot T_s$
7	$6240 \cdot T_s$	$n \cdot 24576 \cdot T_s$

[0239] In Table 2, the n may be an integer number larger than 2 and considered as the repetition factor for the PRACH preamble. For the new additional preamble formats, one or more of following may apply:

[0240] A new additional preamble format per CP length may be introduced for example for coverage enhancement purposes. At least one of following may be used:

[0241] The repetition factor (n , $T_{SEQ} = n \cdot 24576 \cdot T_s$) may be defined with a configuration. For instance, the n may be a PRACH configuration parameter. Therefore, an eNB may inform the value of n as a part of PRACH configuration, where the n only applies for the new preamble format.

[0242] The repetition factor n may be calculated by WTRU and the value n may be configured as a function of downlink pathloss and/or other measurement. As an example WTRU behavior, a WTRU may measure downlink pathloss and if the pathloss is larger than a threshold, the WTRU may use the new additional preamble format. The repetition value n may be obtained by using the pathloss value calculated. Once a WTRU obtains the repetition value n , the WTRU may transmit PRACH preamble in a specific PRACH resource which is used for the new preamble format with the repetition value n .

[0243] According to the repetition value 'n', a separate PRACH resource may be defined. For instance, the repetition candidates {4, 8, 16} may be defined, and if a WTRU need to use the repetition value $n=4$, there may be a specific PRACH resource which may or may only be used for the repetition value $n=4$. In an example, the repetition candidates {4, 8, 16} may be used but another number and value of repetition candidates may be selected.

[0244] The subframe for PRACH may be defined as a function of the repetition factor 'n' since the required subframe may be dependent on the repetition factor. Table 3 shows the required subframe length according to the repetition factors. In an example, if the repetition factor is smaller than a threshold (e.g., 9), the starting subframe for PRACH transmission may be configured in every radio frame, otherwise the subframe may be configured in even or odd radio frame.

[0245] Table 3 below indicates required subframe length for preamble formats according to "n".

Table 3

	n=2	n=4	n=8	n=16
Preamble format 5	2 ms	4 ms	7 ms	13 ms
Preamble format 6	3 ms	4 ms	8 ms	14 ms
Preamble format 7	2 ms	4 ms	7 ms	14 ms

[0246] Multiple new additional preamble formats may be introduced for example for coverage enhancement purposes.

[0247] New additional preamble formats may be defined and each CP length may have different repetition factors. Table 3 shows an example of multiple new additional preamble formats per CP length. The preamble format 5 may include all supportable CP lengths in the preamble format 0-3, while the sequence length may be the same with the repetition factor n1. The same may apply for other new preamble formats except for the repetition factor, thus resulting that the preamble formats 5, 6, and 7 may have the repetition factors n1, n2, and n3, respectively.

[0248] The repetition factors {n1, n2, n3} may be predefined, for instance {4, 8, 16} but not limited to. The repetition factor may be defined as a function of pathloss and/or other measurements.

[0249] The PRACH resource may be configured/defined according to the repetition factors. For instance, a WTRU obtains the repetition factor and then WTRU may know which PRACH resource the WTRU needs to use for preamble transmission.

[0250] The new preamble formats may use the same CP length in the previous preamble formats, while the sequence lengths may be increased.

[0251] Table 4 below includes new additional preamble formats for PRACH.

Table 4

Preamble format	T_{CP}	T_{SEQ}
5-1	$3168 \cdot T_s$	$n1 \cdot 24576 \cdot T_s$
5-2	$21024 \cdot T_s$	$n1 \cdot 24576 \cdot T_s$
5-3	$6240 \cdot T_s$	$n1 \cdot 24576 \cdot T_s$
6-1	$3168 \cdot T_s$	$n2 \cdot 24576 \cdot T_s$
6-2	$21024 \cdot T_s$	$n2 \cdot 24576 \cdot T_s$
6-3	$6240 \cdot T_s$	$n2 \cdot 24576 \cdot T_s$
7-1	$3168 \cdot T_s$	$n3 \cdot 24576 \cdot T_s$
7-2	$21024 \cdot T_s$	$n3 \cdot 24576 \cdot T_s$
7-3	$6240 \cdot T_s$	$n3 \cdot 24576 \cdot T_s$

[0252] The preamble format and subframe configurations may be configured together in broadcasting channel. In the FDD case, the unused PRACH configuration index (i.e., 30, 46, 60, 61, 62) may be used for the new additional preamble formats. A separate random access configuration table may be defined for the coverage enhanced PRACH configuration. A separate group of preamble sequence indices may be allocated, (e.g., “group C”), used specifically by WTRUs for coverage enhancements purposes, and signaled to WTRUs, for example in SIB2.

[0253] Extended preamble format configuration and configuration indices may also be included in the configuration of group C preambles, which may be different than those specified for configuration of preamble group A and B.

[0254] WTRUs may use the group C configuration in addition to or instead of group A/B preamble configuration as specified in SIB2.

[0255] In another solution, the preamble formats 0-3 may be reused with repetitions.

[0256] The same preamble format may be used in the same PRACH resources. In this case, the coverage enhanced PRACH transmission may use repetition of the same PRACH preambles. For the repetition of the PRACH transmission.

[0257] A subset of PRACH preambles may be predefined, or configured for the repetition based PRACH preambles, where the repetition based PRACH preambles may be transmitted repetitively within a time window size. For instance, the time window size may be defined as N_{win} subframe or radio frame and the same PRACH preamble may need to be transmitted in all PRACH resources within the N_{win} time window. As an example, the $N_{win}=3$ is used and the PRACH subframes may be defined as {1 in Any radio frame}, then a WTRU may need to transmit the repetition based PRACH preamble for 3 radio frames. The window size may be predefined or configured as a function of the PRACH configuration.

[0258] Additional frequency resources may be reserved for the repetition based PRACH preambles which may be mutually orthogonal with the frequency resources for non-repetition based PRACH preambles (i.e. PRACH preambles for legacy WTRU). Therefore, both types of WTRU use the same PRACH configuration except for the frequency offset index (i.e. *prach-FrequencyOffset*). The time window may be used in order to indicate the repetition number of PRACH preamble transmissions.

[0259] A subset of PRACH subframes may be reserved for the repetition based PRACH preambles. Therefore, a WTRU may transmit the repetition based PRACH preambles only in the subset of PRACH subframes configured.

[0260] The same preamble format may be used in the different PRACH subframes. As an example, a subframe offset may be used which indicate the PRACH subframe for repetition based PRACH preambles. The subframe offset may be informed to a WTRU via broadcasting channel, so that the WTRU required to transmit repetition based PRACH preambles may use the subframes for transmitting repetition based PRACH preambles.

[0261] To enhance coverage of the paging channel for WTRUs, the following solutions are proposed.

[0262] WTRUs may be allocated a separate set of paging frames (PFs) and occasions (POs) from normal WTRUs for coverage enhancements purposes.

[0263] A paging message for LC-MTCs may be repeated with the same information over a number of frames and/or subframes such that the WTRU may take advantage of accumulation of the paging information.

[0264] The solutions, detailed below, may be applied by the WTRU in any combination.

[0265] A WTRU may be allocated with paging frames and paging occasions that are separate from normal WTRUs such that a subset of paging occasions for a cell may be read by certain WTRUs, (e.g., WTRUs needing coverage enhancement, (such as LC-MTC WTRUs)). This may be performed with one or combination of the following methods.

[0266] Allocation of second P-RNTI: WTRUs may be indicated of an alternative P-RNTI from the P-RNTI that has been allocated in Rel-8, (e.g., P-RNTI value of 0xFFFFE). The WTRU may be indicated with the value of the second P-RNTI, as part of the paging and DRX configuration or it may be provided with an indication to use the second P-RNTI value, which may be pre-determined. For example, the second P-RNTI value may be set as 0xFFFFC. The WTRU may during its allocated paging occasion look for both Rel-8 P-RNTI and second P-RNTI or for the second P-RNTI. The WTRU may be indicated, as part of paging configuration, whether or not to use a second P-RNTI.

[0267] Allocation of LC-MTC specific paging frame (PF): The WTRU may be allocated with a pre-determined paging occasion and DRX/paging cycle by means of signaling, for example via RRC or NAS, instead of being determined by the identity of the WTRU. The allocation of paging occasion to the WTRU by the eNB for paging coverage enhancements may be a function of allocation of paging occasion for normal WTRUs and selecting paging frames that are not occupied by normal WTRUs. The WTRU may be provided with explicit paging frame and paging occasion, and not apply its IMSI to determine the paging frame via normal procedural means. For example, normal WTRUs may be allocated with paging parameters of DRX length of 256 frames

and nB of $T/32$. This allows for PFs for normal WTRUs to occur at frames that are multiples of 32. WTRUs for coverage enhancements may be allocated with LC-MTC POs in frames 1~31 for example with long DRX cycle of 256 such that LC-MTC WTRUs and normal WTRUs do not share a common paging occasion.

[0268] Allocation of multiple paging frames (PF) in DRX/paging cycle: The WTRU may be allocated with multiple PFs specifically for LC-MTC WTRUs during a DRX cycle. For example, this indication of multiple POs, may be in the form of the following: a bitmap to indicate frames during the DRX cycle that are allocated as LC-MTC specific, or an offset of frames indicating consecutive frames from the allocated LC-MTC PO that are allocated to the WTRU.

[0269] The WTRU, with the following methods in any combination, may combine paging information in multiple subframes and/or frames for cumulative gain to enhance paging coverage.

[0270] The WTRU may receive as part of the paging records in the specified LC-MTC PO an indication for connection initiation to the network. The WTRU may not decode its own specific WTRU identity in the paging record but instead, the indication may commonly apply to all the LC-MTC WTRU that are allocated with that particular PO. For example, in RRC Paging message, instead of pagingRecordList IE, which includes WTRU identity of each WTRU being paged, there may be a one bit indicator indicating all WTRUs allocated to this PO respond to the paging message with RRC connection establishment procedure.

[0271] The WTRU may receive repeated RRC paging messages over a period of time such that the WTRU may accumulate the paging message for coverage enhancements gain. The page may contain a WTRU-specific paging record or a group paging indication (as described above). The paging message may be repeated for the multiple allocated LC-MTC paging frames during a DRX cycle or possibly be repeated over the course of multiple DRX/paging cycles.

[0272] The WTRU may, in PFs allocated for LC-MTC WTRUs, receive a repeated paging message in multiple subframes, which can be accumulated over those repeated

subframes. For example, similar to Rel-8 where PO may occur in subframes {0,4,5,9} of all the paging frames, the WTRU may be indicated to receive repeated paging messages in up to four of those paging occasions. The WTRU may be indicated by the network explicitly the number of subframes the paging message may be repeated. Possibly, the WTRU may decode PDCCH with P-RNTI in subframe 0, and not decode PDCCH with P-RNTI in the other subsequent subframes but decode PDSCH in the same location as the first subframe, (e.g., subframe 0).

[0273] For additional cumulative gains of paging message, the WTRU may receive the paging message in other subframes beyond the four as indicated above. The WTRU may be indicated explicitly by the network, the subframes which may send a paging message during the paging frame.

[0274] In one solution, all transmission steps may have a time window so that a WTRU may perform one step at a time. For instance, the downlink transmission steps may be defined as four time windows such as (E)PDCCH window, PDSCH window, Gap, and A/N window so that a WTRU may receive downlink control channel only in the (E)PDCCH window and PDSCH in the PDSCH window. Likewise, the A/N for a PDSCH may be also transmitted only in an ACK/NACK (A/N) window. Figure 14 shows an example of the window based downlink transmission.

[0275] In another solution, a specific step may use the window-based transmission. The (E)PDCCH and PDSCH may have the window, while the A/N transmission is finished within a subframe. The (E)PDCCH may have the time window, while the other transmissions are finished within a subframe. The (E)PDCCH and A/N transmission may have the window, while the PDSCH transmission is finished within a subframe. The PDSCH transmissions may have the window, while the other transmission are finished within a subframe.

[0276] For the window based transmission, each time window may contain two or more subframes and different number of subframes may be used according to the type of window. For instance, N_{epdcch} , N_{pdsch} , N_{gap} , and N_{harq} may be respectively used for ePDCCH window, PDSCH window, Gap, and A/N window to define the window size.

The values for the example configuration in Figure 14 are $N_{\text{epdcch}}=6$, $N_{\text{pdsch}}=11$, $N_{\text{gap}}=4$, and $N_{\text{harq}}=9$. The values of N_{epdcch} , N_{pdsch} , N_{gap} , and N_{harq} may be predefined for the coverage enhanced transmission. The values of N_{epdcch} , N_{pdsch} , N_{gap} , and N_{harq} may be configured via broadcasting channels.

[0277] In the ePDCCH window, a WTRU may monitor search spaces to receive DCIs for PDSCH and/or PUSCH. The ePDCCH window may be defined separately for uplink and downlink transmission. Therefore, two types of ePDCCH windows may be defined such as UL-ePDCCH-window and DL-ePDCCH-window. The UL-ePDCCH-window and DL-ePDCCH-window may be mutually exclusive in time domain, thus a WTRU may be required to monitor either PUSCH related DCI or PDSCH related DCI. Alternatively, the UL-ePDCCH-window and DL-ePDCCH-window may be partially or fully overlapped in time domain, so that a WTRU may monitor both PDSCH and PUSCH related DCI in the subframe where the UL-ePDCCH-window and DL-ePDCCH-window are overlapped.

[0278] The WTRU-specific search space may be split to UL-ePDCCH-window and DL-ePDCCH-window, while the common search space may be located in both windows. For instance, the DCI formats related to the PDSCH transmission (i.e., 1A/2/2A/2B/2C) are only transmitted in the DL-ePDCCH-window and the DCI formats related to the PUSCH transmission (i.e., 0/1) are only transmitted in UL-ePDCCH-window. In this case, the following window may be dependent on the type of ePDCCH window. For instance, the PDSCH window may be or may always be located after DL-ePDCCH-window and the PUSCH window may be located after UL-ePDCCH-window.

[0279] A single ePDCCH window may be used for both PDSCH and PUSCH. Hence, a WTRU may need to monitor DCI formats for both PDSCH and PUSCH within the ePDCCH window. In this case, the following window may be dependent on the DCI format type in the ePDCCH window. For instance, if a WTRU may receive DCI format related to the PUSCH, the following window may become PUSCH window so that the WTRU may transmit PUSCH. On the other hand, if a WTRU receive DCI format

related to the PDSCH, the following window becomes PDSCH window so that the WTRU may receive PDSCH in the following window.

[0280] If a WTRU receives a DCI scrambled with the WTRU's C-RNTI and the DCI is related to PDSCH, the WTRU may need to report A/N within the A/N window. The A/N transmission corresponding to the PDSCH may be transmitted repetitively within the A/N window.

[0281] An ePDCCH targeting a WTRU may be transmitted only in a single subframe within the ePDCCH window. Therefore, if a WTRU receives ePDCCH targeted for the WTRU in the WTRU-specific search space in a subframe within the ePDCCH window, the WTRU may be allowed/permitted not to monitor ePDCCH in WTRU-specific search space in the ePDCCH window. In another word, if a WTRU succeeds to receive a DCI scrambled with C-RNTI in a WTRU-specific search space, the WTRU may assume that there is no other DCI scrambled with C-RNTI in the WTRU-specific search space. This may allow avoiding unnecessary WTRU complexity.

[0282] An ePDCCH may be transmitted over multiple subframes within the ePDCCH window so that a WTRU may accumulate the signals over multiple subframes. In this case, the repetition may be guaranteed in the same ePDCCH candidate so that a WTRU may accumulate the same ePDCCH candidate over multiple subframes within the ePDCCH window. Therefore, the ePDCCH WTRU-specific search space may be fixed over the ePDCCH window. Alternatively, although the same ePDCCH candidate may be used for the repetition the WTRU-specific search space may be changed as a function of the subframe number. In another example, the ePDCCH candidate may be hopped in a predefined manner so that time/frequency diversity gain may be increased.

[0283] In the PDSCH window, a WTRU may receive PDSCH in the PDSCH window. In this case, the PDSCH may be repetitively transmitted in the same frequency resources within the PDSCH window. For instance, if a corresponding DCI for PDSCH indicate that the PDSCH is located in specific PRBs, the PRBs are all reserved within the PDSCH window. Therefore, if a WTRU receives PDSCH, the

WTRU may accumulate the signals in the specific PRBs for PDSCH decoding over multiple subframes within PDSCH window. The PDSCH may be repetitively transmitted in the frequency domain so that a WTRU may accumulate the PRBs in the frequency domain. In this case, the repetition is based on PRB level and the same MCS level may be used. Therefore, a WTRU may integrate signals before demodulation.

[0284] The PDSCH may be repetitively transmitted in the time and frequency domains. In this case, the frequency domain repetition is based on the rate-matching operation while the time domain repetition is based on the data symbol repetition.

[0285] The PDSCH may be transmitted in a specific subframe only. In this case, the DCI for downlink transmission transmitted in the ePDCCH window may contain the subframe information as well as the frequency resource information for the PDSCH transmission. For instance, if 4 subframes are used in PDSCH window, two-bit is used to indicate which subframe contains the PDSCH.

[0286] In the A/N window, a WTRU may transmit A/N in the A/N window if the WTRU received PDSCH in the PDSCH window. In this case, the A/N resource may be allocated as a function of the resource index of the corresponding ePDCCH for the PDSCH transmission. For instance, the first eCCE index of the ePDCCH may be used if the repetition based ePDCCH is used. Alternatively, the A/N resource may be allocated as a function of the resource index and subframe number in which the corresponding ePDCCH is transmitted if ePDCCH is transmitted only in a subframe within the ePDCCH window. For instance, if 4 subframes are used in ePDCCH window, the A/N resource may be allocated as a function of the subframe location within the ePDCCH window, (e.g., 0, 1, 2, or 3), and the first eCCE index.

[0287] The A/N resource may be allocated as a function of the resource index of the PDSCH. For instance, the first PRB index for the PDSCH may be used if the repetition based PDSCH is used. Alternatively, the A/N resource may be allocated as a function of the resource index and subframe in which the PDSCH is transmitted if the PDSCH is transmitted only in a subframe within the PDSCH window. The A/N resource may be allocated as a function of the resource index of the PDSCH and

corresponding ePDCCH. In this case, the first eCCE index and the first PRB index may be used at the same time so that the A/N resource collision may be avoided even though multi-user based ePDCCH and PDSCH transmission is used. The A/N may be transmitted repetitively within the A/N window. For instance, if a PUCCH resource is allocated, the WTRU may need to transmit the same A/N signal repetitively in the same A/N resource in every subframe during A/N window. The A/N corresponding to a PDSCH may be transmitted only in a subframe. Therefore, the A/N resource may be allocated only in a subframe based on the ePDCCH and/or PDSCH resource used.

[0288] A WTRU may apply the all proposed solutions herein individually or in combination as part of “coverage enhancement” mode of operation.

[0289] 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, (e.g., Rel-11), procedures.

[0290] A WTRU may switch between normal 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.

[0291] A WTRU may switch from normal to “coverage enhancement” mode. The WTRU may receive an indication to operate in “coverage enhancement” mode from network and in response to the indication switch to “coverage enhancement” mode. 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.

[0292] The WTRU may switch under one or more of the following example conditions. During cell selection/reselection, WTRU may find a suitable cell under “coverage enhancements” conditions but not in normal operation conditions. For

example, the WTRU may not be able to meet the criteria of suitable cell, as defined in SIB1 of a cell, but may meet the criteria of suitable cell with coverage enhancements, as defined possibly in LC-MIB. Network access attempts and PRACH procedure fails in normal mode, and WTRU switches to “coverage enhancements” mode PRACH procedure. Upon radio link failure detection and subsequent re-establishment to the serving cell. 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.

[0293] If PSS/SSS detection takes a longer time than a certain threshold, the WTRU may switch to “coverage enhancements” mode. The threshold may be defined as a time window such as x-ms. The WTRU may not be able to properly acquire and decode PBCH and/or SIB1 and may be able to acquire LC-MIB and may be able to acquire full or subset of SFN through signals from cell for coverage enhancement purposes.

[0294] For example, the WTRU may continue with a cell access and connection establishment procedure, (e.g., RRC connection request), in coverage enhancements mode if the WTRU acquires the necessary configurations such as for random access through LC-SIB and the SFN value to determine the appropriate RACH resource to initiate random access procedure.

[0295] A WTRU may indicate the change to “coverage enhancements” mode and/or request to change to “coverage enhancements” mode to the network by one or more of the following methods.

[0296] A measurement report, possibly including 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.

[0297] PRACH preambles may indicate to the network that the mode of operation by the WTRU has changed.

[0298] An indication may be made in the RRC connection request or re-establishment that the WTRU may operate in a coverage enhancements mode. For

example, this indication may be included as “cause” IE in RRC connection request or re-establishment request message.

[0299] A WTRU may transition from “coverage enhancement” back to normal operation mode with one or more of the following methods.

[0300] A WTRU may autonomously return back to normal mode operation upon detection of improved coverage conditions while in IDLE or connected mode. The WTRU may detect this improvement by acquiring MIBs and SIBs using Rel-11 specified procedures. The WTRU may be able to meet the suitable cell criteria as specified in SIB1 of a cell. For example, this may be part of cell selection procedure when the WTRU returns from connected to IDLE mode, or possibly as part of connection establishment for data transmission. Random access procedures may be successful using Rel-11 RACH procedures. For example, the WTRU may consider returning to normal operating conditions upon receiving a successful random access response from the eNB within X preamble re-transmission. The threshold value X for preamble transmissions may be defined as the max number of preamble transmissions as defined in SIB2 or a separate value as configured by the cell and may be transmitted as part of RACH configurations in SIB2.

[0301] Based on measurements, the WTRU may detect improvements, for example to RSRP measurement values. Possibly, the WTRU may provide a measurement report to eNB indicating that RSRP has improved above a pre-defined threshold, indicating that normal operation mode may be possible. As another example, WTRU may indicate detected improvements based on PHR and the transmitted UL power. The trigger for PHR to eNB may be triggered by an improvement to measured pathloss.

[0302] A WTRU may, during RRC connection establishment, indicate its return to normal operation mode by using a normal Rel-11 defined cause for RRC connection request.

[0303] The eNB may also detect coverage improvements for the WTRU, and WTRU may be indicated to operate normally by eNB. The WTRU may receive RRC

reconfiguration with data radio bearer parameters are normal Rel-11 configurations. The WTRU receives RRC connection release with an indication for normal operation mode such that the WTRU may perform cell selection to the same cell with normal Rel-11 cell selection procedures and criteria. The WTRU may receive RRC message for intra-cell handover with dedicated RACH procedure. The WTRU may be able to verify improved coverage conditions with the contention free RACH procedure, and additionally the WTRU may reset MAC, RLC, and PDCP layers for the traffic bearer may be to allow for normal mode operation.

[0304] The following are example methods of detection of improved coverage conditions in which eNB may trigger the above signaling for WTRU to return to normal operating mode.

[0305] Decreased number HARQ or RLC ARQ retransmissions: The eNB may detect that the number of HARQ retransmissions and RLC SDU retransmissions for each data packet that the WTRU in coverage enhancements mode needs to receive and/or transmit has decreased. The eNB may also detect the decreased BLER rate of the data bearer.

[0306] Decreased transmission power in UL: The eNB may detect that the transmission power of the WTRU has decreased by a certain threshold based on the closed power control parameters provided to the WTRU for UL transmissions.

[0307] Detection of SRS: The eNB may detect improved UL conditions based on measurements of the SRS, as transmitted by the WTRU.

[0308] 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.

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CLAIMS

What is claimed:

1. A method of a wireless transmit/receive unit (WTRU) operating in a coverage enhancement mode, the method comprising:
predefining or configuring a number of subframes for performing transmission time interval (TTI) bundling; and
bundling the subframes; and
repetitively transmitting the bundled subframes.
2. The method of claim 1 wherein at least one of bundling size or repetition rate is configured via higher layer signaling.
3. The method of claim 2 further comprising:
configuring a transmission mode.
4. The method as in any one of claims 1-3 further comprising:
defining a default value of at least one of bundling size or repetition rate; and
using the default value on a condition that the WTRU is configured to operate in the coverage enhancement mode; and
the WTRU receiving a WTRU-specific configuration of at least one of a bundling size or repetition rate.
5. The method of claim 4 further comprising:
the WTRU receiving a physical downlink shared channel (PDSCH) with the default value; and
the WTRU performing a certain number of trials of PDSCH reception.
6. The method of claim 4 further comprising:

the WTRU increasing at least one of bundling size or repetition rate on a condition that a physical downlink shared channel (PDSCH) is not received.

7. A hybrid automatic repeat request (HARQ) method performed by a wireless transmit/receive unit (WTRU), the method comprising:

collecting and decoding physical downlink shared channel (PDSCH) transmissions within a downlink (DL) subframe bundle; and

generating a single HARQ - positive acknowledgement (ACK) response for transmission on an uplink (UL).

8. The method of claim 7 further comprising:

the WTRU detecting a PDSCH transmission within a first DL subframe; and

the WTRU transmitting the HARQ-ACK response in a first UL subframe and then repeating transmission of the HARQ-ACK response in subsequent UL subframes.

9. 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.

10. The method of claim 9 wherein the data is coded with different RVs according to a subframe index.

11. The method of claim 9 wherein the data is coded with different RVs according to the location of each subframe among the bundled subframes.

12. The method as in any one of claims 9-11 wherein the subframes are configured by an evolved Node-B (eNB) in a semi-static manner.

13. 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.

14. The method of claim 13 wherein the WTRU allocates a sequence number (SN) smaller than 7 bits.

15. The method of claim 13 wherein the WTRU allocates a sequence number (SN) smaller than 5 bits for unacknowledged mode (UM).

16. The method of claim 13 wherein the WTRU allocates a sequence number (SN) smaller than 10 bits for acknowledged mode (UM).

17. 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.

18. The method of claim 17 further comprising:
the WTRU removing the SN bits from an RLC header.

19. The method of claim 17 further comprising:
the WTRU receiving a MAC PDU; and

the WTRU descrambling CRC parity bits with possible SN values; and performing a CRC check.

20. A wireless transmit/receive unit (WTRU) configured to perform a method as in any one of claims 1-19.

21. An integrated circuit (IC) configured to perform a method as in any one of claims 1-19.

22. A wireless transmit/receive unit (WTRU) comprising:
a processor configured to allocate a set of paging frames (PFs) and paging occasions (POs); and
a receiver configured to receive a predetermined paging radio network temporary identity (P-RNTI) value, and a repeated paging message over multiple paging frames, wherein the WTRU accumulates the paging message for coverage enhancements gain.

23. A method of a wireless transmit/receive unit (WTRU) acquiring system frame numbers (SFNs), the method comprising:
the WTRU receiving and decoding signals containing at least one of a full SFN or a subset SFN; and
the WTRU integrating or combining similar signals having a full SFN, and integrating or combining signals having a subset SFN.

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.