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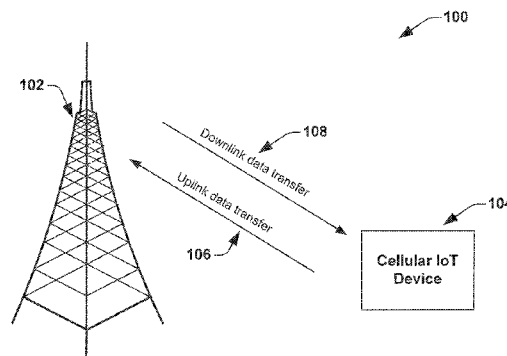


FIG. 1

(57) Abstract: An apparatus for use in an eNodeB of a cellular internet of things (CIoT) system comprising a user equipment (UE), in association with a downlink (DL) data transfer, comprises a memory circuit configured to store system parameters associated with the UE in a coverage area of the eNodeB. The apparatus further comprises a processing circuit configured to provide a signal containing data to the UE, receive a class update request from the UE in response to the signal transmitted to the UE and determine a next coverage class of the UE based on the class update request from the UE and the stored system parameters of the UE. The processing circuit is further configured to provide an updated class information comprising information on the determined next coverage class to the UE.



**METHODS FOR DYNAMICALLY CHANGING DEVICE COVERAGE CLASS FOR  
CLEAN SLATE NARROWBAND CELLULAR INTERNET OF THINGS (CS NB-CIOT)  
SYSTEMS**

**FIELD**

**[0001]** The present disclosure relates to internet of things (IoT) devices and, in particular to an apparatus and a method for dynamically changing device coverage class of a user equipment (UE) in cellular internet of things (CIoT) systems.

**BACKGROUND**

**[0002]** The Internet of Things (IoT) is the network of physical objects, devices, vehicles, buildings and other items which are embedded with electronics, software, sensors, and network connectivity, which enables these objects to collect and exchange data. IoT technology allows IoT devices to be sensed and controlled remotely across existing network infrastructure. Cellular networks play a key role in facilitating communications between a massive number of Internet of Things (IoT) devices. A potential solution for facilitating communications between the IoT devices is the Clean Slate Narrowband Cellular IoT (CS NB-CIoT) system that was proposed in GSM EDGE radio access network (GERAN).

**[0003]** In CS NB-CIoT systems, the CIoT devices are categorized based on their channel quality into different classes, whereby each class is allocated a unique set of uplink and downlink control signaling as well as random access resources. This categorization necessitates that each device performs channel measurements and reporting so that both, the CIoT device and the serving eNodeB, are aware of the device's classes. For such a system to operate efficiently, the class allocation process must be resilient to the instantaneous channel variations. For example, due to the channel conditions, e.g., multipath fading, links between the CIoT devices and their serving eNodeBs will experience instantaneous channel gains/losses. Subsequently, these variations might force the IoT devices to change their classes and accordingly trigger the corresponding signaling procedure. However, since this channel variation is only instantaneous, this will result in wasting the system resources and subsequently impede its performance.

### **BRIEF DESCRIPTION OF THE DRAWINGS**

**[0004]** Some examples of circuits, apparatuses and/or methods will be described in the following by way of example only. In this context, reference will be made to the accompanying Figures.

**[0005]** Fig. 1 shows an example implementation of a cellular internet of things (CloT) system, operable to perform dynamic coverage class selection of a CloT device, according to one embodiment of the disclosure.

**[0006]** Fig. 2a depicts a graphical representation of the dynamic coverage class selection method, for a lower-to-higher coverage class change, according to one embodiment of the disclosure.

**[0007]** Fig. 2b depicts a graphical representation of the dynamic coverage class selection method, for a higher-to-lower coverage class change, according to one embodiment of the disclosure.

**[0008]** Fig. 3 shows an example implementation of a cellular internet of things (CloT) system, operable to perform dynamic coverage class selection of a CloT device during downlink (DL) data transfer, according to one embodiment of the disclosure.

**[0009]** Fig. 4 shows an example implementation of a cellular internet of things (CloT) system, operable to perform dynamic coverage class selection of a CloT device during uplink (UL) data transfer, according to one embodiment of the disclosure.

**[0010]** Fig. 5 depicts a flowchart for implementing the predetermined algorithm on the triggering events D1 and D2 given in equations (1) - (2), for enabling dynamic coverage class selection in CloT systems, according to one embodiment of the disclosure.

**[0011]** Fig. 6 illustrates a block diagram of an apparatus for use in an Evolved NodeB (eNodeB) in a cellular IoT system comprising a CloT device, that facilitates dynamic coverage class selection of the CloT device, according to various embodiments described herein.

**[0012]** Fig. 7 illustrates a block diagram of an apparatus for use in a CloT device in a cellular IoT system comprising an eNodeB, that facilitates dynamic coverage class selection of the CloT device, according to various embodiments described herein.

**[0013]** Fig. 8 illustrates a flow chart of a method that facilitates dynamic coverage class selection of a CloT device in an Evolved NodeB (eNodeB) of a cellular IoT system comprising a CloT device, during downlink (DL) data transfer from the eNodeB to the CloT device, according to one embodiment of the disclosure.

**[0014]** Fig. 9 illustrates a flow chart of a method that facilitates dynamic coverage class selection of a CloT device in an Evolved NodeB (eNodeB) of a cellular IoT system comprising a CloT device, during uplink (UL) data transfer from the CloT device to the eNodeB, according to one embodiment of the disclosure.

**[0015]** Fig. 10 illustrates a flow chart of a method that facilitates dynamic coverage class selection in a cellular internet of things (CloT) device of a cellular IoT system comprising an eNodeB, during downlink (DL) data transfer from the eNodeB to the CloT device, according to one embodiment of the disclosure.

**[0016]** Fig. 11 illustrates a flow chart of a method that facilitates dynamic coverage class selection in a cellular internet of things (CloT) device of a cellular IoT system comprising an eNodeB, during uplink (UL) data transfer from the CloT device to the eNodeB, according to one embodiment of the disclosure.

**[0017]** Fig. 12a depicts a MAC control element (CE) used for signaling a new coverage class (CC) information from an eNodeB to a user equipment (UE), according to one embodiment of the disclosure.

**[0018]** Fig. 12b illustrates a table that depicts the reserved downlink shared channel (DL-SCH) logical channel ID (LCID) for the proposed coverage class signaling using a MAC CE, according to one embodiment of the disclosure.

**[0019]** Fig. 13a depicts a MAC control element (CE) used for signaling a new coverage class (CC) information from a user equipment (UE) to an eNodeB, according to one embodiment of the disclosure.

**[0020]** Fig. 13b illustrates a table that depicts the reserved downlink shared channel (DL-SCH) logical channel ID (LCID) for the proposed coverage class signaling using a MAC CE, according to one embodiment of the disclosure.

**[0021]** Fig. 14 illustrates example components of a User Equipment (UE) device, according to the various embodiments described herein.

### **DETAILED DESCRIPTION**

**[0022]** In one embodiment of the disclosure, an apparatus for use in an eNodeB of a cellular internet of things (CIoT) system comprising a user equipment (UE), in association with a downlink (DL) data transfer is disclosed. The apparatus comprises a memory circuit configured to store system parameters associated with the UE in a coverage area of the eNodeB, wherein the system parameters comprise information on a plurality of available coverage classes of the UE, coverage class thresholds of the plurality of available coverage classes of the UE, a current coverage class of the UE and channel parameters associated with a channel quality between the eNodeB and the UE. The apparatus further comprises a transmit circuit configured to transmit a signal containing data to the UE comprising the DL data transfer and a receive circuit configured to receive a class update request from the UE. The class update request is generated based on the signal transmitted to the UE from the transmit circuit of the eNodeB and the class update request indicates a request to change a coverage class of the UE from the current coverage class to another coverage class of the plurality of the available coverage classes of the UE. In addition, the apparatus comprises a processing circuit configured to determine a next coverage class of the UE from the plurality of the available coverage classes of the UE based on the class update request from the UE and the stored system parameters of the UE. In some embodiments, the transmit circuit is further configured to transmit an updated class information to the UE, wherein the updated class information comprises information on the determined next coverage class for the UE.

**[0023]** In one embodiment of the disclosure, an apparatus for use in an eNodeB of a cellular internet of things (CIoT) system comprising a user equipment (UE), in association with an uplink (UL) data transfer is disclosed. The apparatus comprises a

memory circuit configured to store system parameters associated with the UE in a coverage area of the eNodeB, wherein the system parameters comprise information on a plurality of available coverage classes of the UE, coverage class thresholds of the plurality of available coverage classes of the UE, a current coverage class of the UE and predetermined parameters associated with a channel quality between the eNodeB and the UE. The apparatus further comprises a receive circuit configured to receive a signal containing data from the UE comprising the UL data transfer. In addition, the apparatus comprises a processing circuit configured to determine a quality indicator of the data containing signal received by the receive circuit, and configured to selectively determine an updated class information comprising a next coverage class of the UE from the plurality of the available coverage classes of the UE, based on the determined quality indicator of the signal and the stored system parameters. Lastly, the apparatus comprises a transmit circuit configured to transmit the updated class information to the UE.

**[0024]** In one embodiment of the disclosure, an apparatus for use in a UE of a cellular internet of things (CIoT) system comprising an eNodeB, in association with a downlink (DL) data transfer is disclosed. The apparatus comprises a memory circuit configured to store system parameters associated with the UE, wherein the system parameters comprise information on a plurality of available coverage classes of the UE, coverage class thresholds of the plurality of available coverage classes of the UE, a current coverage class of the UE and channel parameters associated with a channel quality between the UE and the eNodeB. The apparatus also comprises a receive circuit configured to receive a signal containing data from the eNodeB comprising the DL data transfer. The apparatus further comprises a processing circuit configured to determine a quality indicator of the data containing signal received by the receive circuit, and configured to selectively generate a class update request based on the determined quality indicator of the signal and the stored system parameters. The class update request indicates a request to change a coverage class of the UE from the current coverage class to another coverage class of the plurality of the available coverage classes of the UE. The apparatus further comprises a transmit circuit configured to transmit the generated class update request to the eNodeB. In some embodiments, the receive circuit is further configured to receive an updated class information from the eNodeB in response to the transmitted class update request, wherein the updated class

information comprises information on a next coverage class for the UE. The processing circuit is further configured to change the coverage class of the UE from the current coverage class to the next coverage class based on the received updated class information.

**[0025]** In one embodiment of the disclosure, an apparatus for use in a UE of a cellular internet of things (CIoT) system comprising an eNodeB, in association with an uplink (UL) data transfer is disclosed. The apparatus comprises a memory circuit configured to store system parameters associated with the UE, wherein the system parameters comprise information on a plurality of available coverage classes of the UE, coverage class thresholds of the plurality of available coverage classes of the UE, a current coverage class of the UE and channel parameters associated with a channel quality between the UE and the eNodeB. The apparatus further comprises a transmit circuit configured to transmit a signal containing data to an eNodeB comprising the UL data transfer. In addition, the apparatus comprises a receive circuit configured to receive an updated class information from the eNodeB, wherein the updated class information is determined at the eNodeB based on the signal transmitted from the UE and wherein the updated class information comprises information on a next coverage class for the UE. The apparatus also comprises a processing circuit configured to change the current coverage class of the UE to the next coverage class based on the received updated class information.

**[0026]** The present disclosure will now be described with reference to the attached drawing figures, wherein like reference numerals are used to refer to like elements throughout, and wherein the illustrated structures and devices are not necessarily drawn to scale. As utilized herein, terms “component,” “system,” “interface,” and the like are intended to refer to a computer-related entity, hardware, software (e.g., in execution), and/or firmware. For example, a component can be a processor (e.g., a microprocessor, a controller, or other processing device), a process running on a processor, a controller, an object, an executable, a program, a storage device, a computer, a tablet PC and/or a user equipment (e.g., mobile phone, etc.) with a processing device. By way of illustration, an application running on a server and the server can also be a component. One or more components can reside within a process, and a component can be localized on one computer and/or distributed between two or more computers. A set of

elements or a set of other components can be described herein, in which the term “set” can be interpreted as “one or more.”

**[0027]** Further, these components can execute from various computer readable storage media having various data structures stored thereon such as with a module, for example. The components can communicate via local and/or remote processes such as in accordance with a signal having one or more data packets (e.g., data from one component interacting with another component in a local system, distributed system, and/or across a network, such as, the Internet, a local area network, a wide area network, or similar network with other systems via the signal).

**[0028]** As another example, a component can be an apparatus with specific functionality provided by mechanical parts operated by electric or electronic circuitry, in which the electric or electronic circuitry can be operated by a software application or a firmware application executed by one or more processors. The one or more processors can be internal or external to the apparatus and can execute at least a part of the software or firmware application. As yet another example, a component can be an apparatus that provides specific functionality through electronic components without mechanical parts; the electronic components can include one or more processors therein to execute software and/or firmware that confer(s), at least in part, the functionality of the electronic components.

**[0029]** Use of the word exemplary is intended to present concepts in a concrete fashion. As used in this application, the term “or” is intended to mean an inclusive “or” rather than an exclusive “or”. That is, unless specified otherwise, or clear from context, “X employs A or B” is intended to mean any of the natural inclusive permutations. That is, if X employs A; X employs B; or X employs both A and B, then “X employs A or B” is satisfied under any of the foregoing instances. In addition, the articles “a” and “an” as used in this application and the appended claims should generally be construed to mean “one or more” unless specified otherwise or clear from context to be directed to a singular form. Furthermore, to the extent that the terms “including”, “includes”, “having”, “has”, “with”, or variants thereof are used in either the detailed description and the claims, such terms are intended to be inclusive in a manner similar to the term “comprising.”

**[0030]** In the following description, a plurality of details is set forth to provide a more thorough explanation of the embodiments of the present disclosure. However, it will be apparent to one skilled in the art that embodiments of the present disclosure may be practiced without these specific details. In other instances, well-known structures and devices are shown in block diagram form rather than in detail in order to avoid obscuring embodiments of the present disclosure. In addition, features of the different embodiments described hereinafter may be combined with each other, unless specifically noted otherwise.

**[0031]** In the embodiments described below, the user equipment (UE) in a CloT system is defined as a CloT device and hereinafter the UE will be referred to as the CloT device. As indicated above, cellular networks play a key role in facilitating communications between a massive number of Internet of Things (IoT) devices. Existing configurations of Cellular IoT (CloT) systems include, for example, CS NB-CloT system, which support low throughput and low complexity machine type communications (MTC) between a CloT device and an eNodeB. In this configuration, the CloT devices are divided into coverage classes based on their channel quality. Each of these coverage classes dictate the modulation and coding schemes as well as the number of blind repetitions of the transmitted packets necessary for the device to achieve reliable communication with the eNodeB. However, since the class selection is channel dependent, it susceptible to the ping pong effect due to the instantaneous channel variations. In particular, the channel might experience an instantaneous deep fade due to the multipath channel effect that lasts only for a very short interval. Subsequently, these variations might force the CloT devices to change their coverage classes and accordingly trigger a corresponding signaling procedure to indicate the coverage class change to the eNodeB.

**[0032]** Since this channel variation is only instantaneous, this will result in wasting the system resources and subsequently impede its performance. For example, if a device overestimates its class due to an instantaneous channel gain, it can transmit at a higher spectral efficiency resulting in an erroneous transmission. On the contrary, if the device underestimates its class due to an instantaneous channel fade, it will transmit at a much lower spectral efficiency than the one supported by its communication channel. This is in addition to the resources wasted in the signaling procedure to communicate

the device class to the eNodeB. In the existing or conventional implementation of CS NB-CIoT system, there is no proposed technique to handle the effect of the instantaneous channel variations on the device class selection.

**[0033]** Further, in the existing CloT system, the CloT devices decide the coverage class just before the network entry and keep the same class until the end of the session. The CloT devices will not respond to the channel variations during transmission/reception and therefore, may experience higher packet loss and resource wastage. For such a system to operate efficiently, the channel quality between the CloT devices and the eNodeB should remain unchanged during transmission/reception. However, due to the channel conditions, e.g., multipath fading, links between the CloT devices and their serving eNodeBs will experience channel gains/losses thereby affecting channel quality. For example, in CloT devices like a dog collar, bicycle tag, etc., the channel quality may vary significantly depending on the location of the device. If the coverage class is not changed accordingly it may incur high block error rates and result in a significant amount of radio resource wastage. To overcome the above disadvantages, a method for dynamically changing the device coverage class of CloT devices during transmission/reception is proposed. In particular, a method of dynamically changing the coverage class of CloT devices based on a coverage class event triggering mechanism is proposed. The event triggering mechanism enables to handle the effect of instantaneous channel variations (i.e., the ping pong effect) on the coverage class selection.

**[0034]** Fig. 1 shows an example implementation of a cellular internet of things (CloT) system 100, operable to perform dynamic coverage class selection of a CloT device 104, according to one embodiment of the disclosure. In some embodiments, the CloT system 100 comprises both uplink (UL) data transfer 106 and downlink (DL) data transfer 108. In one embodiment, the CloT system 100 comprises an eNodeB 102 and the CloT device 104 associated therewith, however, in other embodiments, the CloT system 100 can have a plurality of CloT devices associated with the eNodeB 102. In some embodiments, the CloT devices are categorized based on their channel conditions into different coverage classes, whereby each coverage class is allocated a unique set of uplink and downlink control signaling as well as random access resources. Each of the CloT devices can have a plurality of coverage classes associated therewith,

one of which is selectively assigned as a current coverage class of a respective CloT device based on a channel condition of the respective CloT device. For example, in some embodiments, the CloT device 104 is assigned a coverage class (i.e., the current coverage class) out of a plurality of available coverage classes associated with the CloT device 104, based on the channel condition of the CloT device 104.

**[0035]** In some embodiments, the channel condition between the CloT device 104 and the eNodeB 102 is assessed based on measuring channel quality parameters like channel quality indicator (CQI), reference signal received power (RSRP), signal to noise ratio (SNR) etc. In some embodiments, the information on the plurality of available coverage classes of the CloT device 104 are determined at the eNodeB 102 based on a deployment strategy and is transmitted to the CloT device 104. In other embodiments, the information on the plurality of available coverage classes of the CloT device 104 are determined at a central network controller (not shown) based on a deployment strategy and is made available to both the CloT device 102 and the eNodeB 104. In some embodiments, it is assumed that both the CloT device 104 and the eNodeB 102 are aware of the plurality of available coverage classes of the CloT device 104 before transmission/reception at the CloT device 104. In some embodiments, the CloT device 104 is configured to report information on the current coverage class of the CloT device 104 to the eNodeB 102.

**[0036]** In some embodiments, the coverage class of the CloT device 104 is selectively changed during transmission/reception based on continuously monitoring the channel condition of the CloT device 104. The CloT device 104 has a coverage class threshold value associated with each of the plurality of the available coverage classes. In some embodiments, the measured channel quality, for example, CQI is compared with a coverage class threshold value, in order to selectively change the coverage class of the CloT device 104 from the current coverage class to a different coverage class of the plurality of available coverage classes of the CloT device 104. For example, if the measured CQI of the CloT device 104 is greater than a class-X threshold of a coverage class X out of the plurality of the available coverage classes of the CloT device 104, and the current coverage class of the CloT device 104 is lower than the coverage class X, then a coverage class update signaling procedure is initiated. In some embodiments, the coverage class threshold is expressed in the same unit as the CQI.

**[0037]** In some embodiments, in order to avoid the effect of instantaneous channel variations, for example, the ping pong effect, two channel parameters, that is, a hysteresis parameter H and a time parameter T are defined. In some embodiments, the parameter H represents a hysteresis value by which the coverage class threshold of a CIoT device must be crossed before initiating the coverage class update signaling procedure, whereas the parameter T indicates the minimum time duration for the hysteresis crossing before the coverage class update signaling procedure is initiated. In some embodiments, the parameters H and T are determined at the eNodeB 102 and transmitted to the CIoT device 104 through DL control signaling, for example, a secondary information transmitted on the broadcasting channel (BCH). In some embodiments, the parameters H and T are transmitted in system information (SI) messages, for example, in an existing system information block (SIB) or in a new SIB proposed solely for CIoT device 104. In some embodiments, the parameters H and T are determined at the central network controller (not shown).

**[0038]** In some embodiments, the parameters H and T can be adaptable over time, e.g., the network may update these parameters over time based on a desired communication strategy. In particular, increasing the H and T parameters provide more protection against the instantaneous channel variations, but at the expense of either a loss in the spectral efficiency or the transmission reliability. To improve the system flexibility, in some embodiments, the network may configure separate sets of H and T parameters for lower-to-higher and higher-to-lower class changes. In one aspect, lower coverage class means devices in this class have lower channel quality and might need higher numbers of repetitions than their upper classes. Similarly, higher coverage class means that the devices have better channel quality and might need a lower number of repetitions compared to their lower classes. Having separate T parameters (i.e.,  $T_{L-H}$  and  $T_{H-L}$ ) and hysteresis parameters (i.e.,  $H_{L-H}$  and  $H_{H-L}$ ) for different coverage class update directions, i.e., the lower-to-higher and higher-to-lower class, may provide several advantages. For example, shorter time-to-trigger ( $T_{H-L}$ ) for higher-to-lower coverage class update is desirable to make sure that the device shifts to its new coverage class as soon as possible when channel quality degrades. This is because the device might need a higher number of signal repetitions compared to the current higher coverage class and thus might experience a high probability of error if the transition time is larger.

**[0039]** In order to initiate the coverage class update signaling procedure, in some embodiments, two triggering events, say events D1 and D2 are defined based on the H and T parameters. A first triggering event, for example, the event D1, is triggered when a measured channel quality of the CloT device is in a higher coverage class than the current coverage class of the CloT device and is defined by the equation below:

$$\text{CQI} - H_{L-H} > \text{Class X-Threshold} \quad (1)$$

where, for example, CQI is the measured channel quality of the CloT device 104 expressed in dB,  $H_{L-H}$  is the hysteresis value expressed in dB and Class X-Threshold is the coverage class threshold of a coverage class X of the CloT device 104, expressed in the same unit as CQI. If the condition in equation (1) holds true for a duration larger than the value of the parameter  $T_{L-H}$ , and the CloT device 104 is in a coverage class lower than Class X, the coverage class update signaling procedure is initiated. In this embodiment, the coverage class update signaling procedure is initiated to upgrade the current coverage class of CloT device 104 to the coverage class X. During DL data transfer 108 from the eNodeB 102 to the CloT device 104, the determination whether the event D1 is triggered is determined at the CloT device 104 and the CloT device 104 initiates the coverage class update signaling to the eNodeB 102. In contrast, during UL data transfer 106 from the CloT device 104 to the eNodeB 102, the determination whether the event D1 is triggered is determined at the eNodeB 102 and the eNodeB 102 initiates the coverage class update signaling to the eNodeB 102. On the other hand, if the equation (1) is not satisfied or is satisfied only within the duration  $T_{L-H}$  but not for a duration that exceeds this timeframe, the timer is reset and the coverage class update signaling procedure is not initiated.

**[0040]** A second triggering event, for example, the event D2, is defined by the equation below:

$$\text{CQI} + H_{H-L} < \text{Class X-Threshold} \quad (2)$$

where, for example, CQI is the measured channel quality of the CloT device 104 expressed in dB,  $H_{H-L}$  is the hysteresis value expressed in dB and Class X-Threshold is the coverage class threshold of a coverage class X of the CloT device 104, expressed in the same unit as CQI. If the condition in equation (2) holds true for a duration larger

than the value of the parameter  $T_{H-L}$ , and the CloT device 104 is in a coverage class higher than or equal to Class X, the coverage class update signaling procedure is initiated. In this embodiment, the coverage class update signaling procedure is initiated to downgrade the current coverage class of CloT device 104 to the coverage class X-1. During DL data transfer 108 from the eNodeB 102 to the CloT device 104, the determination whether the event D2 is triggered is determined at the CloT device 104 and the CloT device 104 initiates the coverage class update signaling to the eNodeB 102. In contrast, during UL data transfer 106 from the CloT device 104 to the eNodeB 102, the determination whether the event D2 is triggered is determined at the eNodeB 102 and the eNodeB 102 initiates the coverage class update signaling to the eNodeB 102. On the other hand, if the equation (2) is not satisfied or is only satisfied within the duration  $T_{H-L}$  but not for a duration that exceeds this timeframe, the timer is reset and the coverage class update signaling procedure is not initiated.

**[0041]** Fig. 2a and Fig. 2b depict a graphical representation of the dynamic coverage class selection method, based on the equations (1) and (2) respectively. The graphs 200 and 250 are described herein with respect to the CloT system 100 in Fig. 1. In Fig. 2a, 202 represents the measured CQI of the CloT device 104, 204 represents the class-X threshold, 210 represents the current coverage class of the CloT device 104,  $H_{L-H}$  206 represents the hysteresis value parameter for the lower-to-higher coverage class change and  $T_{L-H}$  208 represents the time duration parameter for the lower-to-higher coverage class change. In Fig. 2a, it can be seen that the measured CQI 202 of the CloT device 104 exceeds the class-X threshold 204 by a hysteresis value greater than  $H_{L-H}$  206 from a time 212 satisfying equation (1). Further, it can be seen that the condition in equation (1) is satisfied for a time duration greater than  $T_{L-H}$  208. Since the current coverage class 210 of the CloT device 104 is lower than class X, a coverage class update signaling procedure to upgrade the current coverage class 210 to the coverage class X is initiated once the time duration  $T_{L-H}$  208 is reached at time 211.

**[0042]** Similarly, in Fig. 2b, 252 represents the measured CQI of the CloT device 104, 254 represents the class-X threshold, 260 represents the current coverage class of the CloT device 104,  $H_{H-L}$  256 represents the hysteresis value parameter for the higher-to-lower coverage class change and  $T_{H-L}$  258 represents the time duration parameter for the higher-to-lower coverage class change. In Fig. 2b, it can be seen that the measured

CQI 252 of the CloT device 104 falls below the class-X threshold 254 by a hysteresis value greater than  $H_{H-L}$  256 from a time 261 satisfying equation (2). Further, it can be seen that the condition in equation (2) is satisfied for a time duration greater than  $T_{H-L}$  258. Since the current coverage class 260 of the CloT device 104 is equal to class X, a coverage class update signaling procedure to downgrade the current coverage class 260 to the coverage class X-1 is initiated once the time duration  $T_{H-L}$  258 is reached at time 262.

**[0043]** Fig. 3 shows an example implementation of a cellular internet of things (CloT) system 300, operable to perform dynamic coverage class selection of a CloT device 304 during downlink (DL) data transfer, according to one embodiment of the disclosure. The CloT system 300 is similar to the CloT system 100 in Fig. 1. The CloT system 300 comprises an eNodeB 302 and the CloT device 304 associated therewith. The eNodeB 302 is configured to transmit a signal containing data 306 to the CloT device 304. The CloT device 304 is configured to receive the data containing signal from the eNodeB 302 and is configured to determine a quality indicator, for example, CQI of the data containing signal, indicative of a channel quality of the CloT device 304.

**[0044]** The CloT device 304 is further configured to selectively initiate a coverage class update signaling procedure, based on evaluating equations (1) and (2) within the CloT device 304, in accordance with a predetermined algorithm. For example, if either of the events D1 or D2 is triggered, the coverage class update signaling procedure is initiated. During DL data transfer, initiating the coverage class update signaling procedure comprises generating class update request 308 at the CloT device 304 that indicates a request to change a coverage class of the CloT device 304 from the current coverage class to another coverage class of the plurality of the available coverage classes of the CloT device 304. The CloT device 304 is further configured to transmit the generated class update request 308 to the eNodeB 302. Upon receiving the class update request 308, the eNodeB 302 is configured to determine an updated class information 310 comprising information on a next coverage class of the CloT device 304 from the plurality of the available coverage classes of the CloT device 304. In some embodiments, the next coverage class is determined based on the class update request 308. In some embodiments, the another coverage class indicated in the class update request 308 and the next coverage class included in the updated class information 310

are the same. However, in other embodiments, the another coverage class indicated in the class update request 308 and the next coverage class included in the updated class information 310 are different.

**[0045]** In some embodiments, the eNodeB 302 can choose to determine the next coverage class or not, based on network conditions such as resource availability, congestion etc. For example, in some embodiments, even if the class update request is received, the eNodeB 302 may not allow the CloT device 304 to update its coverage class. Further, in other embodiments, the eNodeB 302 may change the coverage class of the CloT device 304 even without receiving the class update request from the CloT device 304. The eNodeB 302 is further configured to transmit the updated class information 310 to the CloT device 304. Upon receiving the updated class information 310, the CloT device 304 is configured to change the coverage class of the CloT device 304 from the current coverage class to the next coverage class based thereon. In some embodiments, the CloT device 304 is further configured to transmit a final coverage class 312 comprising the next coverage class to the eNodeB 302.

**[0046]** Fig. 4 shows an example implementation of a cellular internet of things (CloT) system 400, operable to perform dynamic coverage class selection of a CloT device 404 during uplink (UL) data transfer, according to one embodiment of the disclosure. The CloT system 400 is similar to the CloT system 100 in Fig. 1. The CloT system 400 comprises an eNodeB 402 and the CloT device 404 associated therewith. The CloT device 404 is configured to transmit a signal containing data 406 to the eNodeB 402. The eNodeB 402 is configured to receive the data containing signal 406 from the CloT device 404 and is configured to determine a quality indicator, for example, CQI of the data containing signal, indicative of a channel quality of the CloT device 404.

**[0047]** The eNodeB 402 is further configured to selectively initiate a coverage class update signaling procedure, based on evaluating equations (1) and (2) within the eNodeB 402, in accordance with a predetermined algorithm. For example, if either of the events D1 or D2 is triggered, the coverage class update signaling procedure is initiated. During UL data transfer, initiating the coverage class update signaling procedure comprises determining an updated class information 408 comprising information on a next coverage class of the CloT device 404 from the plurality of the

available coverage classes of the CloT device 404, within the eNodeB 402. In some embodiments, the updated class information 408 is determined based on the equations (1) and (2). In some embodiments, the eNodeB 402 can choose to determine the updated class information or not, based on network conditions such as resource availability, congestion etc. For example, in some embodiments, even if one of the events D1 or D2 is triggered, the eNodeB 402 may not allow the CloT device 404 to update its coverage class. Further, in other embodiments, the eNodeB 402 may change the coverage class of the CloT device 404 even if both the events D1 or D2 are not triggered. The eNodeB 402 is further configured to transmit the determined updated class information 408 to the CloT device 404. Upon receiving the updated class information 408, the CloT device 404 is configured to change the coverage class of the CloT device 404 from the current coverage class to the next coverage class based thereon. In some embodiments, the CloT device 404 is further configured to transmit a final coverage class 410 comprising the next coverage class to the eNodeB 402.

**[0048]** Fig. 5 depicts a flowchart 500 for implementing the predetermined algorithm on the triggering events D1 and D2 given in equations (1) - (2), for enabling dynamic coverage class selection in CloT systems, according to one embodiment of the disclosure. The algorithm herein is described with reference to the CloT system 100 of Fig. 1. However, in other embodiments, this algorithm could be applied for other CloT systems comprising two or more CloT devices. During downlink (DL) data transfer, the predetermined algorithm is implemented within an eNodeB, for example, the eNodeB 102 of Fig. 1 and during uplink (UL) data transfer, the predetermined algorithm is implemented within a CloT device, for example, the CloT device 104 of Fig. 1. At 502, a channel quality between the eNodeB 102 and the CloT device 104 is determined. At 504, a determination is made whether the event D1 according to equation (1) is triggered and the condition is satisfied for a time  $T_{L-H}$ . If No, the algorithm proceeds to 510, where a determination is made whether the event D2 is triggered. If yes at 504, the algorithm proceeds to 506, where a determination is made whether the current coverage class of the CloT device 104 is lower than the Class X utilized in equation (1). If yes, the method proceeds to 508, where the coverage class signaling procedure is initiated. If No at 506, the method proceeds to 502 where a channel quality between the eNodeB 102 and the CloT device 104 is determined again. At 510, a determination whether the event D2 according to equation (2) is triggered and the condition is satisfied

for a time  $T_{H-L}$ . If No, the algorithm proceeds to 502, where a channel quality between the eNodeB 102 and the CloT device 104 is determined again. If yes at 510, the algorithm proceeds to 512, where a determination is made whether the current coverage class of the CloT device 104 is equal to or greater than the Class X utilized in equation (2). If yes, the method proceeds to 514, where the coverage class signaling procedure is initiated. If No at 512, the method proceeds to 502 where a channel quality between the eNodeB 102 and the CloT device 104 is determined again. The algorithm above is one non-limiting example of the method for implementing the predetermined algorithm in the CloT system 100 of Fig. 1. In other embodiments, different ways of implementing the algorithm is contemplated.

**[0049]** Fig. 6 illustrates a block diagram of an apparatus 600 for use in an Evolved NodeB (eNodeB) in a cellular IoT system comprising a CloT device, that facilitates dynamic coverage class selection of the CloT device, according to various embodiments described herein. The eNodeB is described herein with reference to the eNodeB 102 in the CloT system 100 in Fig. 1 comprising the eNodeB 102 and a CloT device 104. However, in other embodiments, the CloT system can comprise a plurality of CloT devices associated with an eNodeB. In some embodiments, the apparatus 600 could be included within the eNodeB 102 in Fig. 1. The apparatus 600 can include a transmitter circuit 610, a receiver circuit 620 and a processing circuit 630. Each of the receiver circuit 620 and the transmitter circuit 610 are configured to be coupled to one or more antennas, which can be the same or different antenna(s). Further, in some embodiments, the apparatus comprises a memory circuit 640 coupled to the processor 630. In some embodiments, the receiver circuit 620 and the transmitter circuit 610 can have one or more components in common, and both can be included within a transceiver circuit, while in other aspects they are not. In various embodiments, the apparatus 200 can be included within an Evolved Universal Terrestrial Radio Access Network (E-UTRAN) Node B (Evolved NodeB, eNodeB, or eNB).

**[0050]** The apparatus 600 within the eNodeB 102 is configured to perform different functions during DL data transfer and UL data transfer. During DL data transfer (e.g., Fig. 3), the transmit circuit 610 is configured to transmit a signal (e.g., signal 306) containing data to the CloT device 104 in the coverage area of the eNodeB 102. The receive circuit 620 is configured to receive a class update request (e.g., signal

308) from the CloT device 104, wherein the class update request is generated based on the signal transmitted to the CloT device 104 from the transmit circuit 610 of the eNodeB 102. In some embodiments, the class update request indicates a request to change a coverage class of the CloT device 104 from a current coverage class to another coverage class of a plurality of the available coverage classes of the CloT device 104.

**[0051]** In some embodiments, the memory circuit 640 is configured to store system parameters associated with the CloT device 104 in the coverage area of the eNodeB 102. In some embodiments, the system parameters comprise information on the plurality of available coverage classes of the CloT device 104, coverage class thresholds of the plurality of available coverage classes of the CloT device 104, the current coverage class of the CloT device 104 and channel parameters, for example, H and T parameters associated with a channel quality between the eNodeB 102 and the CloT device 104. The processing circuit 630 is configured to determine a next coverage class of the CloT device 104 from the plurality of the available coverage classes of the CloT device 104 based on the class update request received at the receive circuit 620 and the system parameters of the CloT device 104 stored in the memory circuit 640. The transmit circuit 610 within the apparatus 600 is further configured to transmit an updated class information (e.g., signal 310) comprising information on the next coverage class of the CloT device 104 to the CloT device 104. In some embodiments, the transmit circuit 610 is further configured to transmit the stored system parameters including the channel parameters to the CloT device 104.

**[0052]** During UL data transfer (e.g., Fig. 4), the receive circuit 620 is configured to receive a signal containing data (e.g., signal 406) from the CloT device 104 in the coverage area of the eNodeB 102. The memory circuit 640 is configured to store system parameters associated with the CloT device (e.g., CloT device 104 in Fig. 1) in the coverage area of the eNodeB (e.g., eNodeB 102 in Fig. 1). In some embodiments, the system parameters stored within the memory circuit 640 are the same for both DL and UL data transfer. The processing circuit 630 is configured to determine a quality indicator of the data containing signal received by the receive circuit 620, and is configured to selectively determine an updated class information comprising a next coverage class of the CloT device 104 from the plurality of the available coverage

classes of the CloT device 104, based on the determined quality indicator of the data containing signal and the stored system parameters within the memory circuit 640. In some embodiments, the updated class information is determined in accordance with the predetermined algorithm in Fig. 5.

**[0053]** The transmit circuit 610 in Fig. 6 is further configured to transmit the updated class information (e.g., signal 408) to the CloT device 104. In some embodiments, the updated class information is transmitted from the transmit circuit 610 using radio resource control (RRC) message having the coverage class information as an information element (IE). Alternately, in other embodiments, the updated class information is transmitted from the transmit circuit 610 using MAC control element (MAC CE). In some embodiments, the transmit circuit 610 is further configured to transmit the stored system parameters including the channel parameters to the CloT device 104.

**[0054]** Fig. 7 illustrates a block diagram of an apparatus 700 for use in a CloT device in a cellular IoT system comprising an eNodeB, that facilitates dynamic coverage class selection of the CloT device, according to various embodiments described herein. The CloT device is described herein with reference to the CloT device 104 in the CloT system 100 in Fig. 1 comprising an eNodeB 102 and the CloT device 104. However, in other embodiments, the CloT system can comprise a plurality of CloT devices associated with an eNodeB. In some embodiments, the apparatus 700 is included within the CloT device 104 in Fig. 1. The apparatus 700 includes a receiver circuit 710, a processor 730, and a transmitter circuit 720. Further, in some embodiments, the apparatus 700 comprises a memory circuit 740 coupled to the processing circuit 730. Each of the receiver circuit 710 and the transmitter circuit 720 are configured to be coupled to one or more antennas, which can be the same or different antenna(s). In some embodiments, the receiver circuit 710 and transmitter circuit 720 can have one or more components in common, and both can be included within a transceiver circuit, while in other aspects they are not. In various embodiments, the apparatus 700 can be included within a UE, for example, with apparatus 700 (or portions thereof) within a receiver and transmitter or a transceiver circuit of a UE.

**[0055]** The apparatus 700 within the CloT device 104 is configured to perform different functions during DL data transfer and UL data transfer. During DL data transfer (e.g., Fig. 3), the receive circuit 710 is configured to receive a signal containing

data (e.g., signal 306) from the eNodeB 102 associated therewith. The memory circuit 740 is configured to store system parameters associated with the CloT device (e.g., CloT device 104 in Fig. 1). In some embodiments, the system parameters are determined within the eNodeB 102, however, in other embodiments, the system parameters are determined within a central network controller (not shown). In some embodiments, the system parameters comprise information on the plurality of available coverage classes of the CloT device 104, coverage class thresholds of the plurality of available coverage classes of the CloT device 104, the current coverage class of the CloT device 104 and channel parameters, for example, H and T parameters associated with a channel quality between the eNodeB 102 and the CloT device 104. In some embodiments, the receive circuit 710 is further configured to receive the system parameters from the eNodeB 102.

**[0056]** The processing circuit 730 is configured to determine a quality indicator of the data containing signal received by the receive circuit 710, and is configured to selectively generate a class update request (e.g., signal 308) based on the determined quality indicator of the signal and the stored system parameters in the memory circuit 740. In some embodiments, the class update request is generated in accordance with the predetermined algorithm in Fig. 5. In some embodiments, the class update request indicates a request to change a coverage class of the CloT device 104 from the current coverage class to another coverage class of the plurality of the available coverage classes of the CloT device 104.

**[0057]** The transmit circuit 720 is configured to transmit the generated class update request to the eNodeB 102. In some embodiments, the class update request is transmitted from the transmit circuit 720 using radio resource control (RRC) message having the coverage class information as an information element (IE). Alternately, in other embodiments, the class update request is transmitted from the transmit circuit 720 using MAC control element (MAC CE). The receive circuit 710 is further configured to receive an updated class information (e.g., signal 310) from the eNodeB 102 in response to the transmitted class update request to the eNodeB 104. In some embodiments, the updated class information comprises information on a next coverage class for the CloT device 104. The processing circuit 730 is further configured to change the coverage class of the CloT device 104 from the current coverage class to

the next coverage class based on the received updated class information from the eNodeB 102.

**[0058]** During UL data transfer (Fig. 4), the transmit circuit 720 is configured to transmit a signal containing data (e.g., signal 406) to the eNodeB 102 associated therewith. The receive circuit 710 is configured to receive an updated class information from the eNodeB 102, wherein the updated class information (e.g., signal 408) is determined at the eNodeB 102 based on the data containing signal transmitted from the transmit circuit 720. In some embodiments, the updated class information comprises information on a next coverage class for the CloT device 104. The memory circuit 740 is configured to store system parameters associated with the CloT device 104. In some embodiments, the system parameters stored within the memory circuit 740 is the same for the UL data transfer and the DL data transfer. The processing circuit 730 is configured to change the current coverage class of the CloT device 104 to the next coverage class based on the received updated class information from the eNodeB 102.

**[0059]** Fig. 8 illustrates a flow chart of a method 800 that facilitates dynamic coverage class selection of a CloT device in an Evolved NodeB (eNodeB) of a cellular IoT system comprising a CloT device, during downlink (DL) data transfer from the eNodeB to the CloT device, according to one embodiment of the disclosure. The method 800 is described herein with reference to the apparatus 600 in Fig. 6. At 802, system parameters associated with the CloT device in the coverage area of the eNodeB are stored in the memory circuit 640 of the eNodeB. At 804, a signal containing data and the stored system parameters are transmitted from the transmit circuit 610 of the eNodeB to the CloT device. At 806, a class update request is received at the receive circuit 620 from the CloT device, in response to the data containing signal. At 808, a next coverage class of the CloT device is determined at the processing circuit 630 based on the class update request received from the CloT device and the stored system parameters. At 810, an updated class information comprising information on the determined next coverage class for the CloT device is transmitted from the transmit circuit 610 to the CloT device.

**[0060]** Fig. 9 illustrates a flow chart of a method 900 that facilitates dynamic coverage class selection of a CloT device in an Evolved NodeB (eNodeB) of a cellular IoT system comprising a CloT device, during uplink (UL) data transfer from the CloT

device to the eNodeB, according to one embodiment of the disclosure. The method 900 is described herein with reference to the apparatus 600 in Fig. 6. At 902, system parameters associated with the CloT device in the coverage area of the eNodeB is stored in the memory circuit 640 of the eNodeB. At 904, a signal containing data is received at the receive circuit 620 from the CloT device. At 906, a quality indicator of the data containing signal received from the CloT device is determined at the processing circuit 630. At 908, an updated class information comprising a next coverage class of the CloT device is selectively determined at the processing circuit 630, based on the determined quality indicator of the signal and the stored system parameters in accordance with a predetermined algorithm. At 910, the updated class information is transmitted from the transmit circuit 610 to the CloT device.

**[0061]** Fig. 10 illustrates a flow chart of a method 1000 that facilitates dynamic coverage class selection in a cellular internet of things (CloT) device of a cellular IoT system comprising an eNodeB, during downlink (DL) data transfer from the eNodeB to the CloT device, according to one embodiment of the disclosure. The method 1000 is described herein with reference to the apparatus 700 in Fig. 7. At 1002, system parameters associated with the CloT device is received and stored in the memory circuit 740 of the CloT device. At 1004, a signal containing data is received at the receive circuit 710 from the eNodeB. At 1006, a quality indicator of the data containing signal received from the eNodeB is determined at the processing circuit 730. At 1008, the class update request that indicates a request to change a coverage class of the CloT device from the current coverage class to another coverage class is selectively generated at the processing circuit 730, based on the determined quality indicator of the signal and the stored system parameters in accordance with a predetermined algorithm. At 1010, the generated class update request is transmitted from the transmit circuit 720 to the eNodeB. At 1012, an updated class information comprising information on a next coverage class for the CloT device is received at the receive circuit 710 from the eNodeB in response to the transmitted class update request. At 1014, the coverage class of the CloT device is changed from the current coverage class to the next coverage class at the processing circuit 730 based on the received updated class information from the eNodeB.

**[0062]** Fig. 11 illustrates a flow chart of a method 1100 that facilitates dynamic coverage class selection in a cellular internet of things (CIoT) device of a cellular IoT system comprising an eNodeB, during uplink (UL) data transfer from the CIoT device to the eNodeB, according to one embodiment of the disclosure. The method 1100 is described herein with reference to the apparatus 700 in Fig. 7. At 1102, system parameters associated with the CIoT device is received and stored in the memory circuit 740 of the CIoT device. At 1104, a signal containing data is transmitted from the transmit circuit 720 to the eNodeB. At 1106, an updated class information comprising information on a next coverage class for the CIoT device is received at the receive circuit 710, in response to the transmitted signal. At 1108, the current coverage class of the CIoT device is changed to the next coverage class at the processing circuit 730 based on the received updated class information.

**[0063]** While the methods are illustrated and described above as a series of acts or events, it will be appreciated that the illustrated ordering of such acts or events are not to be interpreted in a limiting sense. For example, some acts may occur in different orders and/or concurrently with other acts or events apart from those illustrated and/or described herein. In addition, not all illustrated acts may be required to implement one or more aspects or embodiments of the disclosure herein. Also, one or more of the acts depicted herein may be carried out in one or more separate acts and/or phases.

**[0064]** Fig. 12a depicts a MAC control element (CE) used for signaling a new coverage class (CC) information from an eNodeB to a user equipment (UE). The CC bits in the field 1215 in the data field 1210 indicates the new selected coverage class. For example, 000 = CC1, 001 = CC2,...101 = CC6 etc. Further, the table 1250 in Fig. 12b depicts the reserved downlink shared channel (DL-SCH) logical channel ID (LCID) for the proposed coverage class signaling using a MAC CE. For example, the rows 1252 and 1254 indicates the LCID values reserved for device class update.

**[0065]** Fig. 13a depicts a MAC control element (CE) used for signaling a new coverage class (CC) information from a user equipment (UE) to an eNodeB. The CC bits in the field 1315 in the data field 1310 indicates the new selected coverage class. For example, 000 = CC1, 001 = CC2,...101 = CC6 etc. Further, the table 1350 in Fig. 13b depicts the reserved downlink shared channel (DL-SCH) logical channel ID (LCID)

for the proposed coverage class signaling using a MAC CE. For example, the rows 1352 and 1354 indicates the LCID values reserved for device class update.

**[0066]** Embodiments described herein may be implemented into a system using any suitably configured hardware and/or software. Fig. 14 illustrates, for one embodiment, example components of a User Equipment (UE) device 1400. In some embodiments, the UE device 1400 may include application circuitry 1402, baseband circuitry 1404, Radio Frequency (RF) circuitry 1406, front-end module (FEM) circuitry 1408 and one or more antennas 1410, coupled together at least as shown.

**[0067]** The application circuitry 1402 may include one or more application processors. For example, the application circuitry 1402 may include circuitry such as, but not limited to, one or more single-core or multi-core processors. The processor(s) may include any combination of general-purpose processors and dedicated processors (e.g., graphics processors, application processors, etc.). The processors may be coupled with and/or may include memory/storage and may be configured to execute instructions stored in the memory/storage to enable various applications and/or operating systems to run on the system.

**[0068]** The baseband circuitry 1404 may include circuitry such as, but not limited to, one or more single-core or multi-core processors. The baseband circuitry 1404 may include one or more baseband processors and/or control logic to process baseband signals received from a receive signal path of the RF circuitry 1406 and to generate baseband signals for a transmit signal path of the RF circuitry 1406. Baseband processing circuitry 1404 may interface with the application circuitry 1402 for generation and processing of the baseband signals and for controlling operations of the RF circuitry 1406. For example, in some embodiments, the baseband circuitry 1404 may include a second generation (2G) baseband processor 1404a, third generation (3G) baseband processor 1404b, fourth generation (4G) baseband processor 1404c, and/or other baseband processor(s) 1404d for other existing generations, generations in development or to be developed in the future (e.g., fifth generation (5G), 6G, etc.). The baseband circuitry 1404 (e.g., one or more of baseband processors 1404a-d) may handle various radio control functions that enable communication with one or more radio networks via the RF circuitry 1406. The radio control functions may include, but are not limited to, signal modulation/demodulation, encoding/decoding, radio

frequency shifting, etc. In some embodiments, modulation/demodulation circuitry of the baseband circuitry 1404 may include Fast-Fourier Transform (FFT), precoding, and/or constellation mapping/demapping functionality. In some embodiments, encoding/decoding circuitry of the baseband circuitry 1404 may include convolution, tail-biting convolution, turbo, Viterbi, and/or Low Density Parity Check (LDPC) encoder/decoder functionality. Embodiments of modulation/demodulation and encoder/decoder functionality are not limited to these examples and may include other suitable functionality in other embodiments.

**[0069]** In some embodiments, the baseband circuitry 1404 may include elements of a protocol stack such as, for example, elements of an evolved universal terrestrial radio access network (EUTRAN) protocol including, for example, physical (PHY), media access control (MAC), radio link control (RLC), packet data convergence protocol (PDCP), and/or radio resource control (RRC) elements. A central processing unit (CPU) 1404e of the baseband circuitry 1404 may be configured to run elements of the protocol stack for signaling of the PHY, MAC, RLC, PDCP and/or RRC layers. In some embodiments, the baseband circuitry may include one or more audio digital signal processor(s) (DSP) 1404f. The audio DSP(s) 1404f may include elements for compression/decompression and echo cancellation and may include other suitable processing elements in other embodiments. Components of the baseband circuitry may be suitably combined in a single chip, a single chipset, or disposed on a same circuit board in some embodiments. In some embodiments, some or all of the constituent components of the baseband circuitry 1404 and the application circuitry 1402 may be implemented together such as, for example, on a system on a chip (SOC).

**[0070]** In some embodiments, the baseband circuitry 1404 may provide for communication compatible with one or more radio technologies. For example, in some embodiments, the baseband circuitry 1404 may support communication with an evolved universal terrestrial radio access network (EUTRAN) and/or other wireless metropolitan area networks (WMAN), a wireless local area network (WLAN), a wireless personal area network (WPAN). Embodiments in which the baseband circuitry 1404 is configured to support radio communications of more than one wireless protocol may be referred to as multi-mode baseband circuitry.

**[0071]** RF circuitry 1406 may enable communication with wireless networks using modulated electromagnetic radiation through a non-solid medium. In various embodiments, the RF circuitry 1406 may include switches, filters, amplifiers, etc. to facilitate the communication with the wireless network. RF circuitry 1406 may include a receive signal path which may include circuitry to down-convert RF signals received from the FEM circuitry 1408 and provide baseband signals to the baseband circuitry 1404. RF circuitry 1406 may also include a transmit signal path which may include circuitry to up-convert baseband signals provided by the baseband circuitry 1404 and provide RF output signals to the FEM circuitry 1408 for transmission.

**[0072]** In some embodiments, the RF circuitry 1406 may include a receive signal path and a transmit signal path. The receive signal path of the RF circuitry 1406 may include mixer circuitry 1406a, amplifier circuitry 1406b and filter circuitry 1406c. The transmit signal path of the RF circuitry 1406 may include filter circuitry 1406c and mixer circuitry 1406a. RF circuitry 1406 may also include synthesizer circuitry 1406d for synthesizing a frequency for use by the mixer circuitry 1406a of the receive signal path and the transmit signal path. In some embodiments, the mixer circuitry 1406a of the receive signal path may be configured to down-convert RF signals received from the FEM circuitry 1408 based on the synthesized frequency provided by synthesizer circuitry 1406d. The amplifier circuitry 1406b may be configured to amplify the down-converted signals and the filter circuitry 1406c may be a low-pass filter (LPF) or band-pass filter (BPF) configured to remove unwanted signals from the down-converted signals to generate output baseband signals. Output baseband signals may be provided to the baseband circuitry 1404 for further processing. In some embodiments, the output baseband signals may be zero-frequency baseband signals, although this is not a requirement. In some embodiments, mixer circuitry 1406a of the receive signal path may comprise passive mixers, although the scope of the embodiments is not limited in this respect.

**[0073]** In some embodiments, the mixer circuitry 1406a of the transmit signal path may be configured to up-convert input baseband signals based on the synthesized frequency provided by the synthesizer circuitry 1406d to generate RF output signals for the FEM circuitry 1408. The baseband signals may be provided by the baseband circuitry 1404 and may be filtered by filter circuitry 1406c. The filter circuitry 1406c may

include a low-pass filter (LPF), although the scope of the embodiments is not limited in this respect.

**[0074]** In some embodiments, the mixer circuitry 1406a of the receive signal path and the mixer circuitry 1406a of the transmit signal path may include two or more mixers and may be arranged for quadrature downconversion and/or upconversion respectively. In some embodiments, the mixer circuitry 1406a of the receive signal path and the mixer circuitry 1406a of the transmit signal path may include two or more mixers and may be arranged for image rejection (e.g., Hartley image rejection). In some embodiments, the mixer circuitry 1406a of the receive signal path and the mixer circuitry 1406a may be arranged for direct downconversion and/or direct upconversion, respectively. In some embodiments, the mixer circuitry 1406a of the receive signal path and the mixer circuitry 1406a of the transmit signal path may be configured for super-heterodyne operation.

**[0075]** In some embodiments, the output baseband signals and the input baseband signals may be analog baseband signals, although the scope of the embodiments is not limited in this respect. In some alternate embodiments, the output baseband signals and the input baseband signals may be digital baseband signals. In these alternate embodiments, the RF circuitry 1406 may include analog-to-digital converter (ADC) and digital-to-analog converter (DAC) circuitry and the baseband circuitry 1404 may include a digital baseband interface to communicate with the RF circuitry 1406.

**[0076]** In some dual-mode embodiments, a separate radio IC circuitry may be provided for processing signals for each spectrum, although the scope of the embodiments is not limited in this respect.

**[0077]** In some embodiments, the synthesizer circuitry 1406d may be a fractional-N synthesizer or a fractional  $N/N+1$  synthesizer, although the scope of the embodiments is not limited in this respect as other types of frequency synthesizers may be suitable. For example, synthesizer circuitry 1406d may be a delta-sigma synthesizer, a frequency multiplier, or a synthesizer comprising a phase-locked loop with a frequency divider.

**[0078]** The synthesizer circuitry 1406d may be configured to synthesize an output frequency for use by the mixer circuitry 1406a of the RF circuitry 1406 based on a

frequency input and a divider control input. In some embodiments, the synthesizer circuitry 1406d may be a fractional  $N/N+1$  synthesizer.

**[0079]** In some embodiments, frequency input may be provided by a voltage controlled oscillator (VCO), although that is not a requirement. Divider control input may be provided by either the baseband circuitry 1404 or the applications processor 1402 depending on the desired output frequency. In some embodiments, a divider control input (e.g.,  $N$ ) may be determined from a look-up table based on a channel indicated by the applications processor 1402.

**[0080]** Synthesizer circuitry 1406d of the RF circuitry 1406 may include a divider, a delay-locked loop (DLL), a multiplexer and a phase accumulator. In some embodiments, the divider may be a dual modulus divider (DMD) and the phase accumulator may be a digital phase accumulator (DPA). In some embodiments, the DMD may be configured to divide the input signal by either  $N$  or  $N+1$  (e.g., based on a carry out) to provide a fractional division ratio. In some example embodiments, the DLL may include a set of cascaded, tunable, delay elements, a phase detector, a charge pump and a D-type flip-flop. In these embodiments, the delay elements may be configured to break a VCO period up into  $N_d$  equal packets of phase, where  $N_d$  is the number of delay elements in the delay line. In this way, the DLL provides negative feedback to help ensure that the total delay through the delay line is one VCO cycle.

**[0081]** In some embodiments, synthesizer circuitry 1406d may be configured to generate a carrier frequency as the output frequency, while in other embodiments, the output frequency may be a multiple of the carrier frequency (e.g., twice the carrier frequency, four times the carrier frequency) and used in conjunction with quadrature generator and divider circuitry to generate multiple signals at the carrier frequency with multiple different phases with respect to each other. In some embodiments, the output frequency may be a LO frequency ( $f_{LO}$ ). In some embodiments, the RF circuitry 1406 may include an IQ/polar converter.

**[0082]** FEM circuitry 1408 may include a receive signal path which may include circuitry configured to operate on RF signals received from one or more antennas 1410, amplify the received signals and provide the amplified versions of the received signals to the RF circuitry 1406 for further processing. FEM circuitry 1408 may also include a

transmit signal path which may include circuitry configured to amplify signals for transmission provided by the RF circuitry 1406 for transmission by one or more of the one or more antennas 1410.

**[0083]** In some embodiments, the FEM circuitry 1408 may include a TX/RX switch to switch between transmit mode and receive mode operation. The FEM circuitry may include a receive signal path and a transmit signal path. The receive signal path of the FEM circuitry may include a low-noise amplifier (LNA) to amplify received RF signals and provide the amplified received RF signals as an output (e.g., to the RF circuitry 1406). The transmit signal path of the FEM circuitry 1408 may include a power amplifier (PA) to amplify input RF signals (e.g., provided by RF circuitry 1406), and one or more filters to generate RF signals for subsequent transmission (e.g., by one or more of the one or more antennas 1410).

**[0084]** In some embodiments, the UE device 1400 may include additional elements such as, for example, memory/storage, display, camera, sensor, and/or input/output (I/O) interface.

**[0085]** While the apparatus has been illustrated and described with respect to one or more implementations, alterations and/or modifications may be made to the illustrated examples without departing from the spirit and scope of the appended claims. In particular regard to the various functions performed by the above described components or structures (assemblies, devices, circuits, systems, etc.), the terms (including a reference to a "means") used to describe such components are intended to correspond, unless otherwise indicated, to any component or structure which performs the specified function of the described component (e.g., that is functionally equivalent), even though not structurally equivalent to the disclosed structure which performs the function in the herein illustrated exemplary implementations of the invention.

**[0086]** Examples can include subject matter such as a method, means for performing acts or blocks of the method, at least one machine-readable medium including instructions that, when performed by a machine cause the machine to perform acts of the method or of an apparatus or system for concurrent communication using multiple communication technologies according to embodiments and examples described herein.

**[0087]** Example 1 is an apparatus for use in an eNodeB of a cellular internet of things (CIoT) system comprising a user equipment (UE), in association with a downlink (DL) data transfer, comprising a memory circuit configured to store system parameters associated with the UE in a coverage area of the eNodeB, wherein the system parameters comprise information on a plurality of available coverage classes of the UE, coverage class thresholds of the plurality of available coverage classes of the UE, a current coverage class of the UE and channel parameters associated with a channel quality between the eNodeB and the UE; a processor circuit configured to provide a signal containing data to a transmit circuit for subsequent transmission to the UE comprising the DL data transfer, receive a class update request from the UE via a receive circuit, wherein the class update request is generated based on the signal transmitted to the UE from the transmit circuit of the eNodeB and wherein the class update request indicates a request to change a coverage class of the UE from the current coverage class to another coverage class of the plurality of the available coverage classes of the UE; determine a next coverage class of the UE from the plurality of the available coverage classes of the UE based on the class update request from the UE and the stored system parameters of the UE; and provide an updated class information to the transmit circuit for subsequent transmission to the UE, wherein the updated class information comprises information on the determined next coverage class for the UE.

**[0088]** Example 2 is an apparatus including the subject matter of example 1, wherein the processing circuit is further configured to provide the channel parameters to the transmit circuit for subsequent transmission to the UE.

**[0089]** Example 3 is an apparatus including the subject matter of examples 1-2, including or omitting elements, wherein the channel parameters stored within the memory circuit comprises, a hysteresis parameter comprising a hysteresis value (H) by which the channel quality between the UE and the eNodeB exceeds or falls below a coverage class threshold of the plurality of coverage class thresholds of the UE to generate the class update request at the UE, and a time parameter comprising a time duration (T) for which the channel quality between the UE and the eNodeB exceeds or falls below the coverage class threshold by the hysteresis value before generating the class update request at the UE.

**[0090]** Example 4 is an apparatus including the subject matter of examples 1-3, including or omitting elements, wherein the channel parameters are transmitted to the UE using system information block (SIB).

**[0091]** Example 5 is an apparatus including the subject matter of examples 1-4, including or omitting elements, wherein the updated class information is determined based on the class update request from the UE and other system conditions.

**[0092]** Example 6 is an apparatus including the subject matter of examples 1-5, including or omitting elements, wherein the updated class information is transmitted from the transmit circuit using radio resource control (RRC) message.

**[0093]** Example 7 is an apparatus including the subject matter of examples 1-6, including or omitting elements, wherein the updated class information is transmitted from the transmit circuit using MAC control element (MAC CE).

**[0094]** Example 8 is an apparatus for use in an eNodeB of a cellular internet of things (CIoT) system comprising a UE, in association with an uplink (UL) data transfer, comprising a memory circuit configured to store system parameters associated with the user equipment (UE) in a coverage area of the eNodeB, wherein the system parameters comprise information on a plurality of available coverage classes of the UE, coverage class thresholds of the plurality of available coverage classes of the UE, a current coverage class of the UE and predetermined parameters associated with a channel quality between the eNodeB and the UE; a processing circuit configured to receive a signal containing data from the UE via a receive circuit comprising the UL data transfer; determine a quality indicator of the data containing signal received via the receive circuit, and selectively determine an updated class information comprising a next coverage class of the UE from the plurality of the available coverage classes of the UE, based on the determined quality indicator of the signal and the stored system parameters; and provide the updated class information to a transmit circuit for subsequent transmission to the UE.

**[0095]** Example 9 is an apparatus including the subject matter of example 8, wherein the updated class information is determined in accordance with a predetermined algorithm.

**[0096]** Example 10 is an apparatus including the subject matter of examples 8-9, including or omitting elements, wherein the channel parameters stored within the memory circuit comprises a hysteresis parameter comprising a hysteresis value (H) by which the quality indicator of the data containing signal received from the UE exceeds or falls below a coverage class threshold of the plurality of coverage class thresholds of the UE to generate the updated class information at the eNodeB and a time parameter comprising a time duration (T) for which the quality indicator of the data containing signal exceeds or falls below the coverage class threshold by the hysteresis value before generating the updated class information.

**[0097]** Example 11 is an apparatus including the subject matter of examples 8-10, including or omitting elements, wherein the updated class information comprising a first coverage class of the UE is generated when the quality indicator of the data containing signal from the UE exceeds a first coverage class threshold of the first coverage class of the UE by a hysteresis value greater than H for a time duration greater than or equal to T and the current coverage class of the UE is lower than the first coverage class.

**[0098]** Example 12 is an apparatus including the subject matter of examples 8-11, including or omitting elements, wherein the updated class information comprising a first coverage class of the UE is generated when the quality indicator of the data containing signal from the UE falls below a second coverage class threshold of a second coverage class of the UE by a hysteresis value greater than H for a time duration greater than or equal to T, wherein the second coverage class of the UE is higher than the first coverage class and the current coverage class is equal to or greater than the second coverage class.

**[0099]** Example 13 is an apparatus including the subject matter of examples 8-12, including or omitting elements, wherein the updated class information is transmitted from the transmit circuit using radio resource control (RRC) message.

**[00100]** Example 14 is an apparatus including the subject matter of examples 8-13, including or omitting elements, wherein the updated class information is transmitted from the transmit circuit using MAC control element (MAC CE).

**[00101]** Example 15 is an apparatus for use in a UE of a cellular internet of things (CIoT) system comprising an eNodeB, in association with a downlink (DL) data transfer, comprising a memory circuit configured to store system parameters associated with the UE, wherein the system parameters comprise information on a plurality of available coverage classes of the UE, coverage class thresholds of the plurality of available coverage classes of the UE, a current coverage class of the UE and channel parameters associated with a channel quality between the UE and the eNodeB; a processing circuit configured to receive a signal containing data from the eNodeB via a receive circuit comprising the DL data transfer; determine a quality indicator of the data containing signal received via the receive circuit, and selectively generate a class update request based on the determined quality indicator of the signal and the stored system parameters, wherein the class update request indicates a request to change a coverage class of the UE from the current coverage class to another coverage class of the plurality of the available coverage classes of the UE; provide the generated class update request to a transmit circuit for subsequent transmission to the eNodeB; receive an updated class information from the eNodeB via the receive circuit in response to the transmitted class update request, wherein the updated class information comprises information on a next coverage class for the UE; and change the coverage class of the UE from the current coverage class to the next coverage class based on the received updated class information.

**[00102]** Example 16 is an apparatus including the subject matter of example 15, wherein the updated class information is determined in accordance with a predetermined algorithm.

**[00103]** Example 17 is an apparatus including the subject matter of examples 15-16, including or omitting elements, wherein the channel parameters stored within the memory circuit comprises a hysteresis parameter comprising a hysteresis value  $H$  by which a quality indicator of the data containing signal received from the eNodeB exceeds or falls below a coverage class threshold of the UE to initiate the class update request at the UE and a time parameter comprising a time duration  $T$  for which the quality indicator of the data containing signal exceeds or falls below the coverage class threshold by the hysteresis value before initiating the class update request at the UE.

**[00104]** Example 18 is an apparatus including the subject matter of examples 15-17, including or omitting elements, wherein the class update request comprising a request to change the current coverage class of the UE to a first coverage class of the plurality of available coverage classes of the UE is generated, when the quality indicator of the data containing signal from the eNodeB exceeds a first coverage class threshold of the first coverage class of the UE by a hysteresis value greater than H for the time duration greater than or equal to T and the current coverage class of the UE is lower than the first coverage class.

**[00105]** Example 19 is an apparatus including the subject matter of examples 15-18, including or omitting elements, wherein the class update request comprising a request to change the current coverage class of the UE to a first coverage class plurality of available coverage classes of the UE is generated, when the quality indicator of the data containing signal from the eNodeB falls below a second coverage class threshold of a second coverage class of the UE by a hysteresis value greater than H for a time duration greater than or equal to T, wherein the second coverage class of the UE is higher than the first coverage class and the current coverage class is equal to or greater than the second coverage class.

**[00106]** Example 20 is an apparatus including the subject matter of examples 15-19, including or omitting elements, wherein the class update request is transmitted from the transmit circuit using radio resource control (RRC) message.

**[00107]** Example 21 is an apparatus including the subject matter of examples 15-20, including or omitting elements, wherein the class update request is transmitted from the transmit circuit using MAC control element (MAC CE).

**[00108]** Example 22 is an apparatus for use in a UE of a cellular internet of things (CIoT) system comprising an eNodeB, in association with an uplink (UL) data transfer, comprising a memory circuit configured to store system parameters associated with the UE, wherein the system parameters comprise information on a plurality of available coverage classes of the UE, coverage class thresholds of the plurality of available coverage classes of the UE, a current coverage class of the UE and channel parameters associated with a channel quality between the UE and the eNodeB; a processing circuit configured to provide a signal containing data to a transmit circuit for

subsequent transmission to the eNodeB comprising the UL data transfer; receive an updated class information from the eNodeB via a receive circuit, wherein the updated class information is determined at the eNodeB based on the signal transmitted from the UE and wherein the updated class information comprises information on a next coverage class for the UE; and change the current coverage class of the UE to the next coverage class based on the received updated class information.

**[00109]** Example 23 is an apparatus including the subject matter of example 22, wherein the processing circuit is further configured to receive the channel parameters from the eNodeB via the receive circuit.

**[00110]** Example 24 is an apparatus including the subject matter of examples 22-23, including or omitting elements, wherein the channel parameters stored within the memory circuit comprises a hysteresis parameter comprising a hysteresis value (H) by which the channel quality between the UE and the eNodeB exceeds or falls below a coverage class threshold of the plurality of coverage class thresholds of the UE to generate the updated class information at the eNodeB, and a time parameter comprising a time duration (T) for which the channel quality between the UE and the eNodeB exceeds or falls below the coverage class threshold by the hysteresis value before generating the updated class information at the eNodeB.

**[00111]** Example 25 is a computer-readable storage device storing computer-executable instructions that, in response to execution, cause an apparatus for use in an eNodeB of a cellular internet of things (CIoT) system comprising a UE, in association with an uplink (UL) data transfer to store system parameters associated with the user equipment (UE) in a coverage area of the eNodeB, wherein the system parameters comprise information on a plurality of available coverage classes of the UE, coverage class thresholds of the plurality of available coverage classes of the UE, a current coverage class of the UE and predetermined parameters associated with a channel quality between the eNodeB and the UE; receive a signal containing data from the UE comprising the UL data transfer; determine a quality indicator of the data containing signal received and selectively determine an updated class information comprising a next coverage class of the UE from the plurality of the available coverage classes of the UE, based on the determined quality indicator of the signal and the stored system parameters; and transmit the updated class information to the UE.

**[00112]** Example 26 is a computer-readable storage device including the subject matter of example 25, wherein the updated class information is determined in accordance with a predetermined algorithm.

**[00113]** Example 27 is a computer-readable storage device including the subject matter of examples 25-26, including or omitting elements, wherein the channel parameters stored comprises a hysteresis parameter comprising a hysteresis value (H) by which the quality indicator of the data containing signal received from the UE exceeds or falls below a coverage class threshold of the plurality of coverage class thresholds of the UE to generate the updated class information at the eNodeB and a time parameter comprising a time duration (T) for which the quality indicator of the data containing signal exceeds or falls below the coverage class threshold by the hysteresis value before generating the updated class information.

**[00114]** Example 28 is a computer-readable storage device including the subject matter of examples 25-27, including or omitting elements, wherein the updated class information comprising a first coverage class of the UE is generated when the quality indicator of the data containing signal from the UE exceeds a first coverage class threshold of the first coverage class of the UE by a hysteresis value greater than H for a time duration greater than or equal to T and the current coverage class of the UE is lower than the first coverage class.

**[00115]** Example 29 is a computer-readable storage device including the subject matter of examples 25-28, including or omitting elements, wherein the updated class information comprising a first coverage class of the UE is generated when the quality indicator of the data containing signal from the UE falls below a second coverage class threshold of a second coverage class of the UE by a hysteresis value greater than H for a time duration greater than or equal to T, wherein the second coverage class of the UE is higher than the first coverage class and the current coverage class is equal to or greater than the second coverage class.

**[00116]** Example 30 is a computer-readable storage device storing computer-executable instructions that, in response to execution, cause an apparatus for use in a UE of a cellular internet of things (CIoT) system comprising an eNodeB, in association with an uplink (UL) data transfer to store system parameters associated with the UE,

wherein the system parameters comprise information on a plurality of available coverage classes of the UE, coverage class thresholds of the plurality of available coverage classes of the UE, a current coverage class of the UE and channel parameters associated with a channel quality between the UE and the eNodeB; transmit a signal containing data to an eNodeB comprising the UL data transfer; receive an updated class information from the eNodeB, wherein the updated class information is determined at the eNodeB based on the signal transmitted from the UE and wherein the updated class information comprises information on a next coverage class for the UE; and change the current coverage class of the UE to the next coverage class based on the received updated class information.

**[00117]** Example 31 is a computer-readable storage device including the subject matter of example 30, further cause the apparatus to receive the channel parameters from the eNodeB.

**[00118]** Various illustrative logics, logical blocks, modules, and circuits described in connection with aspects disclosed herein can be implemented or performed with a general purpose processor, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array (FPGA) or other programmable logic device, discrete gate or transistor logic, discrete hardware components, or any combination thereof designed to perform functions described herein. A general-purpose processor can be a microprocessor, but, in the alternative, processor can be any conventional processor, controller, microcontroller, or state machine.

**[00119]** The above description of illustrated embodiments of the subject disclosure, including what is described in the Abstract, is not intended to be exhaustive or to limit the disclosed embodiments to the precise forms disclosed. While specific embodiments and examples are described herein for illustrative purposes, various modifications are possible that are considered within the scope of such embodiments and examples, as those skilled in the relevant art can recognize.

**[00120]** In this regard, while the disclosed subject matter has been described in connection with various embodiments and corresponding Figures, where applicable, it is to be understood that other similar embodiments can be used or modifications and

additions can be made to the described embodiments for performing the same, similar, alternative, or substitute function of the disclosed subject matter without deviating therefrom. Therefore, the disclosed subject matter should not be limited to any single embodiment described herein, but rather should be construed in breadth and scope in accordance with the appended claims below.

**[00121]** In particular regard to the various functions performed by the above described components (assemblies, devices, circuits, systems, *etc.*), the terms (including a reference to a "means") used to describe such components are intended to correspond, unless otherwise indicated, to any component or structure which performs the specified function of the described component (*e.g.*, that is functionally equivalent), even though not structurally equivalent to the disclosed structure which performs the function in the herein illustrated exemplary implementations of the disclosure. In addition, while a particular feature may have been disclosed with respect to only one of several implementations, such feature may be combined with one or more other features of the other implementations as may be desired and advantageous for any given or particular application.

## CLAIMS

1. An apparatus for use in an eNodeB of a cellular internet of things (CIoT) system, in association with a downlink (DL) data transfer, comprising:
  - a memory circuit configured to store system parameters associated with a user equipment (UE) in a coverage area of the eNodeB, wherein the system parameters comprise information on a plurality of available coverage classes of the UE, coverage class thresholds of the plurality of available coverage classes of the UE, a current coverage class of the UE and channel parameters associated with a channel quality between the eNodeB and the UE;
  - a processor circuit configured to,
    - provide a signal containing data to a transmit circuit for subsequent transmission to the UE comprising the DL data transfer;
    - receive a class update request from the UE via a receive circuit, wherein the class update request is generated based on the signal transmitted to the UE from the transmit circuit of the eNodeB and wherein the class update request indicates a request to change a coverage class of the UE from the current coverage class to another coverage class of the plurality of the available coverage classes of the UE;
    - determine a next coverage class of the UE from the plurality of the available coverage classes of the UE based on the class update request from the UE and the stored system parameters of the UE; and
    - provide an updated class information to the transmit circuit for subsequent transmission to the UE, wherein the updated class information comprises information on the determined next coverage class for the UE.
2. The apparatus of claim 1, wherein the processing circuit is further configured to provide the channel parameters to the transmit circuit for subsequent transmission to the UE.
3. The apparatus of any of the claims 1-2, wherein the channel parameters stored within the memory circuit comprises,

a hysteresis parameter comprising a hysteresis value (H) by which the channel quality between the UE and the eNodeB exceeds or falls below a coverage class threshold of the plurality of coverage class thresholds of the UE to generate the class update request at the UE, and

a time parameter comprising a time duration (T) for which the channel quality between the UE and the eNodeB exceeds or falls below the coverage class threshold by the hysteresis value before generating the class update request at the UE.

4. The apparatus of any of the claims 1-2, wherein the channel parameters are transmitted to the UE using system information block (SIB).
5. The apparatus of any of the claims 1-2, wherein the updated class information is determined based on the class update request from the UE and other system conditions.
6. The apparatus of any of the claims 1-2, wherein the updated class information is transmitted from the transmit circuit using radio resource control (RRC) message.
7. The apparatus of any of the claims 1-2, wherein the updated class information is transmitted from the transmit circuit using MAC control element (MAC CE).
8. An apparatus for use in an eNodeB of a cellular internet of things (CIoT) system, in association with an uplink (UL) data transfer, comprising:
  - a memory circuit configured to store system parameters associated with a user equipment (UE) in a coverage area of the eNodeB, wherein the system parameters comprise information on a plurality of available coverage classes of the UE, coverage class thresholds of the plurality of available coverage classes of the UE, a current coverage class of the UE and predetermined parameters associated with a channel quality between the eNodeB and the UE;
  - a processing circuit configured to,
    - receive a signal containing data from the UE via a receive circuit comprising the UL data transfer;

determine a quality indicator of the data containing signal received via the receive circuit, and selectively determine an updated class information comprising a next coverage class of the UE from the plurality of the available coverage classes of the UE, based on the determined quality indicator of the signal and the stored system parameters; and  
provide the updated class information to a transmit circuit for subsequent transmission to the UE.

9. The apparatus of claim 8, wherein the updated class information is determined in accordance with a predetermined algorithm.

10. The apparatus of claim 8, wherein the channel parameters stored within the memory circuit comprises a hysteresis parameter comprising a hysteresis value (H) by which the quality indicator of the data containing signal received from the UE exceeds or falls below a coverage class threshold of the plurality of coverage class thresholds of the UE to generate the updated class information at the eNodeB and a time parameter comprising a time duration (T) for which the quality indicator of the data containing signal exceeds or falls below the coverage class threshold by the hysteresis value before generating the updated class information.

11. The apparatus of claim 10, wherein the updated class information comprising a first coverage class of the UE is generated when the quality indicator of the data containing signal from the UE exceeds a first coverage class threshold of the first coverage class of the UE by a hysteresis value greater than H for a time duration greater than or equal to T and the current coverage class of the UE is lower than the first coverage class.

12. The apparatus of any of the claims 10-11, wherein the updated class information comprising a first coverage class of the UE is generated when the quality indicator of the data containing signal from the UE falls below a second coverage class threshold of a second coverage class of the UE by a hysteresis value greater than H for a time duration greater than or equal to T, wherein the second coverage class of the UE is

higher than the first coverage class and the current coverage class is equal to or greater than the second coverage class.

13. The apparatus of any of the claims 8-10, wherein the updated class information is transmitted from the transmit circuit using radio resource control (RRC) message.

14. The apparatus of any of the claims 8-10, wherein the updated class information is transmitted from the transmit circuit using MAC control element (MAC CE).

15. An apparatus for use in a UE of a cellular internet of things (CIoT) system, in association with a downlink (DL) data transfer, comprising:

a memory circuit configured to store system parameters associated with the UE, wherein the system parameters comprise information on a plurality of available coverage classes of the UE, coverage class thresholds of the plurality of available coverage classes of the UE, a current coverage class of the UE and channel parameters associated with a channel quality between the UE and an eNodeB;

a processing circuit configured to,

receive a signal containing data from the eNodeB via a receive circuit comprising the DL data transfer;

determine a quality indicator of the data containing signal received via the receive circuit, and selectively generate a class update request based on the determined quality indicator of the signal and the stored system parameters, wherein the class update request indicates a request to change a coverage class of the UE from the current coverage class to another coverage class of the plurality of the available coverage classes of the UE;

provide the generated class update request to a transmit circuit for subsequent transmission to the eNodeB;

receive an updated class information from the eNodeB via the receive circuit in response to the transmitted class update request, wherein the updated class information comprises information on a next coverage class for the UE; and

change the coverage class of the UE from the current coverage class to the next coverage class based on the received updated class information.

16. The apparatus of claim 15, wherein the updated class information is determined in accordance with a predetermined algorithm.

17. The apparatus of claim 15, wherein the channel parameters stored within the memory circuit comprises a hysteresis parameter comprising a hysteresis value H by which a quality indicator of the data containing signal received from the eNodeB exceeds or falls below a coverage class threshold of the UE to initiate the class update request at the UE and a time parameter comprising a time duration T for which the quality indicator of the data containing signal exceeds or falls below the coverage class threshold by the hysteresis value before initiating the class update request at the UE.

18. The apparatus of claim 17, wherein the class update request comprising a request to change the current coverage class of the UE to a first coverage class of the plurality of available coverage classes of the UE is generated, when the quality indicator of the data containing signal from the eNodeB exceeds a first coverage class threshold of the first coverage class of the UE by a hysteresis value greater than H for the time duration greater than or equal to T and the current coverage class of the UE is lower than the first coverage class.

19. The apparatus of any of the claims 17-18, wherein the class update request comprising a request to change the current coverage class of the UE to a first coverage class plurality of available coverage classes of the UE is generated, when the quality indicator of the data containing signal from the eNodeB falls below a second coverage class threshold of a second coverage class of the UE by a hysteresis value greater than H for a time duration greater than or equal to T, wherein the second coverage class of the UE is higher than the first coverage class and the current coverage class is equal to or greater than the second coverage class.

20. The apparatus of any of the claims 15-18, wherein the class update request is transmitted from the transmit circuit using radio resource control (RRC) message.

21. The apparatus of any of the claims 15-18, wherein the class update request is transmitted from the transmit circuit using MAC control element (MAC CE).

22. An apparatus for use in a UE of a cellular internet of things (CIoT) system, in association with an uplink (UL) data transfer, comprising:

a memory circuit configured to store system parameters associated with the UE, wherein the system parameters comprise information on a plurality of available coverage classes of the UE, coverage class thresholds of the plurality of available coverage classes of the UE, a current coverage class of the UE and channel parameters associated with a channel quality between the UE and an eNodeB;

a processing circuit configured to,

provide a signal containing data to a transmit circuit for subsequent transmission to the eNodeB comprising the UL data transfer;

receive an updated class information from the eNodeB via a receive circuit, wherein the updated class information is determined at the eNodeB based on the signal transmitted from the UE and wherein the updated class information comprises information on a next coverage class for the UE; and

change the current coverage class of the UE to the next coverage class based on the received updated class information.

23. The apparatus of claim 22, wherein the processing circuit is further configured to receive the channel parameters from the eNodeB via the receive circuit.

24. The apparatus of any of the claims 22-23, wherein the channel parameters stored within the memory circuit comprises,

a hysteresis parameter comprising a hysteresis value (H) by which the channel quality between the UE and the eNodeB exceeds or falls below a coverage class threshold of the plurality of coverage class thresholds of the UE to generate the updated class information at the eNodeB, and

a time parameter comprising a time duration (T) for which the channel quality between the UE and the eNodeB exceeds or falls below the coverage class threshold by the hysteresis value before generating the updated class information at the eNodeB.

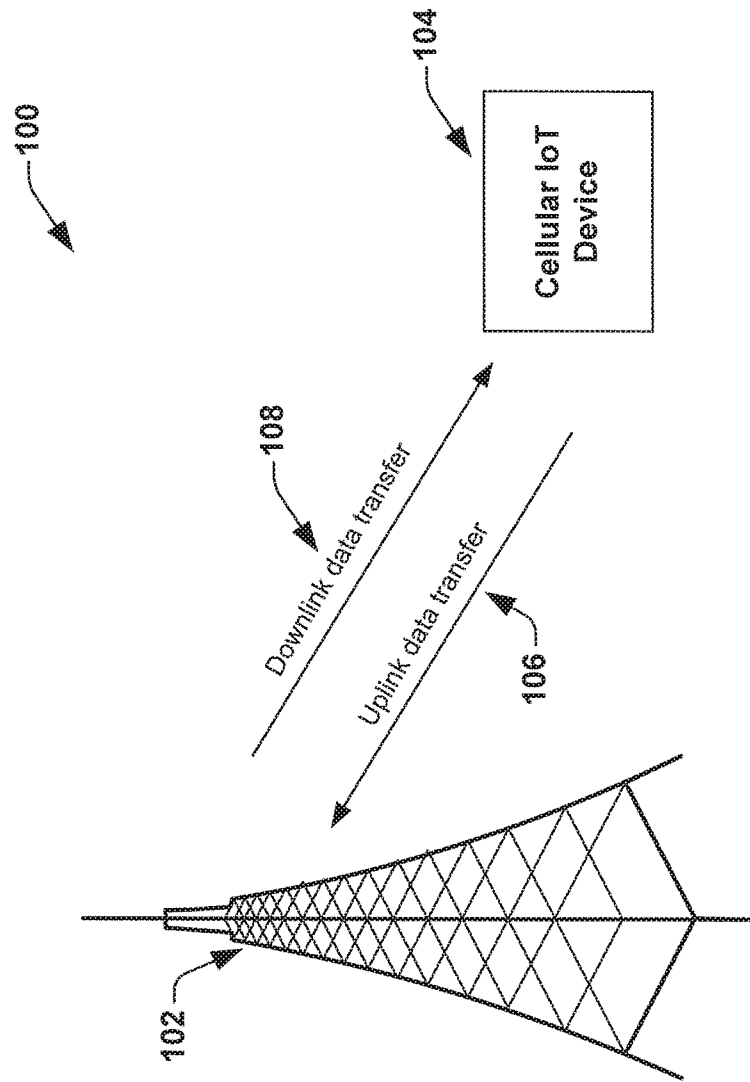


FIG. 1

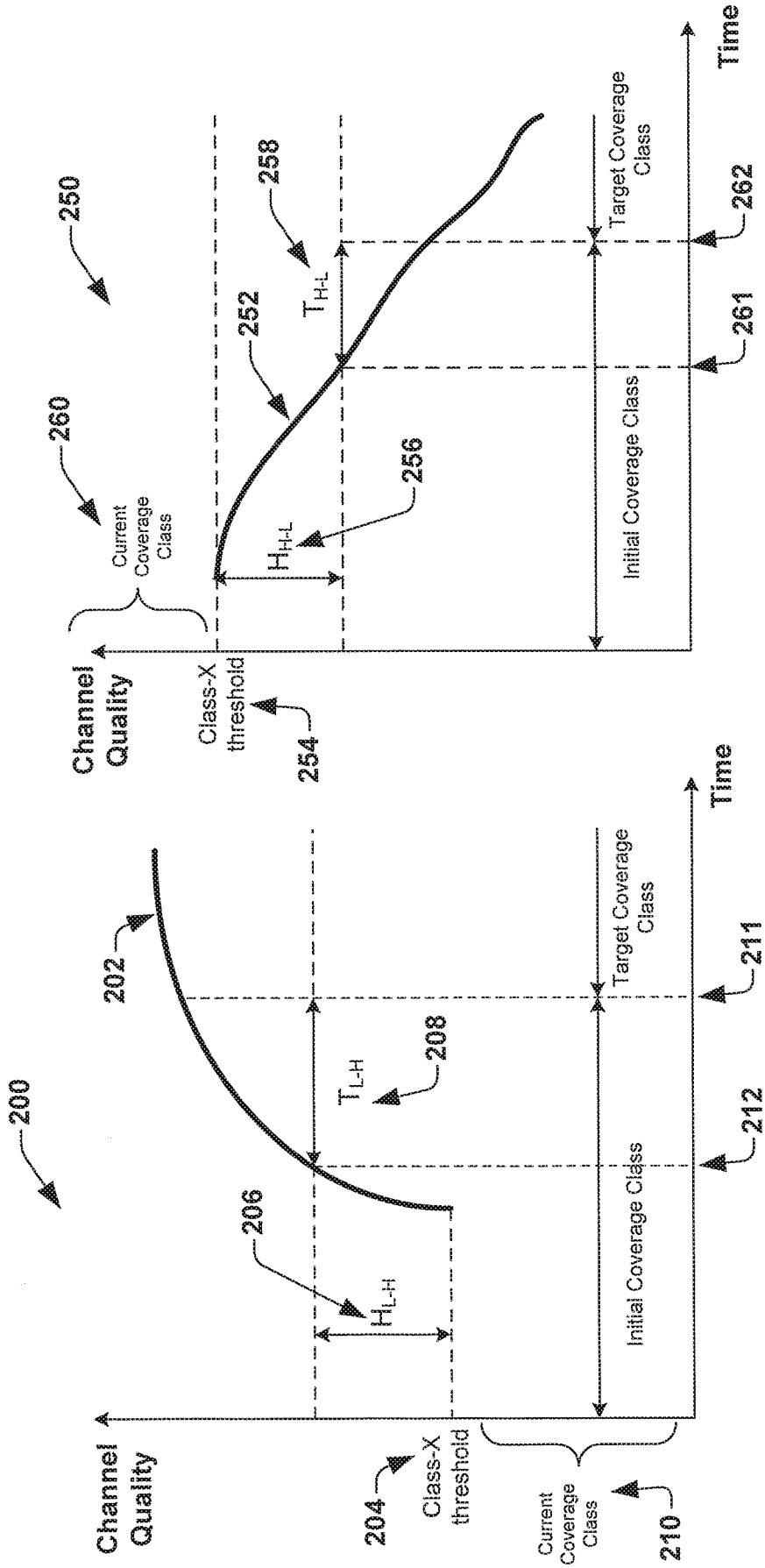


Fig. 2a

Fig. 2b

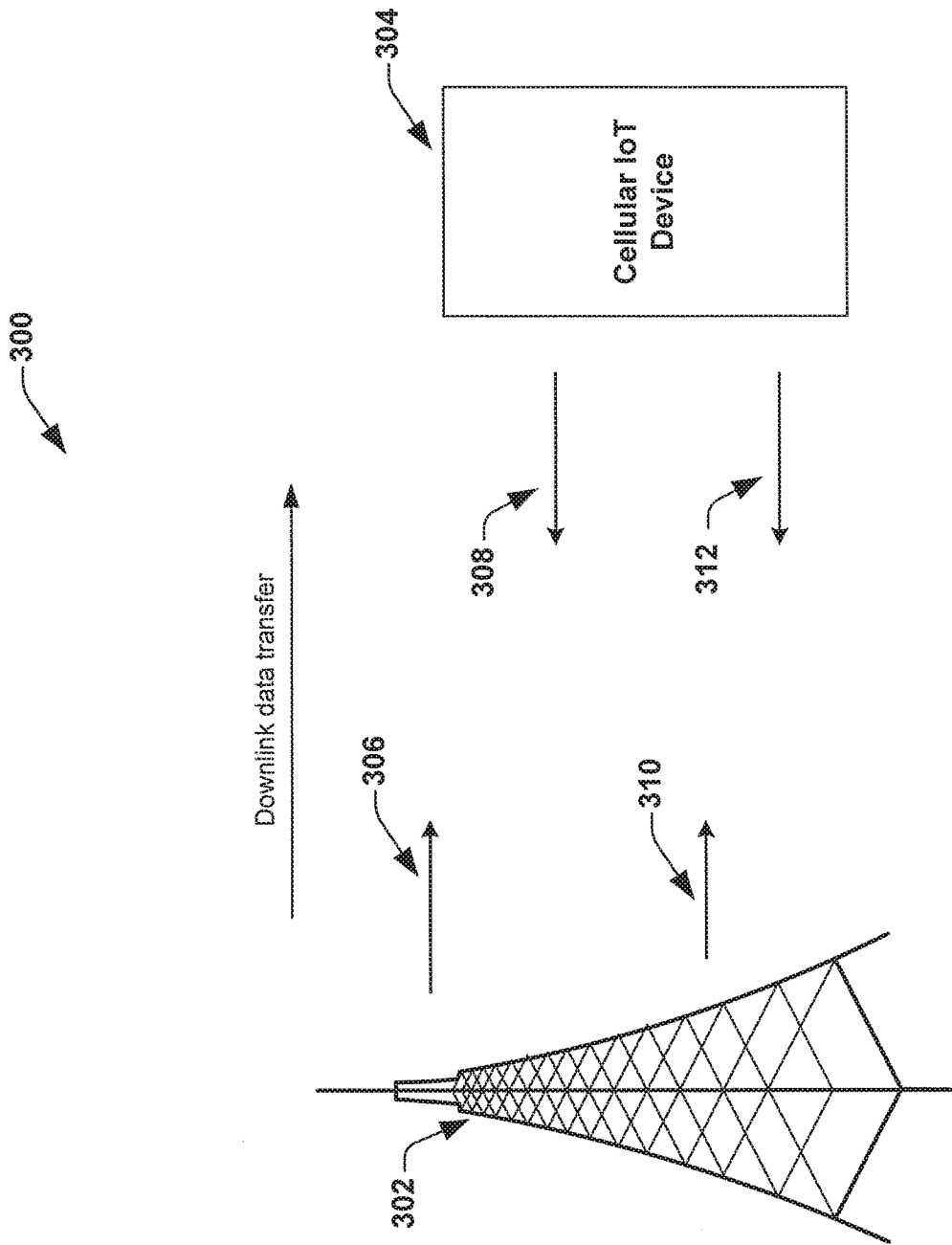


FIG. 3

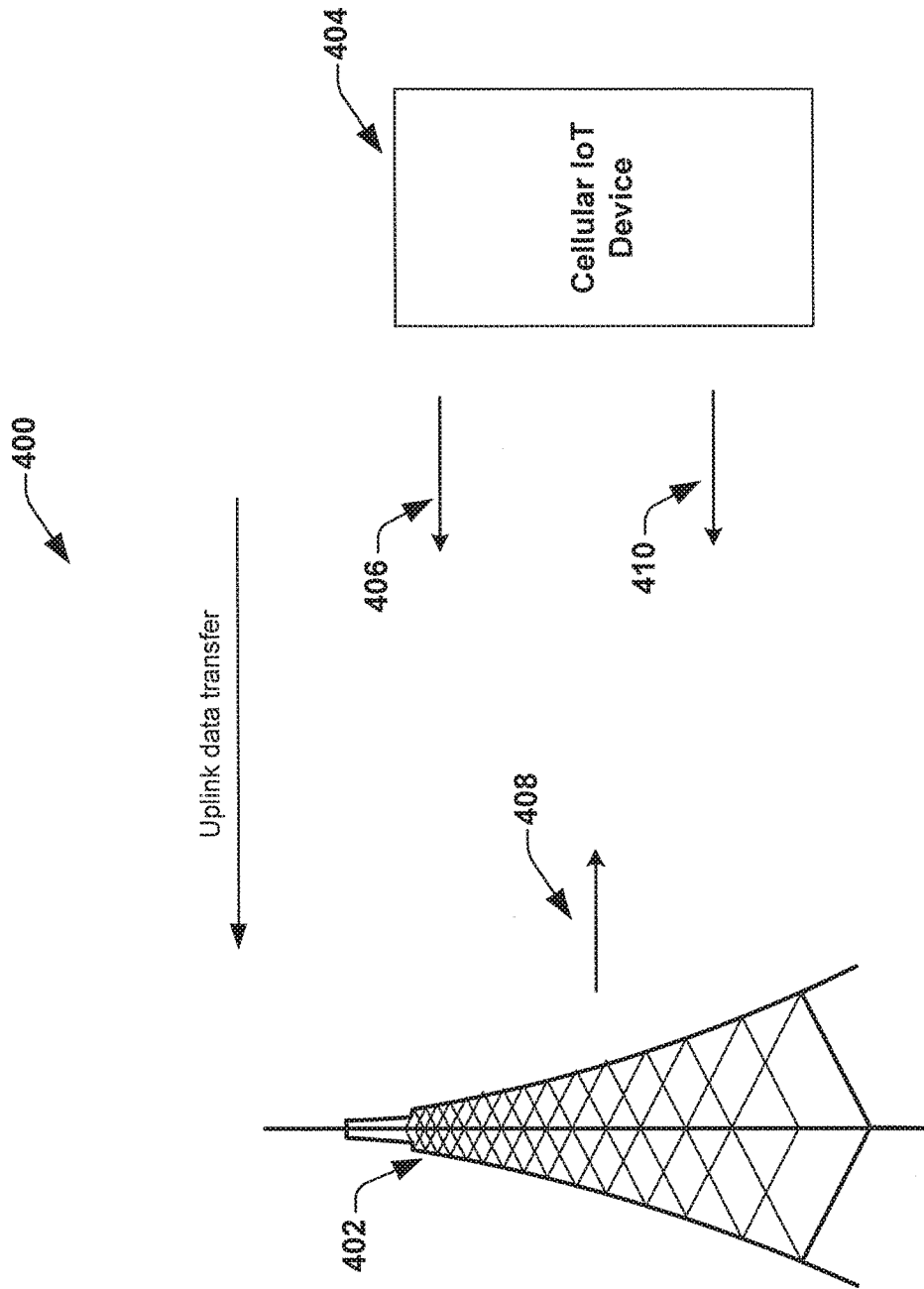


FIG. 4

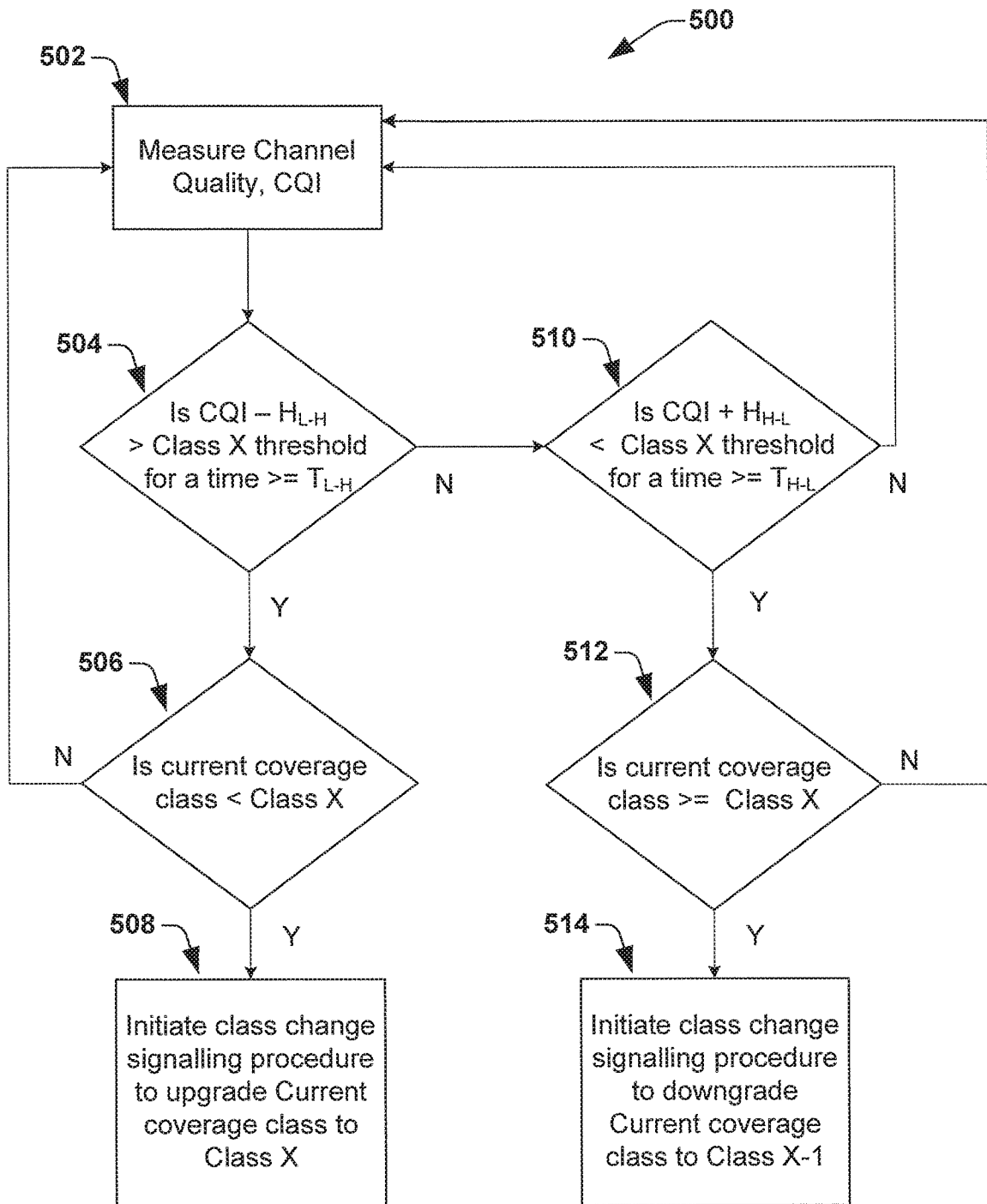


FIG. 5

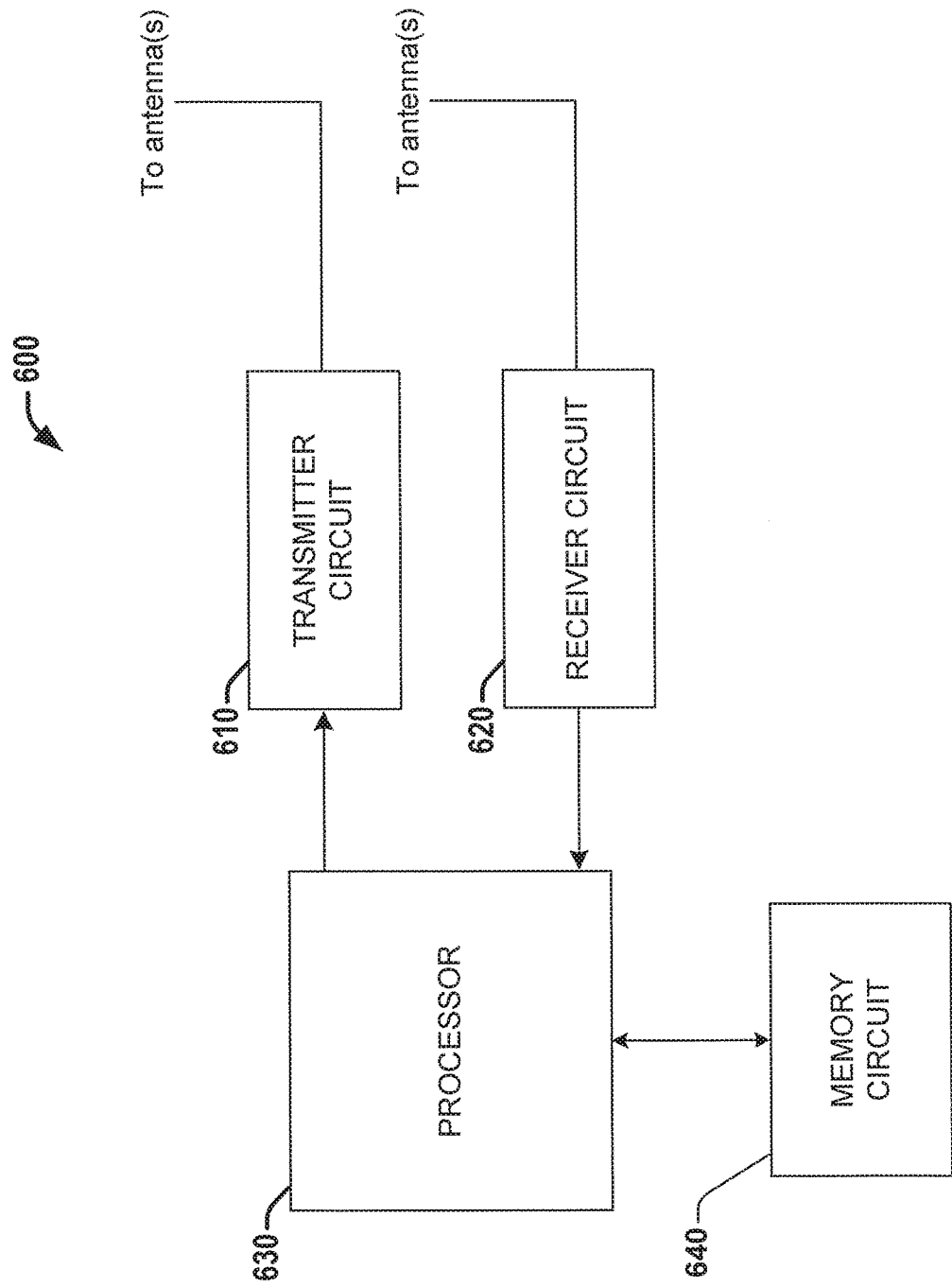


FIG. 6

700 ↗

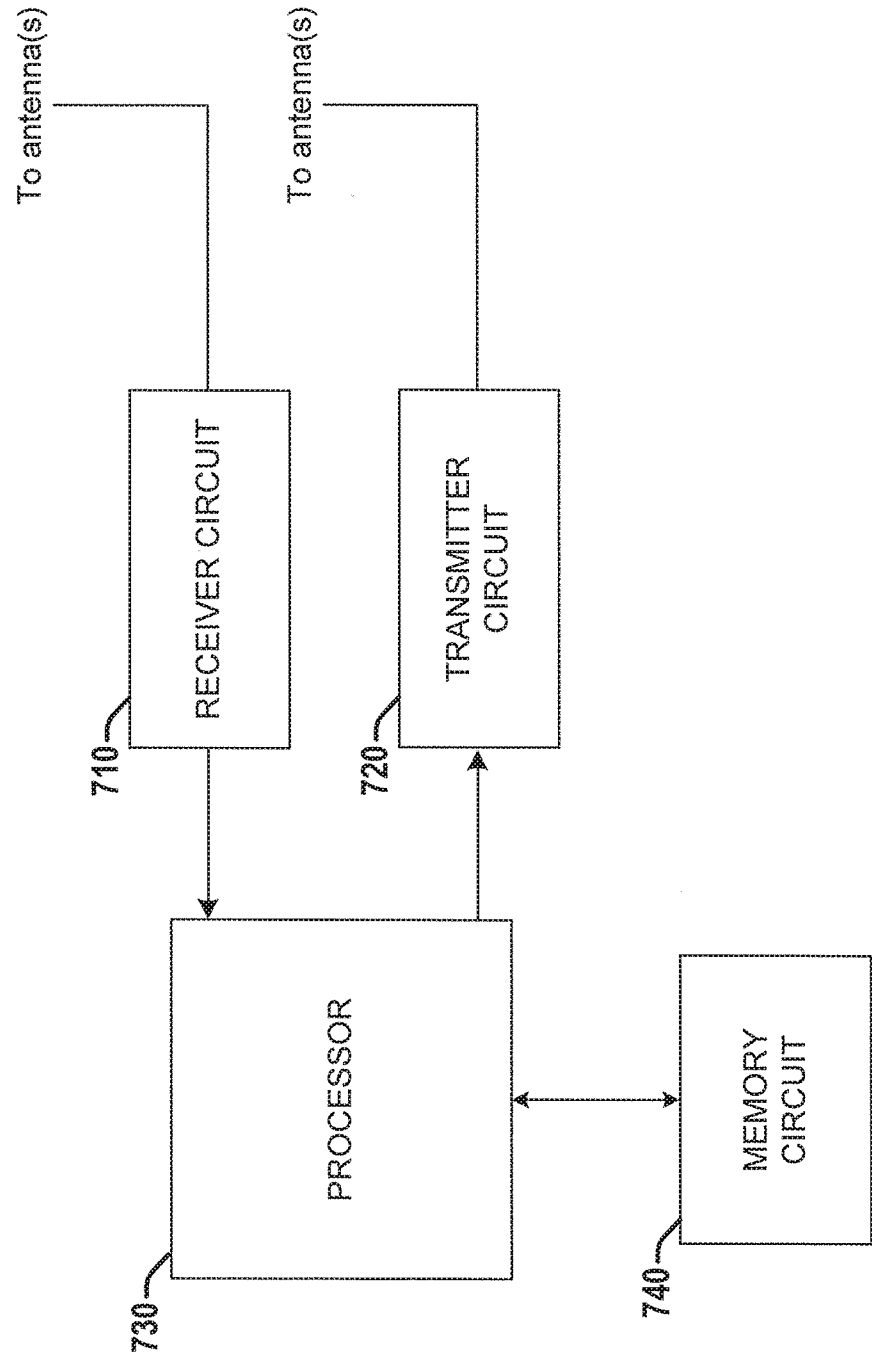


FIG. 7

8 / 14

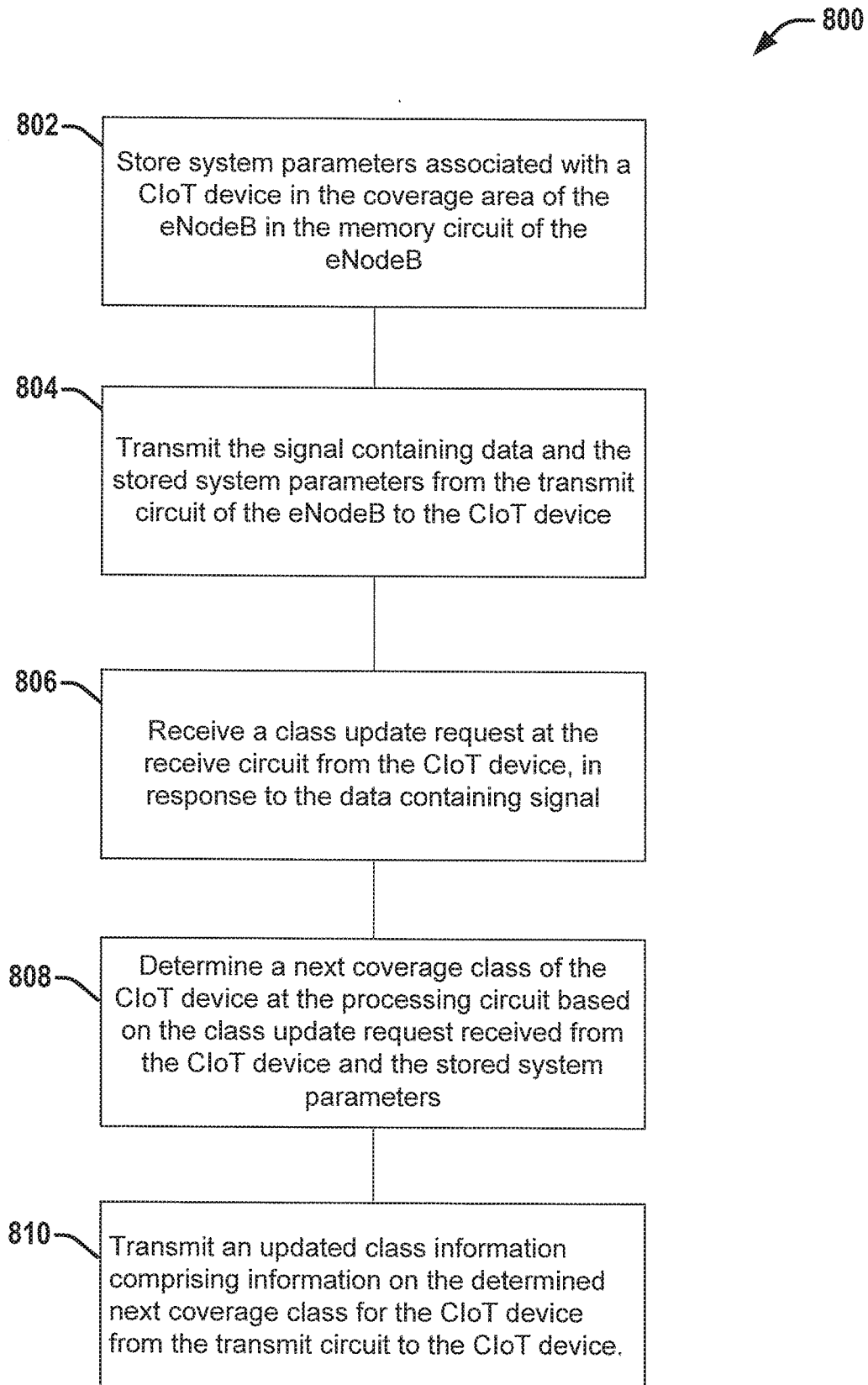


FIG. 8

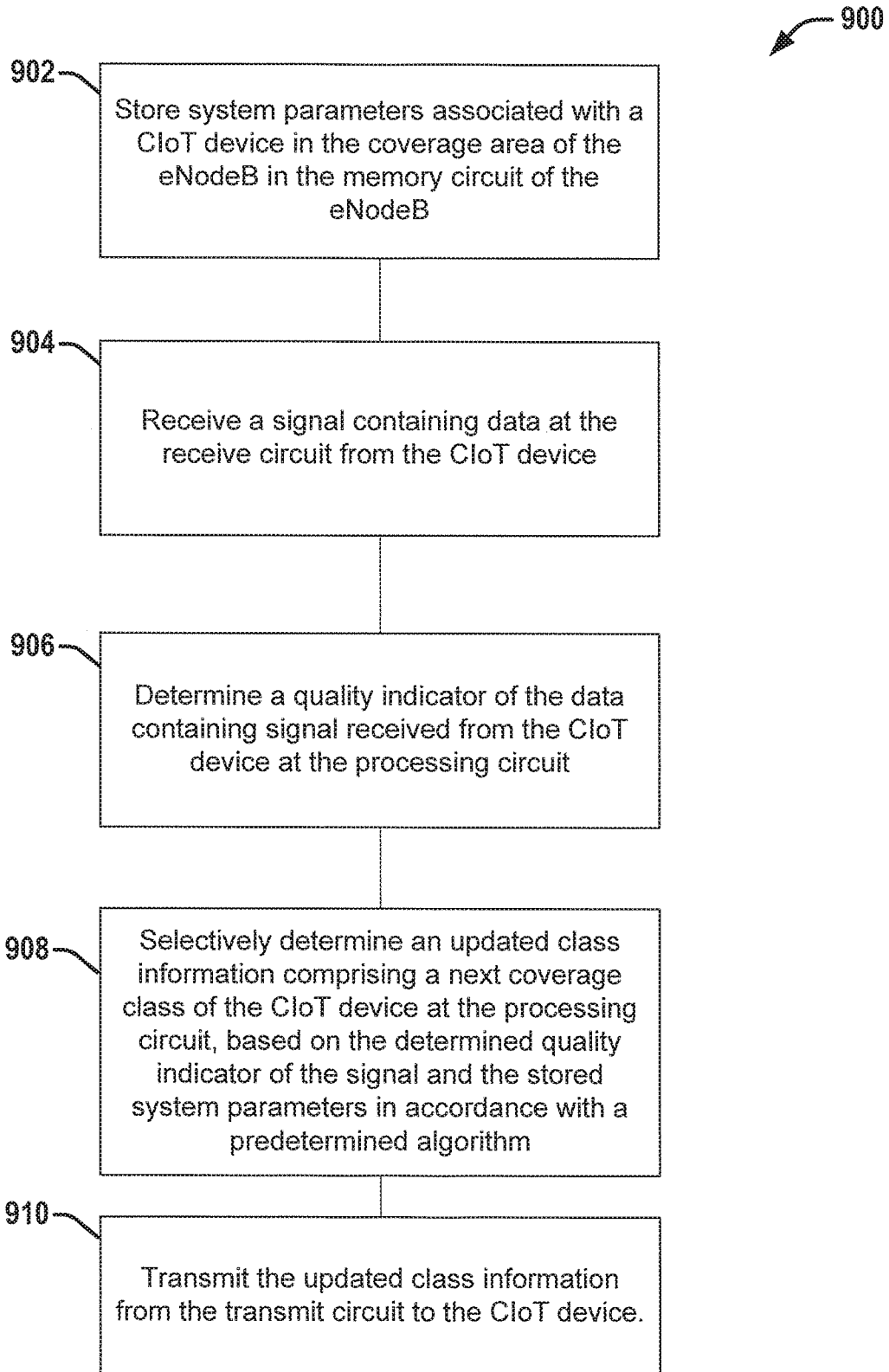


FIG. 9

10 / 14

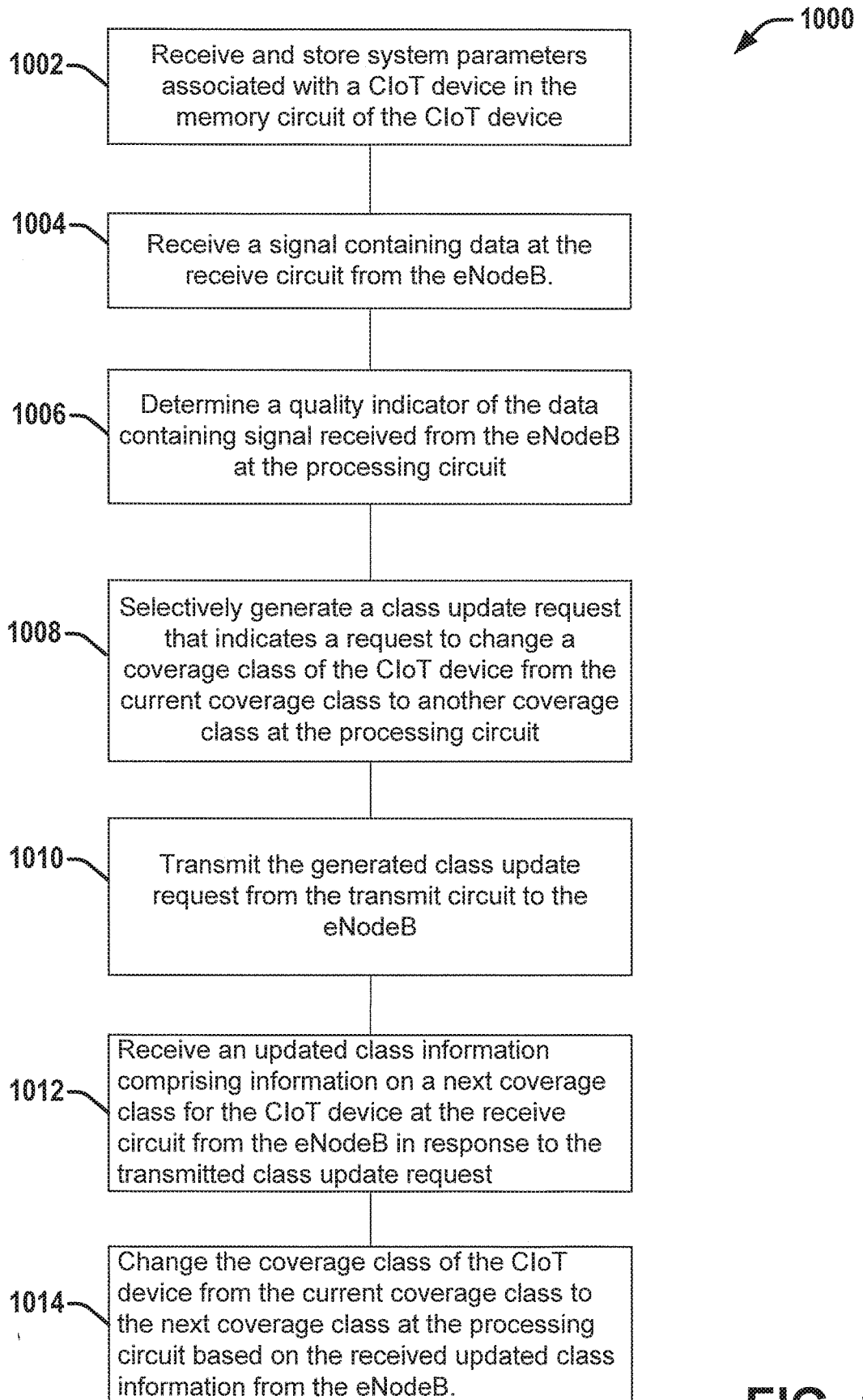


FIG. 10

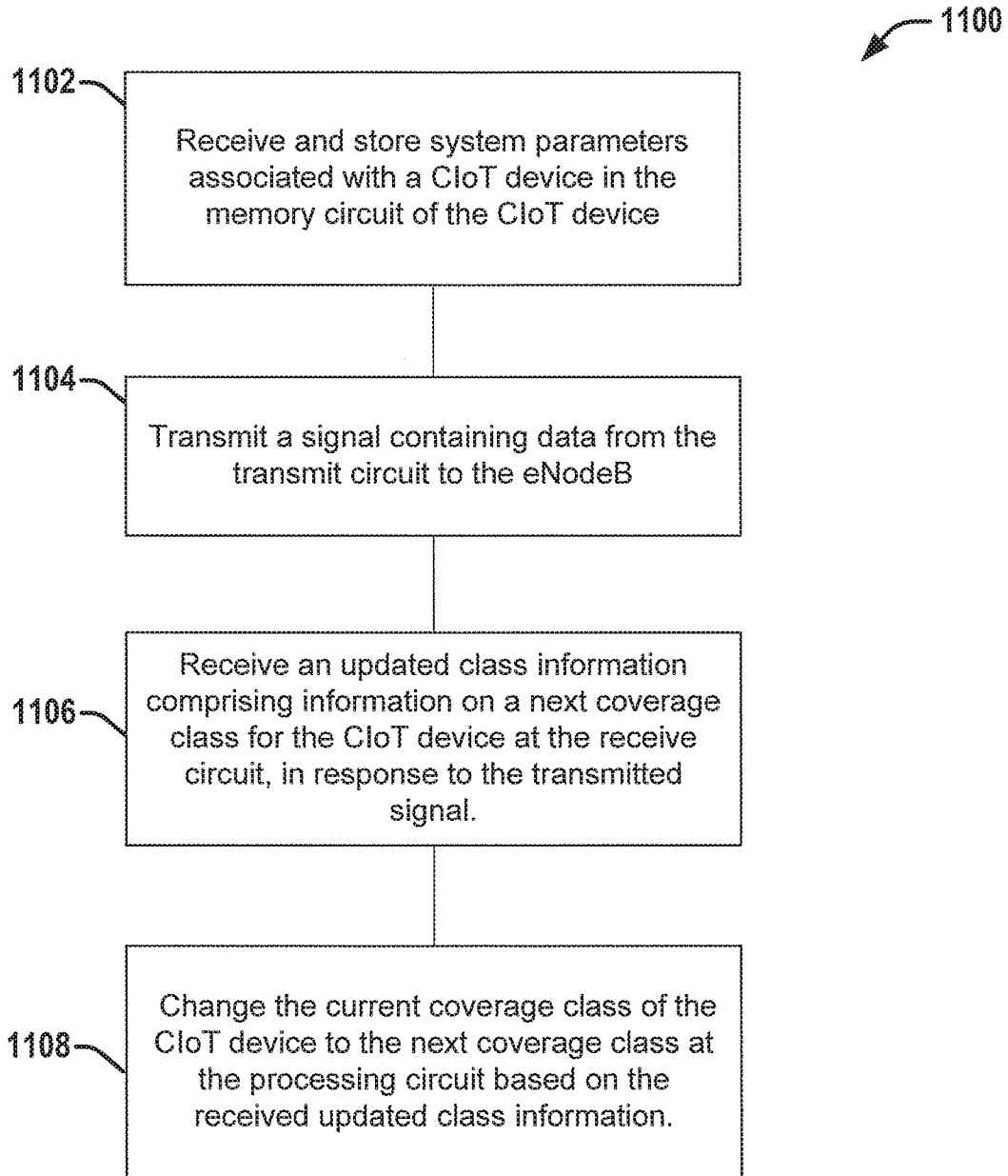


FIG. 11

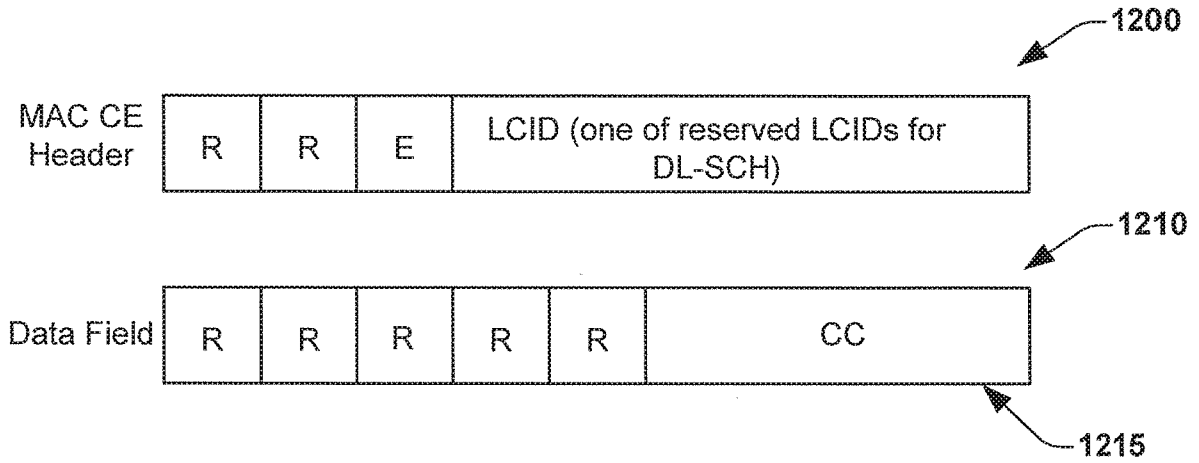


Fig. 12a

1250

Index	LCID values
00000	CCCH
00001-01010	Identity of the logical channel
01011	Device class update
01100-11001	Reserved
11010	Long DRX Command
11011	Activation/Deactivation
11100	UE Contention Resolution Identity
11101	Timing Advance Command
11110	DRX Command
11111	Padding

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Fig. 12b

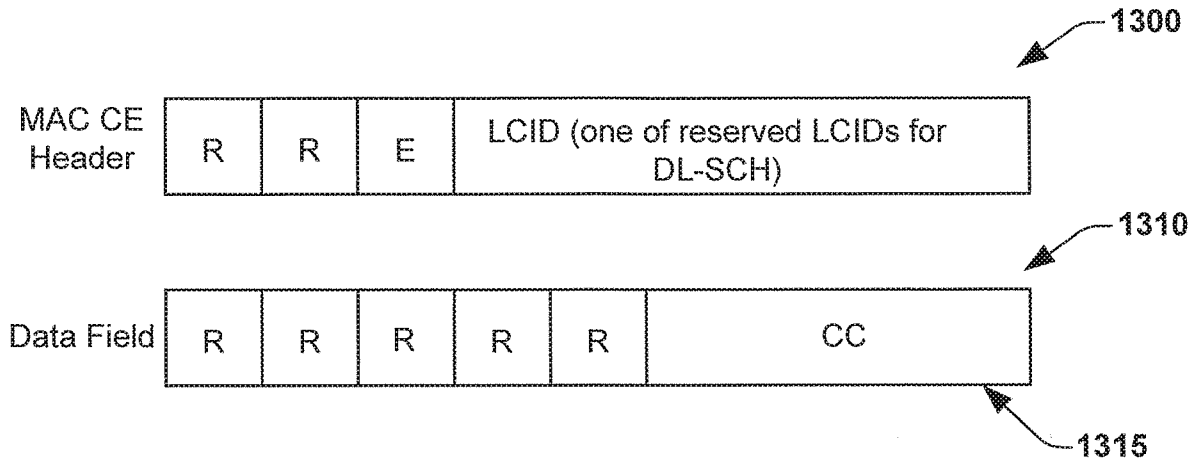


Fig. 13a

1350

Index	LCID values
00000	CCCH
00001-01010	Identity of the logical channel
01011	CCCH
01100	Device class update
01101-10101	Reserved
10110	Truncated Sidelink BSR
10111	Sidelink BSR
11000	Dual Connectivity Power Headroom Report
11001	Extended Power Headroom Report
11010	Power Headroom Report
11011	C-RNTI
11100	Truncated BSR
11101	Short BSR
11110	Long BSR
11111	Padding

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Fig. 13b

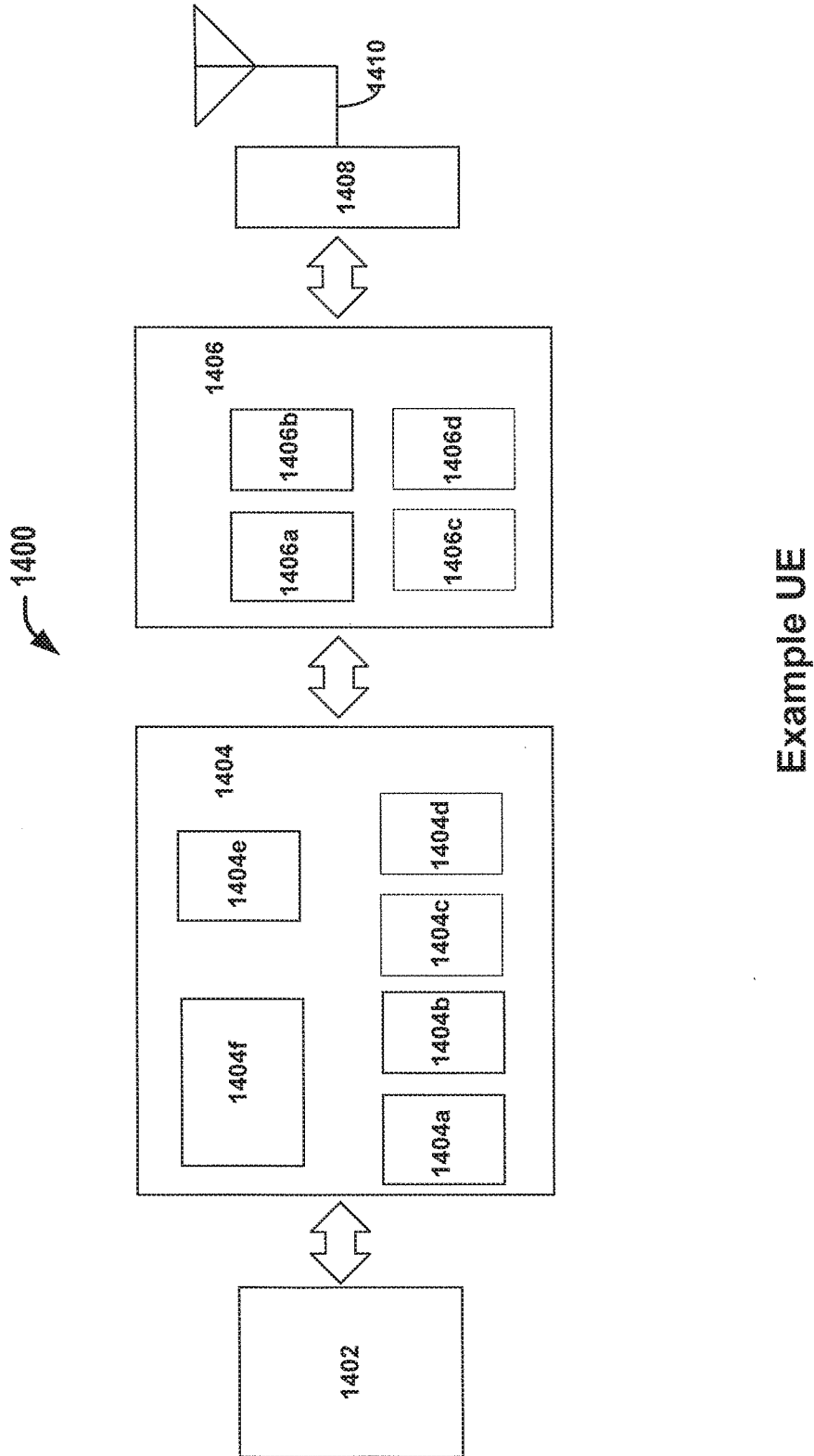


FIG. 14

**INTERNATIONAL SEARCH REPORT**

International application No  
PCT/US2016/019812

**A. CLASSIFICATION OF SUBJECT MATTER**  
 INV. H04W4/00  
 ADD. H04W24/02 H04W52/00

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)  
 H04W

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)  
 EPO-Internal, INSPEC, WPI Data

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	"3rd Generation Partnership Project; Technical Specification Group GSM/EDGE Radio Access Network; Cellular system support for ultra-low complexity and low throughput Internet of Things (CIoT) (Release 13)", 3GPP STANDARD; 3GPP TR 45.820, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE, vol. GERAN WG1, no. V13.1.0, 18 December 2015 (2015-12-18), pages 1-495, XP051047128, [retrieved on 2015-12-18]	1,2,4-9, 13-16, 20-23
Y	in combination with document XP50977130 Sections 7.3, 7.3.5.2.1, 7.3.5.3.1 to 7.3.5.3.4  ----- -/--	3,10-12, 17-19,24

Further documents are listed in the continuation of Box C.

See patent family annex.

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search  17 October 2016	Date of mailing of the international search report  25/10/2016
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Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer  Aguiar, Jorge
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## INTERNATIONAL SEARCH REPORT

International application No  
PCT/US2016/019812

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2015/373683 A1 (SCHLIWA-BERTLING PAUL [SE] ET AL) 24 December 2015 (2015-12-24)	1,2,4-9, 13-16, 20-23
Y	in combination with document XP50977130 paragraphs [0009] - [0011], [0013], [0039], [0043] - [0050], [0054], [0055], [0059] - [0062], [0065] - [0076], [0079], [0094]	3,10-12, 17-19,24
Y	----- NEUL LIMITED: "pCR TR 45.820 NB M2M - Coverage Class Updates for Pa", 3GPP DRAFT; GP-150504 PCR 45.820 NB M2M - COVERAGE CLASS UPDATES FOR PAGING, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CE , vol. TSG GERAN, no. Vilnius, Lithuania; 20150525 - 20150529 22 May 2015 (2015-05-22), XP050977130, Retrieved from the Internet: URL: <a href="http://www.3gpp.org/ftp/Meetings_3GPP_SYNC/GERAN/Docs/">http://www.3gpp.org/ftp/Meetings_3GPP_SYNC/GERAN/Docs/</a> [retrieved on 2015-05-22] in combination with any one of documents XP051047128 or US 2015/373683 A1 Section 7.1.5.3.4 -----	3,10-12, 17-19,24

# INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2016/019812

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2015373683 A1	24-12-2015	US 2015373683 A1	24-12-2015
		WO 2015198244 A1	30-12-2015
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