METHOD AND SYSTEM FOR THE SUPPORT OF A LONG DRX IN AN LTE_ACTIVE STATE IN A WIRELESS NETWORK

[0001] The present disclosure relates generally to the long term evolution (LTE) of Third Generation Partnership Project (3GPP), and in particular to discontinuous reception (DRX) for user equipment (UE) in the LTE infrastructure.

[0002] In the long term evolution infrastructure, a UE can be in one of two radio resource control (RRC) states. These are LTE_IDLE and LTE_ACTIVE.

[0003] The UE can be configured for discontinuous reception (DRX) in both the LTE_IDLE and the LTE_ACTIVE states. DRX allows the UE to synchronize its listening period to a known paging cycle of the network. By synchronizing the listening period, the UE can turn off its radio transceiver during the standby, thereby significantly saving battery resources. As will be appreciated by those skilled in the art, unless a UE is used extensively, a large drain on its battery comes from the standby cycle in which it monitors the paging channel and measures serving and neighboring cells. DRX parameters allow the mobile to synchronize with the network and to know that it will not receive another signal until a specified time has elapsed.

[0004] Utilizing DRX in an IDLE state is utilized in present UMTS systems and is done by the network signaling to the UE a DRX parameter and synchronizing the UE and the network. As will be appreciated, in IDLE mode the UE can change cells from one cell to the other. Thus utilizing a DRX parameter does not cause significant issues.

[0005] In an ACTIVE state however, various issues exist for turning off the receiver based on a DRX parameter. This includes the fact that only network controlled handover is allowed in the LTE_ACTIVE state. Also, other issues include efficient signaling of activation and deactivation of DRX, measurement requirements of network signals during the DRX, handling of missed handover opportunities, and issues dealing with the length of the DRX value in which entity in the network can request DRX activation and reconfiguring the DRX period.

GENERAL

[0006] The present disclosure may provide various methods and systems for addressing the deficiencies in the prior art regarding DRX in an LTE_ACTIVE state.

[0007] In particular, a DRX signaling procedure between the UE and the eNB, in which the eNB signals DRX values and timing margins as part of a modified MAC-PDU header, is described. The eNB signaled DRX value can range from zero to indicate DRX deactivation to a value for the DRX period. The timing margin can indicate a delay for activating DRX to overcome NACK-ACK misinterpretations or ACK-NACK misinterpretations. In one embodiment the timing margin can be also signaled by the RRC.

[0008] The DRX value, in one embodiment can be incrementally increased to a certain maximum value that will be either defined in the standards or signaled. The increment may be carried out without signaling by both the UE and the eNB if no data has been received for a preset number of DRX cycles. In a further embodiment, the DRX value can be incrementally decremented until DRX is deactivated without signaling by both the UE and the eNB.

[0009] In a further embodiment, application level traffic characteristics can be leveraged for an optimization of the DRX period to improve battery life. The UE could, in this case, send a request to initiate or amend a DRX value to the eNB and the eNB can either accept this value or reject it. Various considerations including mobility, location of the cell, traffic characteristics, or missed handover opportunities can be determined for both the UE and the eNB in choosing and accepting a DRX value.

[0010] In a further embodiment, measurement accuracy may be improved by shortening the measurement cycle from the DRX cycle if a certain threshold signal value is reached for a certain amount of time. Thus, in the case of signal degradation, the UE may decide that more frequent measurement needs to be performed if the quality of the signal falls below a threshold for a predetermined time. Subsequently, the measurement cycle can be increased if the signal rises above a threshold for a certain time period, or a handover condition can be triggered if the signal falls below a threshold.

[0011] In a further embodiment, missed handover opportunities can be handled if the channel quality or signal strength of a serving cell is less than a neighboring cell by a threshold value for a certain duration. Procedures for switching to a target eNB are disclosed.

[0012] The present disclosure therefore provides a method of DRX signaling in a long-term evolution infrastructure between an evolved node B (eNB) and user equipment (UE), the method comprising the steps of: providing a DRX value or coded DRX value in a header of a medium access control protocol data unit (MAC-PDU); and activating, deactivating or reconfiguring DRX based on the provided DRX value.

[0013] The present disclosure further provides a method of leveraging application level traffic characteristics to improve battery life of user equipment (UE) communicating with an evolved Node B (eNB) comprising the steps of: requesting, from the UE, a discontinuous reception (DRX) based on application traffic characteristics of the UE; receiving the request from the UE at the eNB; and granting, negotiating an alternative period or rejecting the request at the eNB.

[0014] The present disclosure may further provide a method for improved measurement accuracy during discontinuous reception (DRX) on user equipment (UE) comprising the steps of: checking whether a channel quality or signal strength of a serving cell is lower than a first threshold for a predetermined time period; and if yes, shortening the measurement cycle to have a shorter measurement cycle than the DRX cycle.

[0015] The present disclosure may further provide a method of handling missed handover opportunities based on discontinuous reception (DRX) in user equipment (UE) comprising the steps of: checking whether a channel quality or signal strength of a serving cell is less than the channel quality or signal strength of a neighboring cell by a threshold value for a certain time duration; and if yes, connecting to the neighboring cell.

[0016] The present disclosure may further provide: an evolved node B (eNB) operating in a long-term evolution infrastructure, the eNB being characterized by means for: providing a DRX value in a header of a medium access control protocol data unit (MAC-PDU); and activating or deactivating DRX based on the DRX value.

[0017] The present disclosure may further provides a user equipment (UE) operating in a long-term evolution (LTE) infrastructure, the UE being characterized by means for: receiving a DRX value in a header of a medium access control protocol data unit (MAC-PDU) and acknowledging the MAC-PDU; and activating, deactivating or reconfiguring DRX based on the DRX value.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] The present application will be better understood with reference to the drawings, in which:

Figure 1 is a block diagram showing a long term evolution user plane protocol stack;

Figure 2 is a block diagram showing a long term evolution control plane protocol architecture;

Figure 3a is a flow chart showing a method to activate deactivate and reconfigure DRX period using a MAC-PDU header from the eNB side;

Figure 3b is a flow chart showing a method to acknowledge the activation, deactivation or reconfiguration of the DRX period from the UE side;

Figure 4a is a flow chart showing a method for a UE to leverage application traffic characteristics to improve battery life from the UE side;

Figure 4b is a flow chart showing a method for a UE to leverage application traffic characteristics to improve battery life from the eNB side;

Figure 5 is a diagram showing signal strength thresholds and measurement cycle times;

Figure 6a is a flow chart illustrating procedural steps involved in switching to a target eNB from the UE side;

Figure 6b is a flow chart illustrating procedural steps involved in switching to a target eNB from the eNB side;

Figure 7 is a graph showing channel status going below a lower threshold value and then above a threshold value without any uplink data;

Figure 8 is a graph showing channel status going below a lower threshold value and then above a higher threshold value with uplink data; and

Figure 9 is a graph showing signal degradation in which a handover condition is triggered.

DESRIPTION OF PREFERRED EMBODIMENTS

[0019] Reference is now made to the drawings. **Figure 1** shows a block diagram illustrating the long-term evolution (LTE) user plane protocol stack.

[0020] A UE **110** communicates with both an evolved Node B (eNB) **120** and an access gateway (aGW) **130**.

[0021] Various layers are illustrated in the protocol stack. The packet data convergence protocol (PDCP) layer **140** is illustrated both on the UE **110** and on aGW **130**. The PDCP layer **140** performs internet protocol (IP) header compression and decompression, encryption of user data, transfer of user data and maintenance of sequence numbers (SN) for radio bearers.

[0022] Below the PDCP layer **140** is the radio link control protocol layer **142**, which communicates with the radio link control protocol layer **142** on the eNB **120**. As will be appreciated, communication occurs through the physical layer in protocol stacks such as those illustrated in **Figures 1** and **2**. However, RLC-PDUs from the RLC layer **142** of the UE are interpreted by the RLC layer **142** on the eNB **120**.

[0023] Below RLC layer **142** is the medium access control (MAC) data communication protocol layer **146**. As will be appreciated by those skilled in the art, the RLC and MAC protocols form the data link sublayers of the LTE radio interface and reside on the eNB in LTE and user equipment.

[0024] The layer 1 (L1) LTE (physical layer **148**) is below the RLC/MAC layers **144** and **146**. This layer is the physical layer for communications.

[0025] Referring to **Figure 2**, **Figure 2** illustrates the LTE control plane protocol architecture. Similar reference numerals to those used in **Figure 1** will be used in **Figure 2**. Specifically, UE **110** communicates with eNB **120** and aGW **130**. Further, physical layer **148**, MAC layer **146**, RLC layer **142** and PDCP layer **140** exist within **Figure 2**.

[0026] **Figure 2** also shows the non-access stratum (NAS) layer **210**. As will be appreciated, NAS layer **210** could include mobility management and session management.

[0027] The radio resource control protocol layer (RRC) **220**, is the part of the protocol stack that is responsible for the assignment, configuration and release of

radio resources between the UE and the E-UTRAN (Evolved universal terrestrial radio access network). The basic functionalities of RRC protocol for LTE is described in 3GPP TR25.813.

[0028] As will be appreciated by those skilled in the art, in UMTS, automatic repeat request (ARQ) functionality is carried out within the RLC layer which resides in the radio network controller (RNC). Long Term Evolution (LTE) moves the ARQ functionality from the RNC to eNB where a tighter interaction may exist between the ARQ and the HARQ (within the MAC layer, also located in the eNB).

[0029] Various issues regarding DRX in an LTE-ACTIVE state are considered herein.

DRX signaling procedure

[0030] Very efficient signaling procedures for activating and de-activating DRX and specifying the duration of DRX periods are required in order to support a large population of UEs in a cell that are utilizing DRX in an LTE_ACTIVE state.

[0031] As will be appreciated by those skilled in the art, if the evolved node B (eNB) transmits data to the UE during its receiver off period due to a DRX operation, the UE cannot receive the data. Therefore, an indication is required to ensure the UE and the eNB are synchronized regarding when DRX is activated and deactivated.

[0032] The indication between the UE and the eNB can be explicit signaling by the radio resource control (RRC) or layer 1/layer 2 (L1/L2) signaling. As will be appreciated, however, explicit signaling may not be as efficient desired.

[0033] A more efficient solution is to include an optional field in the MAC header of a MAC-PDU (MAC Protocol Data Unit) to indicate DRX activation and deactivation. The field preferably indicates the DRX value and timing margin for activation and deactivation. A value of zero, for example, could mean DRX deactivation in the DRX value field in a preferred embodiment. Conversely, if data that is to be transmitted in the next MAC-PDU is the last one in the buffer for the UE, the eNB may extend the MAC header field to include a DRX length initial value. For example, this could be 320 milliseconds. The timing margin is explained below, and is utilized to reduce the consequences of a NACK to ACK or

ACK to NACK misinterpretation, for the reception status of the MAC-PDU between the UE and the eNB.

[0034] For example, three bits may be added to the MAC header to indicate eight values of the DRX period. Thus, rather than a specific time value being sent, a bit value from 000 to 111 could indicate one of eight discrete values.

[0035] In an alternative, a smaller field in the MAC header could be used (for example two bits) to indicate increment or decrement. The RRC could indicate default values, and if the MAC header indicates increment or decrement then the UE could change to the prespecified value.

[0036] Once the UE receives the DRX value, it acknowledges it to the eNB by transmitting HARQ ACK and starts the DRX at the system frame time considering propagation delay and processing delay at the eNB. When the eNB receives the ACK from the UE, it also starts the DRX at the next system frame time. As will be appreciated, the eNB does not turn off its transceiver, but simply knows not to transmit messages to the individual UE.

[0037] During a DRX period, if new data arrives at the eNB, the eNB can send a MAC-PDU with a header extension set to DRX deactivation or a shorter DRX length depending on the amount of data in the buffer or the quality of service requirements. The UE reconfigures the DRX accordingly and acknowledges the MAC-PDU. When the eNB receives the ACK, it reconfigures the DRX. As indicated above, the deactivation could be accomplished by merely setting the length value to zero.

[0038] Reference is now made to **Figure 3a and 3b**. **Figure 3a** shows an exemplary method for controlling DRX activation in an LTE_ACTIVE state. The process starts at step **300** and proceeds to step **310** in which data is transmitted to the UE. As will be appreciated by those skilled in the art, data transmission in an LTE_ACTIVE state utilizes the MAC-PDU at the data link layer to transmit the data.

[0039] The process next proceeds to step **312** in which a check is made to see whether the buffer of data to be sent to the UE will be empty after the next transmit. If no, the process proceeds back to step **310** in which data is transmitted to the UE. Alternatively, if the buffer will be empty after the next

transmit and the data arrival rate is lower than a threshold value, the process proceeds to step **314**.

[0040] In step **314**, the eNB sets DRX activation in the MAC-PDU header. As indicated above, this includes a DRX activation value indicating the length of the DRX period. In another embodiment the eNB may simply indicate an increase in the DRX interval. The UE reconfigures the existing DRX interval to a predetermined reduced interval. The predetermined interval may be either known to both eNB and UE or pre-signaled to the UE from the eNB via explicit signaling; either by system broadcast or RRC signaling.

[0041] The process then proceeds to step **316** in which the data including the modified MAC-PDU header is sent to the UE.

[0042] Reference is now made to **Figure 3b**. In step **318**, the UE receives the data and sees that DRX activation is specified in the MAC-PDU header. The process proceeds to step **320** in which the UE sends an acknowledgement (ACK) to the eNB and starts the DRX at the system frame time considering propagation delay and processing delay at the eNB.

[0043] In step **330** of **Figure 3a**, the eNB receives the ACK from the UE and starts the DRX at the next system frame time.

[0044] As will be appreciated, the DRX can continue until various events occur which may require the DRX to be adjusted. One event is the reception of data from aGW by the eNB for the UE. Depending on the amount of data received, the DRX can either be deactivated or the period of the DRX can be reduced. Other events that may require the adjustment of the DRX include a change of signal power level between the eNB and the UE or possibly a gradual increase in the DRX cycle due to continued data inactivity, among others. These other events are discussed in more detail below.

[0045] In step **332** the eNB checks to see whether the DRX needs to be adjusted. As indicated above, this could be the situation where data is received to be sent to the UE. Here the DRX can either be deactivated or the period adjusted.

[0046] From step **332**, if the DRX does not need to be adjusted, the process proceeds back to step **332** and continues to check whether or not the DRX needs to be adjusted.

[0047] Once the process in step **332** finds that the DRX does need to be adjusted, the process proceeds to step **334** in which it adjusts the DRX. This could be deactivating the DRX by transmitting a zero value for the DRX or a shorter DRX or a longer DRX as required.

[0048] The MAC-PDU with the modified header is sent to the UE in step **336**. The MAC-PDU in step **336** could also include any data that has been received by the eNB that needs to be transmitted to the UE.

[0049] Referring to **Figure 3b,** the process then proceeds to step **318** in which the MAC-PDU with modified header is received at the UE. The UE recognizes the DRX period is to be adjusted and in step **320** it sends an acknowledgement to the eNB and it adjusts its DRX period at the same system frame time considering propagation delay and processing delay as at the eNB.

[0050] Referring to **Figure 3a**, in step **342** the eNB receives the ACK and starts the modified DRX period at the appropriate system frame time. The process then proceeds back to step **332** to see whether the DRX needs to be adjusted again.

[0051] As will be appreciated by those skilled in the art, one issue with the above occurs in the case of a misinterpretation of an ACK or a NACK. Specifically, the hybrid automatic repeat request (HARQ), which is a variation of the ARQ error control method, does not always properly demodulate an ACK or a NACK due to poor channel conditions. Thus, in some situations, one can be interpreted as the other. By having the DRX activation and deactivation occur in the MAC-PDU header, an ACK to NACK or NACK to ACK misinterpretation needs to be handled.

[0052] A possible solution to the above is the introduction of timer threshold values before activating or deactivating DRX.

[0053] When the UE NACKs a MAC-PDU that has DRX header information, the UE is unaware that it should adjust the DRX period. It will expect a retransmission from the eNB. If a NACK to ACK misinterpretation occurs, the eNB receives an ACK and it will not send a retransmission and will change the DRX period. The UE waits for a time to receive the retransmission. If the UE does not receive the expected retransmission, the waiting time should be limited by an upper threshold (TH-A) considering possible NACK to ACK misinterpretations. If the UE does not receive a retransmission, it should maintain its current DRX status. The eNB will expect an exchange of information with the UE at the next

DRX period. If the UE does not respond, the eNB should revert to the previous DRX period and attempt to "synchronize" with the UE.

[0054] Even when a UE ACKs a MAC-PDU, the UE needs to wait for retransmission due to possible ACK to NACK misinterpretation or possible ACK to DTX misinterpretation by the eNB. The waiting time should be limited by an upper threshold (TH-B).

[0055] If the UE is missing data as indicated on the L1/L2 signaling channel, assuming the eNB will retransmit at the next earliest opportunity, the UE needs to check the L1/L2 signaling channel within a certain duration (TH-C).

[0056] Based on the various threshold parameters above, the minimum time before DRX activation should therefore be greater than (max(TH-A, TH-B)+TH-C). This threshold value can be signaled either by system broadcast or RRC signaling.

[0057] Various scenarios are considered herein:

DRX activation and ACK to NACK errors:

[0058] For an ACK to NACK misinterpretation or an ACK to a discontinuous transmit (DTX) misinterpretation (i.e. the channel conditions are so poor that the ACK appears as noise to the receiver), the following occurs. The UE receives the DRX activation in the header of the MAC-PDU and sends an ACK to the eNB. The eNB receives the ACK but misinterprets it as a NACK or a DTX misinterpretation. This results in the UE activating the DRX before the eNB, which may result in the UE missing the retransmission of the MAC-PDU from the eNB.

[0059] In the situations indicated above, an ACK to NACK or DTX misinterpretation can be solved by the UE waiting for the timing margin before activation of DRX. The margin can be based on the normal time that it takes a retransmission to occur and weighted by the average number of HARQ retransmissions to the UE that may be experienced. The DRX activation may be indicated by the RRC signaling or in the MAC-PDU header extension. When the UE acknowledges the retransmission before the timing margin expires, the UE will start the DRX at the system frame time considering propagation delay and eNB

processing time assuming that two consecutive misinterpretations are very unlikely.

DRX activation and NACK to ACK errors:

[0060] Similarly, if the UE sends a NACK for a MAC-PDU, this could be misinterpreted as an ACK by the eNB. In the case of DRX activation, the eNB activates the DRX before the UE. If the eNB maintains the CQI resource for the UE for a short period of time after activating DRX, it will detect that the UE has not activated the DRX indicated by checking the frequency of CQI report and it can signal the DRX activation by L1/L2 control signaling. If the eNB releases the CQI resource just after activating DRX and assigns it to another UE, CQI reports from the two UE may collide. The eNB could use Time Division Multiplexing or Code Division Multiplexing to avoid the collision.

[0061] In the case that the RLC is operating in acknowledged mode (AM), when a NACK to ACK misinterpretation occurs, recovery for DRX synchronization between the eNB and the UE is established via the normal RLC retransmission mechanism. This is because the RLC layer in the transmitter will determine that the PDU is lost and therefore instigate normal ARQ recovery by resending the original data not received.

[0062] In the case that the RLC is operating in unacknowledged mode (UM mode), no recovery mechanism exists. One solution is, in the HARQ, the receiver sends a channel quality indicator (CQI). In continuous reception, the channel quality indicator is repeated every 100 milliseconds, for example. Based on the CQI report, the transmitter decides and indicates a coding rate, modulation scheme, and Transport Block size. During active DRX, the eNB may expect a CQI, for example, every second. If the eNB gets this CQI at a different rate (for example 300 milliseconds) it knows that the UE is not in DRX and a correction can occur. For the deactivation DRX in a NACK to ACK misinterpretation, the UE still thinks it is in DRX while the eNB thinks it is in an active state. This can lead to missed data; however, the next MAC-PDU an indication of DRX deactivation can again occur.

[0063] Thus assuming that the CQI (channel quality indicator) reporting will be aligned to the DRX length, the eNB will know if DRX activation is completed in the

UE by checking the frequency of CQI reporting. If not completed, the eNB may use L1/L2 signaling or send only a MAC-PDU header to correct the DRX activation or reconfiguration.

[0064] Another recovery method can triggered when the eNB receives a Timing Advance (TA) Request message from a UE that should be in DRX. When the UE returns power to its transceiver and, hence, emerges from the DRX state, it will often need to send control (e.g. measurement reports) and other data messages the eNB. It is important that the UE have the proper TA before sending these messages so that the UE messages do not partially overlap with messages from other UEs as they arrive at the eNB. Hence, after a DRX cycle the UE will often send a TA Request on a random access channel so that it can get the proper TA from the eNB. If the TA request arrives at a point when the UE should be in DRX, the eNB will know that the UE did not receive the last DRX activation or modification properly. The eNB can then revert to the prior DRX period for that UE and recover DRX-period synchronization.

DRX deactivation and ACK to NACK errors:

[0065] In the case of DRX deactivation or DRX length reconfiguration, an ACK to NACK or DTX misinterpretation leads to the UE deactivating the DRX before the eNB, which may require no special handling if the UE acknowledges the normal retransmission from the eNB and the eNB successfully received the ACK.

DRX deactivation and NACK to ACK errors:

[0066] In the case of DRX deactivation or DRX length reconfiguration, a NACK to ACK misinterpretation results in the eNB deactivating the DRX before the UE, which may result in the UE missing the new data transmissions. The possible solution to this is that the eNB indicates DRX deactivation on a MAC-PDU header extension of subsequent MAC-PDUs. Assumptions are that consecutive misinterpretations are very unlikely and that no DRX reconfiguration is needed when only one MAC-PDU is needed to transmit the new data which has arrived at the eNB.

DRX Automatic Incrementation

[0067] A further consideration is the incremental extension of the DRX. Rules that dictate how the DRX period can be incremented or decremented (e.g. by factors of two), in a preferred embodiment, can be signaled during the radio bearer (RB) set up. The rules are carried in the RRC RB set-up/reconfiguration or measurement control messages to the UE. In this case, if no data is received after N current DRX cycles, the eNB and the UE increase the DRX length to the next larger value automatically. This eliminates the need for signaling between the eNB and the UE to increase the DRX length and therefore saves network and battery resources.

UE REQUEST FOR DRX

[0068] Since the UE terminates all protocols from layer 1 to layer 7, the UE may be able to determine if it can go into a longest DRX value after receiving some specific data packets rather than waiting for the network to increase the DRX value gradually. In this case, however, it is required that the UE have the capability of requesting DRX activation.

[0069] As will be appreciated by those in the art, the eNB is not very intelligent when considering a UE higher layer or application activities and thus would normally gradually increase the DRX. However, the UE may know that the increase does not need to be gradual in certain cases and can immediately go to a higher value.

[0070] The eNB also signals if the UE may request for DRX activation via the radio resource control radio bearer set-up or a reconfiguration message.

[0071] However, if the UE needs to inform the eNB of the possibility of a rapid change, the user plane data is not always available to piggyback a request for DRX from the UE. In a preferred embodiment, L1/L2 signaling messages are used. The UE sends a DRX request message to the eNB and the eNB replies with a DRX grant message.

[0072] Various considerations may be taken into account by the UE besides the application data flow characteristics in determining the proper DRX period. The mobility and location within the cell, for example, may be taken into account. If

the UE is highly mobile or if it sees good neighboring cells, the UE may choose to request a shorter DRX period to prepare for a possible handover.

[0073] The eNB may also grant a shorter value than requested when it knows that the UE is in a high-mobility state or the UE has already missed handover opportunities, as described below. The eNB can also consider how close the UE is to the cell's edge. If the UE is close to a cell's edge, the eNB can reject or indicate a shorter time value for the DRX.

[0074] If it is allowed by the eNB, the UE indicates a proposed value for a DRX period in the optional field of uplink scheduling requests. Even if the UE already has the uplink resources, the message is used without the actual resource request part for the DRX indication.

[0075] On the eNB, the eNB responds to the requests by indicating an allowed value for the DRX. The activation time is also indicated if the request for DRX is granted.

[0076] In some embodiments, the DRX request can be integrated in the UL scheduling request and DRX grant can be integrated in the UL scheduling grant.

[0077] The UE also considers its mobility and the likelihood of handover when requesting DRX values, which can be based on the channel quality measurement of the serving cell and its neighboring cells. The UE may also increase measurement frequencies independently to detect handover conditions more accurately, as described below. The UE may consider its mobility status, whether high or low, which may be based on positioning measurements, an accelerometer or the filtering of L1 data.

[0078] Reference is now made to **Figure 4a**. The process of **Figure 4** starts at step **400** and proceeds to step **410** in which the UE receives data.

[0079] The process then proceeds to step **412** in which the UE considers the data and optionally considers other factors as described above. Specifically, the UE may consider the mobility of the UE or the signal strength of neighboring cells.

[0080] Based on the considerations of step **412**, the process proceeds to step **414** in which it requests a DRX in the L1/L2 uplink scheduling request.

[0081] Reference is now made to **Fig. 4b.** The process then proceeds to step **416** in which the eNB receives the request.

[0082] The eNB, in step **418** considers the request and other optional factors as described above. Specifically, the eNB may consider whether the UE has missed a cell handover opportunity before or is close to a cell boundary, or is highly mobile. In step **420** the eNB decides whether to allow the request of step **414** based on the factors in step **418**. If yes, the process proceeds to step **430** in which it signals that the request has been accepted. If no, the process proceeds from step **420** to step **440** in which the eNB can either reject the request completely or can suggest a shorter duration for the DRX.

[0083] Referring to **Fig. 4a**, the UE receives the response from the eNB in step **442**, and may acknowledge in step **444**.

[0084] As will be appreciated by those skilled in the art, a long DRX may lead to inaccurate handover decisions and executions by the UE. When activating the DRX, the receiver will have less measurement opportunity and thus the accuracy of the channel condition estimation is degraded. Due to the measurement accuracy degradation caused by DRX, the UE may miss a handover opportunity.

[0085] Based on the above, the eNB can reject the request or grant a shortened DRX value if it knows that the UE is located close to a cell edge. This decision can be based on the current timing adjustment value assuming its available, the UE mobility status, whether high or low, the number of handovers within a certain period considering cell radius or the number of occasions that the UE goes out of the serving cell or indeed knowledge regarding the actual size of the cell (e.g. macro, micro or pico). These are all factors that can be considered in step **418** of **Figure 4b**.

MEASUREMENT ACCURACY

[0086] A third factor for DRX in the LTE-ACTIVE state is the possibility of missed handover opportunities. Since the UE receiver is turned off during the DRX period, the measurement quality of serving and neighboring cells is likely degraded compared to a continuous measurement. This degradation may lead to premature handover or missed handover opportunities, which should be avoided to the maximum extent possible.

[0087] In order to reduce the number of premature handovers or missed handover opportunities in DRX, in a preferred embodiment the UE is allowed to have a

shorter measurement cycle than the DRX cycle when necessary. For example, if the channel quality of the serving cell is lower than a threshold value A, the UE may start continuous measurements or shorter measurement cycles to prepare for a possible handover condition. If it turns out to be a false alarm, i.e. if the channel quality obtained by the continuous measurement is greater than a threshold value B, the UE can go back to the measurement cycle equal to the DRX cycle. As will be appreciated by those skilled in the art, the two threshold values represent better channel conditions than a value that triggers handover so that a sufficient level of accuracy is obtained when required to evaluate handover conditions, thus missed handover opportunities can be reduced.

[0088] In one embodiment of the present disclosure, the measurement interval may be configured to be equal to a DRX interval divided by N where N is an integer. This would be in the situation where the mobile may be expecting a handover and/or there is high mobility.

[0089] The network can configure the thresholds and the shorter measurement cycles, and this can be signaled to the UE via broadcast information or an RRC measurement control message. The MAC-PDU header can indicate to the network the shortened DRX cycle value once the UE has shortened the measurement cycle.

[0090] An example of the above is when there is an RRC connection or a radio bearer is established. In this case, the eNB can indicate the two channel quality values to which shorter DRX is started and stopped respectively, and the ratio between measurement and DRX cycles.

[0091] On the UE, the UE acts on the RRC signaling and starts or stops the shorter measurement cycles according to the measurement of channel quality compared to the threshold values.

[0092] Reference is made to **Figure 5**. **Figure 5** illustrates various zones where the UE may be situated including threshold values to indicate the DRX cycle. In the first zone **510**, the DRX cycle equals the measurement cycle. The UE stays within this zone until it reaches a threshold **520** in which it needs to start a shorter measurement cycle.

[0093] The UE stays with the shorter measurement cycle until either the signal degrades to indicate a handover condition **530** or if the signal improves until it

achieves an upper threshold **540,** at which point the DRX cycle and measurement cycle equal each other.

[0094] Preferably the eNB signals the following information in the radio bearer set-up or in a measurement control message:

- A higher threshold value used to lengthen the DRX cycle. This higher threshold value indicates higher channel quality and/or signal strength;
- A lower threshold value used to shorten the DRX cycle. The lower threshold value indicates lower channel quality and/or signal strength;
- Time-to-trigger associated with the higher threshold value and the lower threshold value; and
- The handover condition, such as the "best cell changed" and the measurement cycle equals zero, indicating continuous measurement.

[0095] The diagram of **Figure 7** shows an example in which the channel quality or signal power (as indicated in measurement reports) goes below the lower threshold value (LTV) and then goes above the higher threshold value (HTV) without uplink data. In this case, the shortened measurement period is implemented between A and B, whereas the DRX cycle equals the measurement cycle before A and after B.

[0096] Figure 8 shows an example in which the channel quality or signal power (as indicated in measurement reports) goes below the lower threshold value (LTV) and then goes above the higher threshold value (HTV) with uplink (UL) data. In this case, the UE goes to a short measurement cycle if the channel quality is below the lower threshold value more than a certain duration (time to trigger). If there is uplink data, the UE starts an initial UL access procedure to obtain a UL resource grant by sending the scheduling request. The scheduling request or the header of the uplink MAC-PDU could indicate a request for a shorter DRX period. The eNB responds to the request by sending scheduling grant message with a preferred DRX value or the eNB could indicate a preferred DRX value in the next downlink MAC-PDU. When the scheduling grant is received or the downlink MAC-PDU is acknowledged, the eNB can start using the new DRX value. The figure then shows the channel quality or signal power (as indicated in measurement reports) goes above a higher threshold value for a certain duration (time to trigger).

The UE indicates a request for a longer DRX value in the scheduling request or in the header of the MAC-PDU if UL data is available. The eNB responds to the request by sending a scheduling grant message with a preferred DRX value and an indication to start the automatic mode or the eNB could indicate a preferred DRX value with an indication to start the automatic mode in the header of the next downlink MAC-PDU. When the scheduling grant is received or the downlink MAC-PDU is acknowledged, automatic mode is started with the initial DRX value specified by the eNB. If no data is available then the UE needs to send a L1/L2 control message to request the automatic increment of DRX.

[0097] The example of **Figure 9** shows a handover condition trigger. In this case, the signal is gradually degrading until it proceeds below a lower threshold value for a certain time to trigger, at which point, the UE starts using a shorter measurement. The UE then sees the handover condition for a certain duration (time to trigger). At this moment the UE initiates the UL access procedure and transmits a scheduling request in order to obtain UL resources for the measurement report message. DRX value of zero or a request for going back to continuous reception mode can be indicated in the scheduling request or in the MAC-PDU carrying the measurement report message. The eNB responds to the request by sending scheduling grant message with the preferred DRX value of zero or the eNB could indicate a preferred DRX value of zero in the next downlink MAC-PDU. When the scheduling grant is received or the downlink MAC-PDU is acknowledged, both sides deactivate DRX. On handover, the UE receives a handover command and obtains downlink synchronization to the target cell. The UE then indicates the channel quality and/or signal strength of the target cell in the handover complete response. The eNB can then evaluate when it is safe to activate DRX. If so the eNB indicates DRX activation in the downlink (DL) MAC-PDU header or L1/L2 control signaling.

[0098] In the above paragraphs, the requests made by the UE for a shorter or longer DRX period or the DRX value itself are in the scheduling request or the header of the uplink MAC header. The eNB responds to the UE, by specifying the preferred DRX period with an indication if an automatic DRX increase/decrease rule can be applied, within the scheduling grant or downlink MAC-PDU header.

[0099] In another embodiment, the scheduling request indicates the cause of uplink access. For example, suppose that during a DRX period of 2.56 seconds a VOIP call is originated. In order for the network to respond the VOIP call setup promptly, the UE sends the scheduling request with a cause of uplink access, e.g. call setup. The eNB replies to the request by sending a scheduling grant indicating a DRX value of zero (the preferred DRX value).

DETECTION AND HANDLING OF VERY LATE HANDOVER

[00100] In order to utilize the DRX in the LTE_ACTIVE state, a standardized criterion for the UE to determine if a handover opportunity is missed is preferable. If such a condition is satisfied, the UE should establish a connection to a neighboring cell rather than the serving cell. As will be appreciated by those skilled in the art, in the LTE infrastructure, only network based handover procedures apply and there are no UE based procedures such as cell reselection as used in UMTS.

[00101] If, in a preferred embodiment, the channel quality of the serving cell is less than a neighboring cell by a threshold value C for a certain time duration T, the UE is required to connect itself to the neighboring cell on the target eNB. The value C and T can be signaled by system broadcast information or RRC signaling.

[00102] The process for switching to the target eNB includes the steps of :

1. Start UL initial access procedure to obtain a timing advance value for the target cell and uplink resources for the subsequent control messages;
2. Transmit a reconnect request to the target eNB with the current RNTI (radio network temporary identifier) and previous cell ID;
3. The target eNB contacts the serving eNB in order to obtain the UE context and downlink data needs to be transferred. The target eNB also connects itself to the access gateway and removes the serving eNB from the aGW; and
4. The target eNB transmits a reconnect response to the UE with a new RNTI and uplink grant.

[00103] An optional component includes a status message to be carried over the reconnect request and response so that the amount of data transferred

between the target and serving eNB and between the target and serving eNB and the air interface with the UE can be minimized.

[00104] Optimizations include the reconnect request in step 2 above to be sent with a status report showing the PDCP (packet data convergence protocol) SDU (service data unit) sequence numbers which the UE has received successfully. This information helps to reduce the amount of downlink user data to be transferred from the serving to the target eNB and over the air to the UE. Since the RLC is likely reset in the procedure, PDCP SDU sequence numbers need to be used.

[00105] Likewise, the reconnect response can be sent with a status report showing PDCP SDU sequence numbers which the serving eNB receives successfully so that the UE can retransmit data that was missed.

[00106] Further, if the target eNB finds that there is no data to be transferred from the serving eNB and from the aGW, the reconnect response indicates DRX activation.

[00107] The above is illustrated in **Figure 6a** in which, in step **612**, the UE obtains a timing advance value for the target cell and uplink resources for the subsequent control messages. The process then proceeds to step **614** in which the UE transmits a reconnect request to the target eNB with the current RNTI and cell ID. The UE then waits for and acknowledges a response from the target eNB in step **650**.

[00108] Referring to **Fig. 6b**, the target eNB receives the request at step **615** and then proceeds to step **616** in which the target eNB contacts the serving eNB in order to obtain the UE context.

[00109] In step **618**, the target eNB transmits a reconnect response to the UE with the new RNTI and uplink grant.

[00110] The above can be implemented on any UE. Such UEs include, but are not limited to, personal digital assistants, cellular telephones, wireless data devices, among others.

[00111] The embodiments described herein are examples of structures, systems or methods having elements corresponding to elements of the techniques of this application. This written description may enable those skilled in the art to make and use embodiments having alternative elements that likewise

correspond to the elements of the techniques of this application. The intended scope of the techniques of this application thus includes other structures, systems or methods that do not differ from the techniques of this application as described herein, and further includes other structures, systems or methods with insubstantial differences from the techniques of this application as described herein.

Claims:

1. A method of DRX signaling in a long-term evolution infrastructure between an evolved node B (eNB) and user equipment (UE), the method comprising the steps of

providing a DRX value in a header of a medium access control protocol data unit (MAC-PDU);

acknowledging the MAC-PDU; and

activating, deactivating or reconfiguring DRX based on the provided DRX value.

2. The method of claim 1, wherein the activating of the DRX step is delayed by a period.

3. The method of claim 2 wherein the period of the delay is limited by a first threshold, said first threshold being configured to handle possible negative acknowledgement (NACK) to acknowledgement (ACK) misinterpretations.

4. The method of claims 2 or 3 wherein the period of the delay is limited by a second threshold, the second threshold being set for the UE to wait for a retransmission due to possible ACK to NACK or discontinuous transmit misinterpretation.

5. The method of claim 1, further comprising recovering from a possible negative acknowledgement (NACK) to acknowledgement (ACK) misinterpretation by the eNB providing a DRX indication in multiple downlink MAC-PDUs.

6. The method of claim 1, further comprising recovering from a possible negative acknowledgement (NACK) to acknowledgement (ACK) misinterpretation by checking channel quality indicator (CQI) frequency at the eNB.

7. The method of claim 1, further comprising recovering from a possible negative acknowledgement (NACK) to acknowledgement (ACK) misinterpretation upon receipt of a Timing Advance (TA) Request message at the eNB.

8. The method of any one of claims 2 to 7 wherein the period of the delay is limited by a third threshold, the third threshold being set to allow the UE to check the layer 1/layer 2 (L1/L2) signaling channel for a high speed shared control channel indication that data is transmitted on high speed physical downlink shared channel.

9. The method of claim 2, wherein the period of the delay is limited by:

a first threshold, said first threshold being configured to handle possible negative acknowledgement (NACK) to acknowledgement (ACK) misinterpretations;

a second threshold, the second threshold being set for the UE to wait for a retransmission due to possible ACK to NACK or discontinuous transmit misinterpretation; and

a third threshold, the third threshold being set to allow the UE to check the layer 1/layer 2 (L1/L2) signaling channel for a high speed shared control channel indication that data is transmitted on high speed physical downlink shared channel

wherein the period is set to greater than the maximum of the first threshold and the second threshold, added to the third threshold value.

10. The method of claim 9 wherein the threshold value is signaled by the radio resource control.

11. The method of any one of claims 1 to 10, wherein the DRX value is increased by both the UE and the eNB in a predetermined manner without any explicit signaling, the predetermined manner comprising the steps of:

checking that no data has been received within N DRX cycles, where N is an integer; and

if no data has been received in the N DRX cycles, increasing the DRX cycle by a pre-specified amount.

12. A method of leveraging application level traffic characteristics to improve battery life or for signaling traffic characteristics to improve system response time of user equipment (UE) communicating with an evolved Node B (eNB) comprising the steps of:

requesting, from the UE, a discontinuous reception (DRX) based on application traffic characteristics of the UE;

receiving the request from the UE at the eNB; and

granting, negotiating an alternative period or rejecting the request at the eNB.

13. The method of claim 12 further comprising the step of specifying, at the eNB, a preferred value with an indication if automatic DRX increment/decrement is allowed in response to the UE request.

14. The method of claim 12, wherein the requesting step indicates a request for an increase or decrease of a current DRX period.

15. The method of claim 12, wherein the requesting step indicates a cause of uplink access.

16. The method of claim 12, wherein the requesting step specifies a value for the DRX.

17. The method of claim 16, wherein the value is set by the UE based on the application level traffic characteristics.

18. The method of claim 17, wherein the UE further sets the value based on one or more of whether it knows it is located close to a cell edge, whether the UE knows it is highly mobile and whether the UE has missed a handover.

19. The method of claim 18, wherein the mobile knows it is highly mobile based on one or more of: positioning measurements for mobility status, use of an accelerometer for mobility status, and based on L1 measurement filtering.

20. The method of claim 12, wherein the eNB rejects the request from the UE based on one or more of: knowledge at the eNB that the UE is highly mobile, knowledge at the eNB that the UE is close to a cell edge; and knowledge that the UE has missed a handover.

21. The method of claim 12 wherein the eNB suggests a shorter DRX value in the granting step.

22. A method for improved measurement accuracy during discontinuous reception (DRX) on user equipment (UE) comprising the steps of :

checking whether a channel quality of a serving cell is lower than a first threshold for a predetermined time period; and

if yes, shortening the measurement cycle to have a shorter measurement cycle than the DRX cycle.

23. The method of claim 22, wherein the shorter measurement cycle is the DRX cycle divided by N, wherein N is an integer.

24. The method of claim 22, wherein the method further comprises the step of:

monitoring whether the channel quality of the serving cell increases to greater than a second threshold for a predetermined time period, the second threshold being greater than the first threshold; and

if yes, setting the measurement cycle to be the same as the DRX cycle.

25. The method of claim 22 wherein the method further comprises the step of monitoring whether the channel quality of a serving cell falls below a third threshold, and if yes, initiating a handover procedure.

26. A method of handling missed handover opportunities based on discontinuous reception (DRX) in user equipment (UE) comprising the steps of:

checking whether a channel quality and/or signal strength of a serving cell is less than the channel quality and/or signal strength of a neighboring cell by a threshold value for a certain time duration; and

if yes, connecting to the neighboring cell.

27. The method of claim 26 wherein the threshold value and the time are signaled by a system broadcast or by radio resource control signaling.

28. The method of claim 26 further comprising the steps of:

obtaining a UE transmission timing advance value for the neighboring cell and uplink resources for subsequent control messages;

transmitting a reconnect message to a target evolved node B (eNB) of the neighboring cell with current radio network temporary identifier (RNTI) and cell identifier information;

contacting, from the target eNB, the serving eNB in order to obtain the UE context and downlink data needs to be transferred; and

transmitting, from the eNB, a reconnect response to the UE with a new radio network temporary identifier and uplink grant.

29. The method of claim 28 wherein the transmission of the reconnect request is sent with a status report showing packet data convergence protocol service data unit sequence numbers that the UE has successfully received.

30. The method of claim 28, wherein the transmission of the reconnect response includes packet data convergence protocol service data unit sequence numbers that the serving eNB successfully received.

31. The method of claim 28, wherein the target eNB can activate DRX if no data is to be transferred.

32. An evolved node B (eNB) operating in a long-term evolution infrastructure, the ENB being characterized by means for:

providing a DRX value in a header of a medium access control protocol data unit (MAC-PDU); and

activating or deactivating DRX based on the DRX value.

33. A user equipment (UE) operating in a long-term evolution (LTE) infrastructure, the UE being characterized by means for:

receiving a DRX value in a header of a medium access control protocol data unit (MAC-PDU)

acknowledging the MAC-PDU; and

activating deactivating, or reconfiguring DRX based on the DRX value.