

Video performance using adaptive DRX Switching for LTE-A

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Abstract—The DRX (Discontinuous Reception) mechanism is the currently used technique for power saving in mobile devices. This approach is also utilized for LTE-Advanced and efforts are being made in order to enhance the performance of this mechanism. The currently used algorithm saves power in trade-off with delays. Using the same DRX configurations all the time with various traffic characteristics is not efficient when the aim is to achieve better performance. Lower delays and lower power consumption levels could be realized by implementing an efficient adaptive DRX approach. The proposed scheme for LTE-Advanced implements adaptive DRX configuration switching based on the traffic characteristics by tuning the DRX configurations to achieve the required power saving while at the same time keeping delays to a minimum and improving the mobile device's performance. Preliminary results indicate that a multi-DRX configuration is an effective way to achieve the best performance. In this contribution, the performance of the power saving mechanism for different types of video streaming such as: low resolution, high resolution and Full HD quality videos will be presented. The DRX configurations are switched based on the traffic characteristics in order to avoid limitations, such as overhead and the trade-off between delays and power saving, while taking into account the performance of other running processes such as HARQ, scheduling and handovers.

I. Introduction

LTE and LTE-advanced offer a large bandwidth compared with the legacy technology of 3G and this enables video data streaming close to real time over the wireless mobile networks. The increased capacity over the air for LTE-A enabled a diversity of data applications such as Facebook, YouTube, and Skype to be developed and to become popular. This new generation of mobile device applications increased the power consumption of wireless devices due to the nature of the generated packets from such applications.

DRX (Discontinuous Reception) has been adopted for power saving for wireless terminals. DRX saves the wireless terminal battery life by enabling the UE to switch off its transceiver circuit whenever there is no traffic sent to it by its serving cell. Therefore, the UE spends less time on monitoring the downlink control channel searching for its dedicated data and energy is saved. However, DRX energy saving comes at the expense of potential delays due to the configured DRX sleeping cycles, and delays are a serious issue especially with video traffic.

Understanding the traffic models and the ability to anticipate the traffic behaviour for different applications plays an essential role in adopting new algorithms for future networks so that performance is improved and power consumption can be estimated accurately. The mobile's battery life has to keep pace with evolution in the mobile

industry and its technology. The DRX approach for power saving is expected to continue for future releases of LTE systems, with new developments to the current DRX standard. DRX is a flexible mechanism and several factors can be implemented to control its performance according to the UE's preferences. Although DRX was originally devised to save power, evolving technology has extended the effects of this mechanism to the whole system and application performance.

As mentioned earlier, power saving is achieved in trade-off with delays which decrease throughput. The DRX timers' configurations have a major impact on the power saving performance and throughput.

Nowadays, user-generated video streaming is becoming more and more widespread and this loads the wireless networks with different types of applications and traffic. However, power consumption and consequently battery life of smartphones is a limiting factor. The currently proposed methods to save energy in this regard introduce undesirable delays, such as video frames bundling when the generated frames are buffered for a period of time before being transmitted [1].

In this work, the importance of DRX switching for UE video performance is highlighted. A mechanism for DRX switching is introduced for exchanging DRX settings between eNB and UE and the DRX configuration switching will be discussed so that the optimum DRX parameters are selected for the employed video streaming.

The outline of this paper will be as following, section two will introduce the full DRX process for LTE systems, then the DRX analytical model is presented in section three. Section four will introduce the optimization problem and the simulated scenarios with the results. Section five presents the conclusions and future work.

II. DRX process for LTE-A systems

Different DRX states and state transitions are illustrated in Fig. 1. The DRX state of the UE is determined by the following:

- **DRX Inactive or Normal:** In the DRX Inactive (or Normal) state, power consumption is the highest. The UE enters the Normal state when it either suspends its DRX cycle and starts the inactivity timer (A) or receives higher layer data that needs to be transported to the eNodeB on the uplink (N).
 - An inactivity timer starts after the reception of a packet on the downlink.
 - If the UE receives a new downlink packet while it is running the inactivity timer, the inactivity timer is restarted (V).
 - If no other packets are received before the timer expires, the UE enters the DRX cycle, thus beginning a power savings mode (K).
 - The UE may still enter the Normal state while it is running the

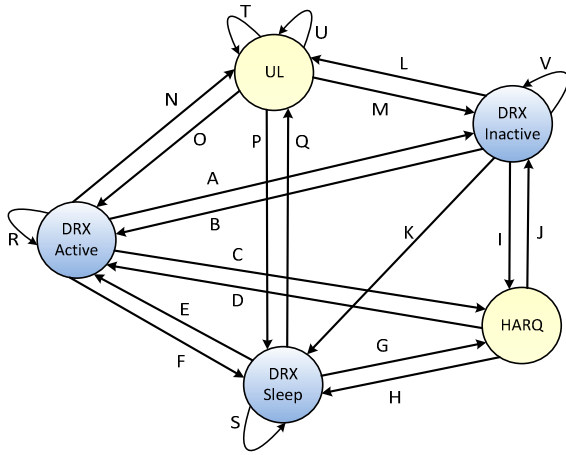


Fig. 1a. DRX process model.

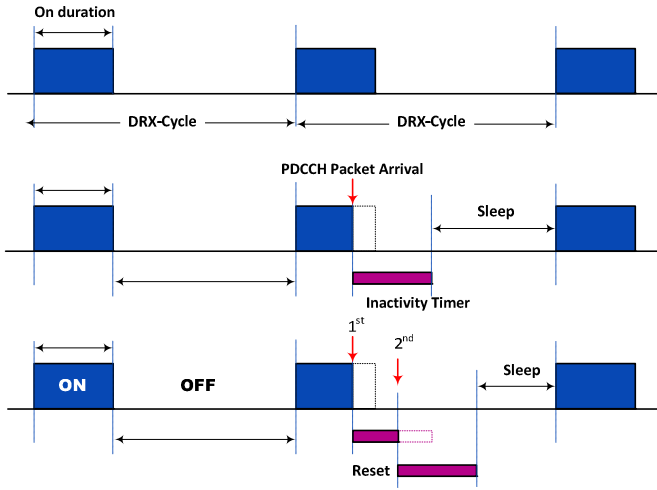


Fig. 1b. DRX timing.

DRX cycle (in either an Active or Sleep period) when it receives higher layer data (N, Q and L)

- **DRX Active:** when the UE enters the RRC_Connected state, it starts the DRX cycle that consists of the “On” duration (DRX Active) and the “Off” duration (DRX Sleep).
 - During the DRX Active period, the UE scans the PDCCH for any downlink control indicators (DCI) that indicate downlink MPDUs to be received from the eNodeB. If such a packet arrives, the UE terminates the DRX cycle and enters the Normal state (A).
- **DRX Sleep:** when the “On Duration Timer” expires, if no MPDUs are being received, the UE enters the DRX sleep state, which provides maximum power savings (F).
 - When the UE enters the sleep period, the sleep timer starts and the UE does not receive any downlink data. The eNodeB caches data until the UE enters the DRX Active period again (E) at the end of the short DRX sleep period.
 - Only the arrival of higher-layer uplink data (UL state) or the expiration of sleep period will end the DRX cycle (Q).
 - At the end of the short DRX sleep period, the UE enters the DRX active period again and scans for transmissions.

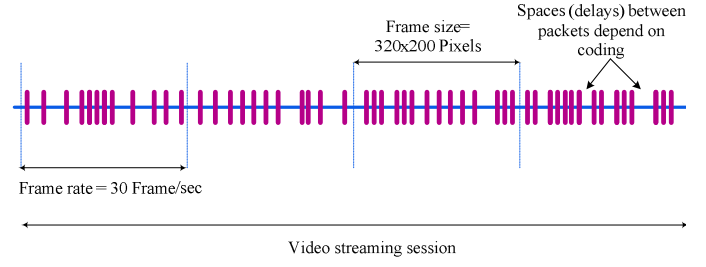


Fig. 2 Video streaming traffic model

Table 1 Video Types

Type	Resolution	Bit Rate (kb/s)
CGA	320x200	293
EGA	640 x350	802
HD	1280 x720	2433
Full HD	1920 x1080	4656

- Hybrid Automatic Repeat Request (HARQ state) is considered to take into account the packet processing delays and processing HARQ ACKs/NACKs in both the uplink and the downlink

III. Methodology

Video streaming is a one way traffic. Fig. 2 shows the traffic model of the video streaming as viewed by the eNB. Data arrive in frames (sliced into packets) on regular intervals – frames per second, and delays, are related to the encoding process. Buffering is used with video streaming to mitigate jitter and ensure that the display is not interrupted. The transport protocol is the UDP and the performance of the application depends on the streaming interarrival times and the frame size information. TCP could be used but this would cause multiple independent sessions to be opened. Video parameters used are shown in Table 1.

In this work, a scheme is proposed to optimize the DRX parameters in order to achieve the best performance in terms of power saving and low latency. This scheme is implemented by introducing preferences for the DRX configurations for each of the video streaming types by considering the different packet interarrival times. The same analysis method followed in [2] is going to be used to model the state transitions among different DRX states and derive the average power consumption and delays for the DRX cycle. The state transitions of DRX process shown in Fig. 1 will be modelled as a Semi-Markov process model.

The average delays (D) and power consumption (P) during one DRX sleep cycle, assuming an exponential distribution of frames with a frame interarrival time of $1/\lambda$ (0.02s) are:

$$D = (1 - e^{-\lambda T_s})e^{-\lambda(T_{IN}-T_s)} \left(T_s - \frac{1}{\lambda}(1 - e^{-\lambda T_s}) \right)$$

$$P = \left(\frac{1 - e^{-\lambda T_{ON}}}{\lambda} \right) P_{ON} + \left(\frac{1 - e^{-\lambda T_{IN}}}{\lambda} \right) P_{IN}$$

$$+ (T_s(1 - e^{-\lambda T_s})e^{-\lambda(T_{IN}-T_s)}) P_S$$

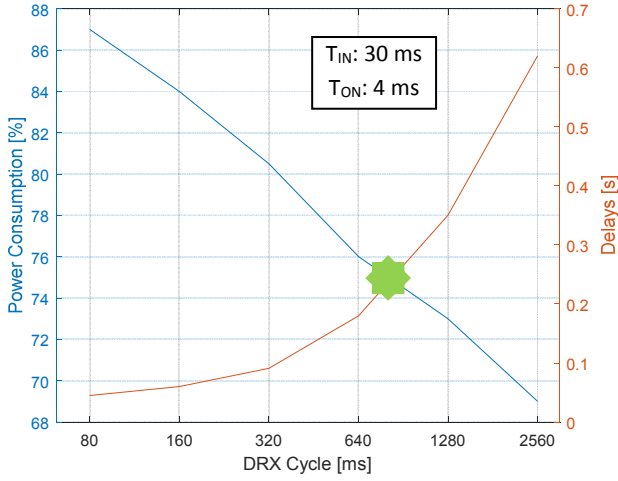


Fig.3 DRX delays and power consumption.

Where:

T_{ON} is the ON duration timer, and P_{ON} is the operating power in the active state ($P_{ON} = 40$ mW).

T_{IN} is the inactivity timer, and P_{IN} is the operating power in the normal (or inactive) state ($P_{IN} = 100$ mW).

T_S is the DRX sleep period, and P_S is the operating power in sleep state ($P_S = 10$ mW).

Error! Reference source not found. Fig. 3 shows an example of delays and power consumption in response to the number of arrived packets during the active period. Depending on the used parameters of the DRX cycle and the values of the timers, there is an optimal operation point that corresponds to the lower costs according to the packet interarrival times. From Fig. 3 it is obvious that there is an optimum configuration for the timers and this depends on the number of arrived packets (or packet/ frame interarrival time) for the active traffic. The higher values of DRX cycle and inactivity timer are preferable and yield a lower latency and power consumption with higher interarrival packets. Therefore longer DRX cycles are recommended for traffic with lower interarrival time where less number of packets is expected to be received during the wake up period. This approach creates an adaptive DRX mechanism and helps the wireless terminal to enter sleep periods (off periods) for longer times.

The presented work investigates the benefits of power saving preferences switching and adjusting the configured DRX parameters depending on the application types requested by the UE. To present this, DRX is configured with different sets. Some of these are for optimizing power consumption and others for accounting for delays. It is shown that DRX switching improves latency performance while maintaining the power saving.

In order to achieve the maximum DRX performance, it is not practical that the UE continuously uses the same DRX configurations. In order to take appropriate actions, regarding the optimum selections of DRX parameters it is necessary to evaluate the performance over different parameter combinations in any video streaming traffic type. Therefore, based on the selected video type, the corresponding DRX parameters are determined. Different DRX sets are defined and the optimal set can be selected at any time based on the characteristics of the running application and also base on the power preferences at the UE side. The power savings attributes in OPNET 18 is used to define multiple sets of DRX at both eNB and UE.

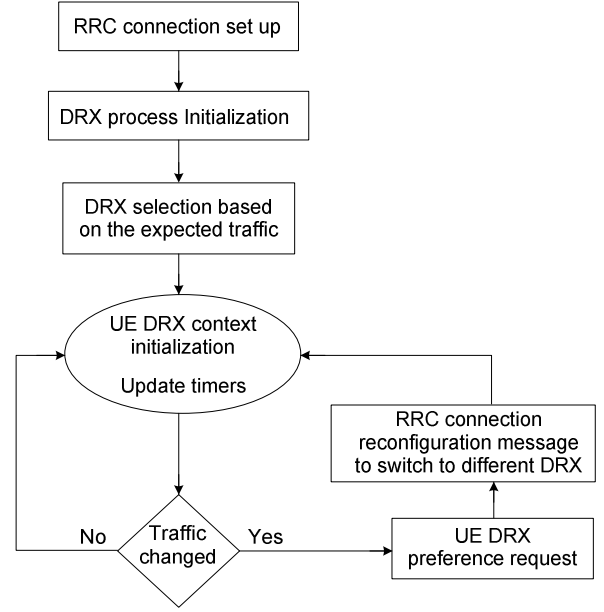


Fig.4 DRX Switching Scheme.

The best performance for each video streaming type will be assigned an optimum set of parameters and this will be employed to improve the performance of DRX for smartphones prior to launching the video application.

Unlike most DRX schemes proposed to improve energy efficiency of smartphones [3], [4], [5], the scheme proposed in this work does not require to perform DRX reconfiguration. Therefore, it does not increase RRC signalling overhead which reduces the energy efficiency due to the processing required by UEs. Our proposal just requires setting the DRX configurations that best serve the quality of the chosen video application.

DRX may be configured in the RRC-Connected mode automatically if the inactivity timer expires without arrival of any downlink data, or it can be configured by the eNB by sending the MAC Control Element of the DRX Command to the UE. For starting the DRX process an offset is used and transmitted by the eNB to initiate the DRX on the UE. An RRC-Connection start up message is sent with the offset value. Upon receiving the offset value, the UE configures it at the start of the next frame following the reception of the RRC message. Both the UE and the eNB follow the same procedure to calculate the offset, and thus synchronisation and exchanging DRX settings are maintained [6].

The switching mechanism is presented in Fig.4. The UE and the serving eNB select one of the DRX parameter sets during the UE attach procedure. The UE receives the parameters configurations through the RRC connection set up, the RRC connection reconfiguration message (which is a command to modify an RRC connection and contains modification of the DRX configuration) and sometimes through the MAC-MainConfig [7, 9]. Updates may take place explicitly every 200 ms when running the DRX process and OPNET supports updates at the time of the MPDU delivery to insure that updates take place for all UEs who receive downlink traffic. The video types depends on different issues such as the link quality and power preference at the UE side. The DRX context is initialized for every UE by the access stratum layer which is also responsible for the initialization of the DRX synchronization time and keeping the records updated by monitoring the DRX records for associated UEs every 200 ms. The subframe number needs to be recorded for the DRX process in order to be used later by the DRX logic for determining if retransmissions are possible for a specific UE or not. After the UE expresses its power preferences, it may request a specific DRX setting based on expected video traffic

	Inactivity timer (ms)			
Type	8	10	20	30
CGA	62	59	57	55
EGA	60	57	54	52
HD	56	55	53	50
Full HD	52	51	50	48

Fig.5a. Sleep time (%), DRX=60 (ms)

	Inactivity timer (ms)			
Type	8	10	20	30
CGA	73	64	60	58
EGA	64	63	59	56
HD	61	60	57	55
Full HD	55	53	52	50

Fig.5b. Sleep time (%), DRX=360 (ms)

	Inactivity timer (ms)			
Type	8	10	20	30
CGA	0.026	0.02485	0.01901	0.0132
EGA	0.02	0.018	0.016	0.012
HD	0.018	0.017	0.013	0.011
Full HD	0.01	0.0011	0.001	0.0009

Fig.6a. DL Delays (s), DRX=60 (ms)

	Inactivity timer (ms)			
Type	8	10	20	30
CGA	0.038	0.027	0.022	0.015
EGA	0.027	0.022	0.021	0.004
HD	0.026	0.024	0.021	0.0033
Full HD	0.014	0.0033	0.003	0.003

Fig. 6b. DL Delays (s), DRX=360 (ms)

characteristics. After the initial DRX parameters selection, the UE maintains DRX operation with the selected DRX settings unless there is a need for a DRX parameter update, e.g for a different traffic type. The DRX switching is performed in such a way that it is aligned with the start-end of different applications profiles at the UE side.

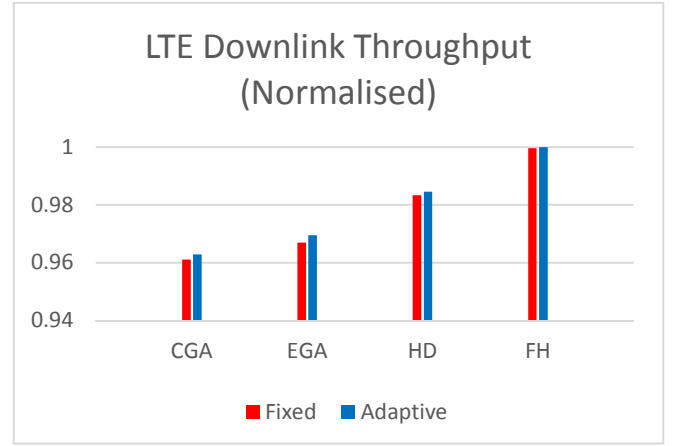


Fig.7. Downlink throughput.

IV. Simulation Results

OPNET 18 is used for simulation and modelling the different types of videos, power preferences and interarrival time. Since DRX sleep is the minimum power consuming state of UE, the percentage of time spent in DRX sleep has been chosen to estimate the UE's battery power saving. Fig.5 shows a comparison between the sleep time percentage for the DRX cycle (ms) and the values of inactivity timer (ms) for the end user with different types of videos. When DRX cycle period is increased from 60 ms to 360 ms for the same value of the inactivity timer, this results in an increase in the sleeping period which means that the UE sleeps for longer duration each cycle and this indicates an improvement in the power saving. It is obvious from the figure that due to the high bit rate of Full HD type, the sleeping period is lower compared with the other types because the interarrival rate of the packets is higher and will keep triggering the inactivity time and interrupts the DRX cycle. With other types of videos, the bit rate is lower compared with the Full HD type, the sleeping period increases and more power saving is achieved. On the other hand and as shown in Fig.6 it is obvious that the delay increases with the increase in the DRX cycle and decrease in the inactivity timer because there is higher probability that the UE enters the sleeping mode. According to the running video type, delay performance differs depending on the packet interarrival time and inactivity timer value. For the Full HD type, because the interarrival rate is higher compared with other types, the effect of inactivity timer is small but the DRX cycle still has a significant effect. In order to meet the latency requirement with optimum DRX parameters, the chosen DRX cycle value has an important role for the delay performance of the running active traffic. For the Full HD type, shorter DRX cycle periods will satisfy the delay requirements at the expense of more power consumption; while power optimized DRX parameters provides higher power savings and longer battery life.

In general, energy saving is accompanied with a decrease in the throughput. Here the throughput could be maintained compared with the fixed method and sometimes enhance it. Normally, according to the scheduling mechanism at the eNB, bearer context

requests and scheduling requests are sent from the UEs, and each UE is allocated a specific bearer. Hence there is a difference between one UE and another over the uplink and the downlink throughput, but the overall system throughput is stable and improving. Throughput stability is related to the improvements in packet delays and losses, in addition to the flexibility in allocating the DRX parameters according to the UEs preferences. When implementing power-saving algorithms, a little throughput loss is accepted and QoS requirements (QoS Class Identifier) define a minimum level for throughput decrease and packet delay budget provided by LTE which should not be exceeded in order to maintain efficiency. In the adaptive mode, the UEs have the ability to exploit the granted allocated resources in a quicker manner before the DRX process is invoked and UEs enter the energy-saving mode. During simulation and according to different application sessions, the throughput level between fixed and adaptive approaches is comparable (Fig. 7). Using multiple sets of DRX parameters and switching among them according to UE preferences has proved to be beneficial. The packet interarrival rate of the simulated video conferencing is used by the UE to switch between the three sets of DRX parameters (DRX cycle: 160, 320 and 640 ms) and the inactivity timers value are (10, 20 and 30 ms). Fig. 7 shows a reduced packet end-to-end delay for the adaptive switching DRX method compared to using the same parameters of DRX (the fixed DRX) for video conferencing. Furthermore, this has a positive impact on the system throughput which shows an increase as indicated in Fig. 8. This improved performance is related to the reduction in the packet delays and losses because of the longer periods of DRX cycles allocated to users during short interarrival periods.

V. Conclusions

A special emphasis has been put on the benefits of DRX switching to adapt the DRX configurations according to the employed traffic type. This has an immediate impact on a smartphone's energy consumption and on buffering delays. Our preliminary results indicate that there are optimum power saving parameters and the best performance is achieved by adopting adaptive DRX process parameters depending on the video type and not simply using the conventional fixed DRX parameters. Adaptive DRX and switching parameters provide a good balance between energy savings and latency requirements for different types of applications for future LTE-A systems.

VI. References

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