Tradeoff Between Performance and Energy-Efficiency in DRX Mechanism in LTE-A Networks

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***Abstract*—One of the most concerning issues in current wireless technology is managing the energy consumption in the User Equipment (UE). LTE-A brings along with its massive data transmission speeds with a caveat of heavy energy consumption. Energy saving albeit, comes at the cost of Quality of Service (QoS), which is the delay in serving packets in the UE. The Discontinuous Reception Scheme (DRX) is an energy saving scheme in LTE-A networks. Given the parameters of DRX, there is a tradeoff between the energy saving and QoS. The modelling and theoretical results for one-way and two-way communications with DRX are presented in [2]. In this paper, the simulation results of one-way and two-way communications with the DRX scheme are presented.**

I. INTRODUCTION

3rd Generation Partnership Project (3GPP), which is considered as the bridge of the IMT-2000 system and IMT-Advanced system, is recently in the process of defining Long-Term Evolution (LTE) of 3G [5]. The key metrics to be improved in LTE performance are higher bit-rates and lower latencies. As the data bandwidth depends upon the battery capacity of the UE; hence, the power saving in the UE is a significant research problem for wireless data transmission. Therefore conserving the battery also becomes a vital metric in the performance analysis of LTE networks [1].

Power saving is the most concerning issue in the UE for a limited source of power in LTE-A networks. The battery power of a UE gets exhausted quickly due to the excess use of many service applications and heavy data transmission. In the LTE-A networks, DRX is a mechanism used for power saving in UE. In the target networks, a key mechanism to allow low power utilization without dealing with the QoS is the ability to predict when UE will be active, and when it will be asleep.

The objective of the DRX scheme is to switch the UE into sleep mode for a maximum length of time and keeping the QoS (delay of a packet) within a fixed threshold. This threshold depends on the application (voice, multimedia, etc.) [2]. In the LTE-A network, while the DRX scheme is subscribed with evolved Node (eNB), the UE enters into sleep mode, which leads to more amount of power saving. This is the fundamental difference between the DRX mechanism and other schemes.

Therefore, there is a tradeoff between the energy savings and the delay experienced [7]. Theoretically, energy saving can be made to achieve almost 100%, but then the delay would also be too large for any communication to be made possible. Henceforth, in the following sections, various parameters are varied to show the effect on delay as well as power savings [9]. The results from the following variations show the tradeoff between energy saving and the QoS.

The study is carried out via simulation. Using a fully-fledged C++ based simulator NS3, which includes detailed models of all the layers and functions of LTE, models of applications and mobility, and relevant QoS metric [6]. The QoS metric observed is the delay, that is the time between the arrival and serving of a packet.

The rest of this article is organized as follows. Description of the DRX Mechanism is given in Section II; what is the Topology of the Architecture used in the simulation is discussed in Section III. Section IV briefly presents the steps involved in the simulation. Moreover, the simulation and the theoretical results are presented and discussed in Section V, the paper is concluded in Section VI along with the future work.

II. THE DRX MECHANISM

Fig. 1 shows the DRX mechanism. Its parameters are discussed in brief as follows: DRX mechanism is comprised of two states, power active state and power saving state [4].

- Inactivity timer: It refers to the period for which the UE waits before starting the DRX. It works as a timer that initiates itself after the successful reception of packets on the PDCCH (Physical Downlink Control Channel). The

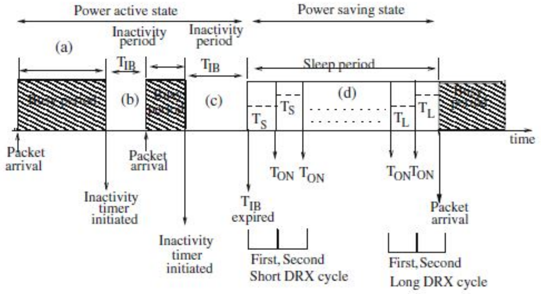

Fig. 1: Discontinuous Reception Scheme

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UE enters into a short DRX cycle on the expiration of the inactivity timer.
- On duration timer: It is the length of a short time interval inside the DRX cycle towards its end. The UE monitors the PDCCH for the arrival of a new packet during the ON period. A packets arrival indication at the PDCCH during the ON period wakes up the UE, and it begins to serve the data packet [3].
- Short DRX cycle: It is a length of the first DRX cycle after the initiation of the DRX mechanism in UEs. This short cycle is repeated for a predetermined number of times if no data packet arrives and ends otherwise. During this period, the UE turns off most of its components.
- Long DRX cycle: It is a length of the first long DRX cycle, which initiates on the expiration of the short DRX cycle if no data packet arrives. Also, this cycle repeats for a predetermined number of times. This cycle consists of two parts, sleep period and ON period.
- Busy period: It is the time duration for which the UE provides service to the data packets after waking up from DRX.

One of the advantages of the DRX mechanism is that when the UE is registered with the eNB, even then, the DRX mode can be enabled [2]. However, to maximize power saving without incurring network re-entry and packet delay, there is a need to optimize the DRX parameters. Hence to state that different applications like multimedia, voice, etc. will have different thresholds for QoS, i.e., delay. A real time application will have a lesser threshold, and on the contrary, a non real time application will have a larger threshold. Therefore, the DRX parameters for such applications will also be different for optimal battery savings and maintaining the QoS.
There are some terminologies defined below:

- eNB(Evolved Node B): It is a main building block or system in LTE-A networks. It provides the interface with UEs. It has similar functionality as base stations used in cellular systems.
- RRC(Radio Resource Control): It is a protocol used in LTE networks. It is a layer that exists between the UE and eNB node.
- MME(Mobility Management Entity): It is a major control plane element in LTE-A architecture. It takes care of authentication and authorization related security functions.
- PDN Gateway(Packet Data Network Gateway): The PGW element acts as a bridge between 3GPP and non-3GPP technologies. 3GPP technologies include LTE and LTE-A standards, and non-3GPP may include WiMAX, etc. A UE connects to any external Packet Data Network through this gateway.
- SGW(Serving Gateway): The main purpose this gateway serves is to link the PDN-Gateway using the S5 protocol and to handle the inter-eNB handover algorithms. It also serves an additional purpose of interception of packets, packet routing, and also the forwarding of packets.
- EPC(Evolved Packet Core): The EPC is a multi-access core network based on the Internet Protocol (IP) that enables operators to deploy and operate one common packet core network for 3GPP radio access (LTE, 3G, and 2G), non-3GPP radio access.

III. THE TOPOLOGY OF THE ARCHITECTURE USED IN SIMULATION

The topology on which the implementation has been achieved makes use of the LENA (LTE + EPC) module of the NS3 simulator, and Fig. 2 shows the same. In the LTE-EPC architecture use of two eNB nodes and two UE's are used. Each UE is connected to a respective eNB node and is kept stationary.

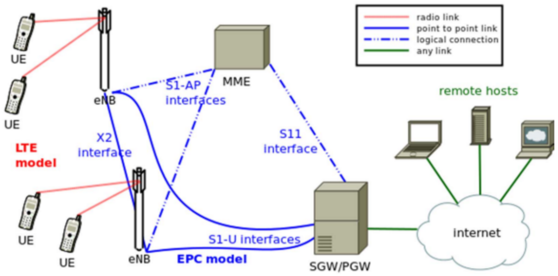

Fig. 2: Topology of the architecture used in simulation

The task is to establish communication between the two UE's connected with the same eNB node such that they start sending and receiving packets to each other. Between this communication establishment, the Discontinuous Reception Scheme (DRX) has been implemented for energy saving. Once the simulation completes values for the time period, the RRC was in ACTIVE mode, i.e., when UE is in power active state, then RRC goes in IDLE mode, i.e., when UE is in power saving state and the number of switches from IDLE to ACTIVE mode, is obtained. Using this information, the amount of energy consumed in the simulation is deduced [2].

IV. SIMULATION STEPS FOR ONE-WAY AND TWO-WAY COMMUNICATION

The following are the brief steps of the carried out simulation [8].

1) Create the PGW Node using the EPC helper of NS3.
2) Create a single remote host.
3) Create the internet and install it on the remote host, and connect the host to the PGW node
4) Create the UE and eNB nodes and install the LTE module on them.
5) Assign a constant mobility model to the UE and eNB nodes. Connect the UEs to the eNB nodes.
6) Create a socket on UE devices to monitor packet traffic.
7) Create a MyApp application, which contains the DRX scheme. This application is installed on the UE devices.
8) Parameters of the DRX mechanism and packet traffic are assigned.

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9) Similar results for Energy Savings and QoS (delay) are obtained.

V. SIMULATION AND THEORETICAL RESULTS

A. *Simulation Environment*

The simulation is achieved using the Network Simulator 3 (NS3). NS3 is a discrete event simulator licensed under the GNU GPLv2 license and can be used for research and development. LTE-EPC Network Simulator (LENA) is developed for the NS3 LTE Module.

For the benefit of visualization, the presented results are of a simulated time of 20 seconds. Also, the workstation ran the simulation for seven days, and the results were consistent there as well.

B. *One-Way Communication*

Simulation of one-way communication has the parameters as presented in Table I.

Parameter	Value
Half Frame Duration	5ms
DRX On Timer	1ms
DRX Inactivity Period	50ms
Short DRX Cycle Length	20ms
Long DRX Cycle Length	40ms
Power Consumption in Awake Mode	0.24mJ/s
Power Consumption in Sleep Mode	0.02mJ/s
Additional Power Consumption in Switching	0.002mJ/s

TABLE I: Parameters for One-Way Communication

The following formula is used to compute the Energy Consumption: $E_0 = Time_{sleep}$ x P_{sleep} + $Time_{active}$ x P_{active} + $NumberOfSwitches$ x P_{switch}
where,
$Time_{sleep}$ is the time when UE is in sleep mode.
$Time_{active}$ is the time when UE is in active mode.
P_{sleep} is the power saved when UE is in sleep mode.
P_{active} is the power saved when UE is in active mode.

1) Theoretical Results: The theoretical results for one way communication, as presented in [2], are given as follows:
The Total Energy Consumption ratio, $E_0 = 0.180$;
The Total Power Saving ratio, $P_0 = 0.8195$.

2) Simulated Results: Using NS3 and above discussed topology and parameters, the following results were obtained for the one way communication:
The Total Energy Consumption ratio, $E_0 = 0.2234$;
The Total Power Saving ratio, $P_0 = 0.7766$.

C. *Results for Two Way Communication*

Parameters used as per [2] for the simulation of two-way communication are presented in Table II.

1) Theoretical Results: The theoretical results for two way communication as presented in [2], are given as follows:
The Total Energy Consumption ratio, $E_0 = 0.313$;
The Total Power Saving ratio, $P_0 = 0.687$.

Parameter	Value
Half Frame Duration	5ms
DRX On Timer	5ms
DRX Inactivity Period	0-100ms
Short DRX Cycle Length	20-60ms
Long DRX Cycle Length	40ms
Power Consumption in Awake Mode	0.24mJ/s
Power Consumption in Sleep Mode	0.02mJ/s
Additional Power Consumption in Switching	0.002mJ/s

TABLE II: Parameters for Two-Way Communication

2) Simulated Results: The results are observed varying the length of short cycles. Table III shows the variation of length of short cycles. The corresponding Sleep and Active period of the UE are obtained. The table also presents the delay experienced by the user and the energy savings achieved through the DRX mechanism. The length of short cycles is of the form (sleep period in short drx cycle + listening period).

The trend of energy savings and delay when the length of short cycles is varied is presented in Fig. 3. Observation:

Length of short cycle	Sleep period (s)	Active period (s)	Delay (s)	Energy Saving (%)
15+5	12.885	7.036	0.1379	59.37
35+5	15.785	4.136	0.338	72.70
55+5	16.995	2.956	0.605	78.11
75+5	17.475	2.445	0.828	80.47
95+5	17.86	2.136	1.293	81.86

TABLE III: Performance measures by varying the length of short cycles

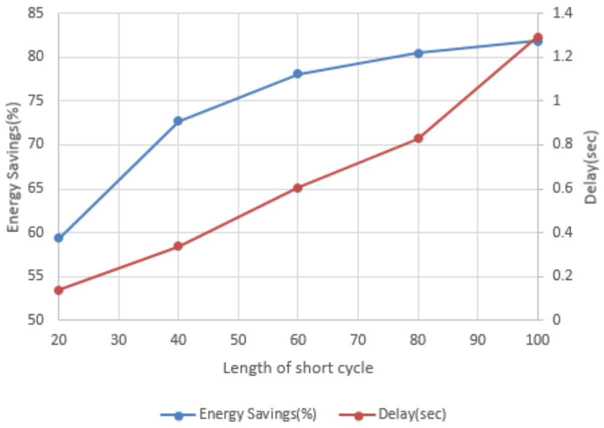

Fig. 3: Tradeoff between energy saving and delay when length of short cycles are varied

On increasing the length of short cycles, the energy savings increase but the delay also increases, causing a lower Quality of Service.

The length of the inactivity timer is varied, corresponding results in the UE, active period, sleep period, the delay experienced, and energy savings are presented in Table IV.

Fig. 4 shows the energy savings as the length of inactivity

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Length of inactivity timer	Sleep period (s)	Active period (s)	Delay (s)	Energy Saving (%)
0	15.030	4.884	0.095	69.22
5	14.805	5.123	0.198	68.13
25	14.100	5.814	0.095	64.97
50	12.885	7.036	0.137	59.37
75	11.97	7.948	0.137	55.20
100	11.235	8.688	0.2036	51.81

TABLE IV: Performance measures by varying the length of inactivity timer

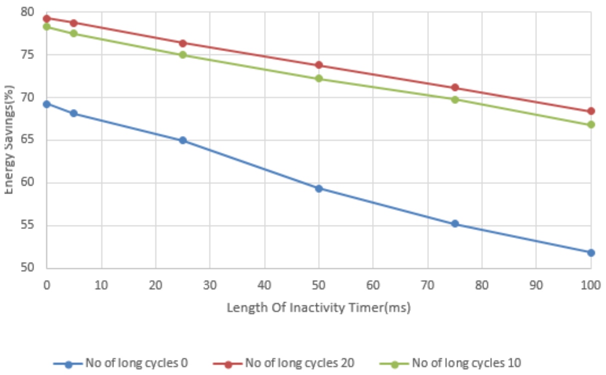

Fig. 4: Trend of energy savings when the length of inactivity timer is varied for different long cycles

timer is varied. These three plots are obtained by taking three different values of the number of long cycles, 0, 10, and 20. Observation: It can be seen that on increasing the length of the inactivity timer, the energy savings drop. Energy saving can be zero if the inactivity timer is increased such that UE never goes to sleep period.

The results in UE from varying the number of short cycles is presented in Table V.

Number of short cycles	Number of long cycles	Inactive period (s)	Active period (s)	Delay (s)	Power Saving (%)
20	0	14.805	5.12	0.198	68.14
20	20	17.117	2.81	0.739	78.77
40	20	15.981	3.94	0.605	73.54
60	20	15.308	4.609	0.373	70.5
80	20	15.084	4.83	0.264	69.47

TABLE V: Performance measures by varying the number of short cycles

Fig. 5 presents the tradeoff between energy savings and QoS as the number of short cycles is varied.

Observation: Long DRX cycles reduce the power consumption of the UE but increase the delay experienced by the user. Whereas, short DRX cycles reduce the delay but increase power consumption.

The number of long cycles is varied from a range of 0 to 60, and the corresponding results in UE are presented in Table VI.

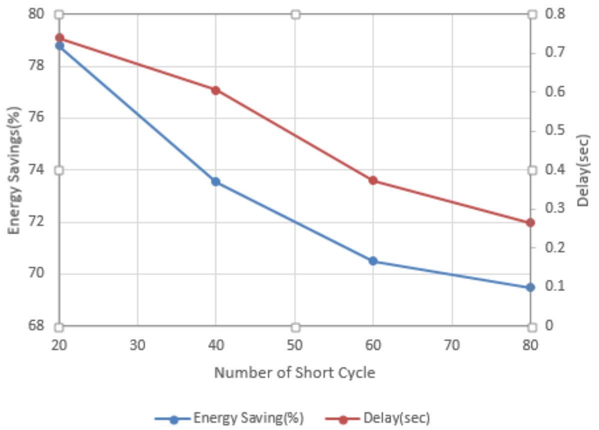

Fig. 5: Tradeoff between energy saving and delay when number of short cycles are varied

Number of long cycles	Sleep period (s)	Active period (s)	Delay (s)	Energy Saving (%)
0	14.805	5.123	0.198	68.13
10	16.877	3.08	0.474	77.5138
20	17.117	2.810	0.739	78.767
40	17.31	2.77	0.742	79.134
60	17.47	2.63	0.744	79.16

TABLE VI: Performance measures by varying the number of long cycles

The QoS(delay) and energy savings are plotted against the varying number of long cycles to observe a trend in Fig. 6.

Observation: Initially, on increasing the number of long cycles, the sleep period increases. This leads to more power saving but also more delay. Finally, there will be a saturation on power saving and delay because UE never goes beyond a fixed number of long cycles depending on the rate of incoming packets.

The trend varying the length of long cycles is presented in Table VII. The length of long cycles is of the form (sleep period in a long DRX cycle + listening period).

The tradeoff between energy savings and QoS(delay) on

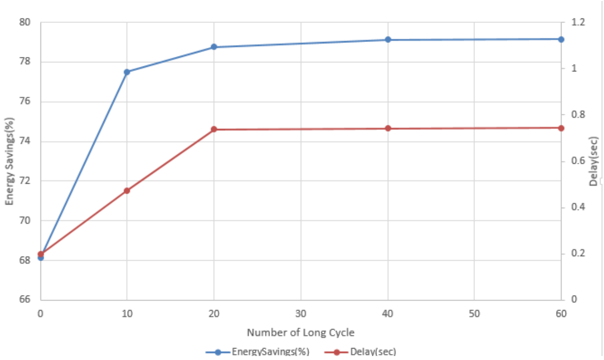

Fig. 6: Tradeoff between energy saving and delay when number of long cycles are varied

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Length of long cycles	Sleep period (s)	Active period (s)	Delay (s)	Energy Saving (%)
16+4	15.089	4.829	0.1632	69.48
36+4	15.888	4.033	0.2075	73.1447
56+4	16.538	3.399	0.3342	76.054
76+4	16.877	3.08	0.474	77.5138
96+4	17.031	2.883	0.686	78.436

TABLE VII: Performance measures by varying the length of long cycles

varying the length of long cycles is presented in Fig. 7.

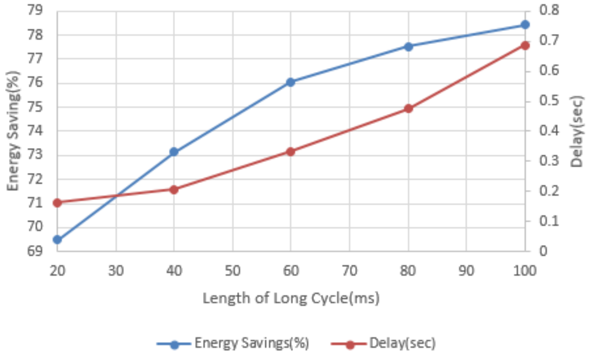

Fig. 7: Tradeoff between energy saving and delay when length of long cycles are varied

Observation: It can be seen that increasing the length of the long cycle while keeping its number fixed increases the total sleep period, which leads to more power saving but also more delay.

D. Analysis of results with an alternate distribution of packets

In the aforementioned results, the inter-arrival time between the arrival of packets follows an exponential distribution. The results of inter-arrival times following other distribution is compared with the previously obtained one in this section. Hence, the power saving results of two way communication are analyzed when the distribution is changed to uniform, keeping the mean same.

In Fig. 8, the mean is varied on the X axis while energy savings on respective distributions are presented in the Y axis.

Observation: As the mean increases Energy saving in both cases increases. Since the mean represents the average inter-arrival time between two consecutive packets, therefore an increase in mean should lead to an increase in energy savings. Moreover, there is no significant difference in energy saving in the two distributions.

VI. CONCLUSION AND FUTURE WORK

It is evident from section IV that the DRX scheme indeed helps saves energy, but there is a tradeoff between the amount of energy saved and the QoS. Moreover, the results from [2], it can be seen coherent with the simulated ones on even longer duration of the simulation.

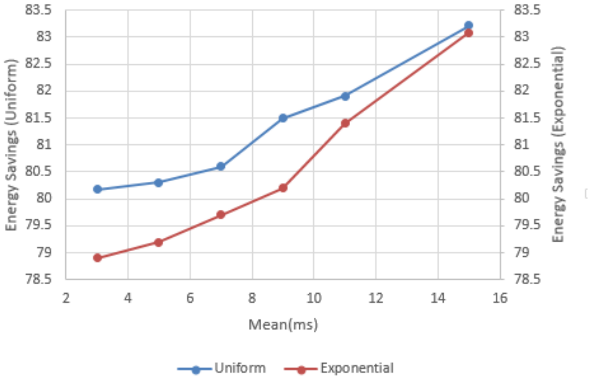

Fig. 8: Energy saving on Uniform and Exponential distributions with same mean

The DRX parameters are decided based on the underlying assumption of packets in the UE being generated as per Poisson Distribution. The assumption may not hold from user to user. Therefore, further fine tuning of DRX parameters can lead to more energy savings while maintaining the QoS.

5G will be the one major highlight for IoT devices, and it is a step further for energy saving. By utilizing solar, wind, and energy from the electromagnetic radiation, small scale non critical IoT devices might just become self-sufficient.

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