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Research Article

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Channel Quality Driven Discontinuous Reception (DRX) Model for Power Saving in LTE System

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Abstract

Long-Term Evolution (LTE), which is a standard for wireless communication, has incorporated Discontinuous Reception (DRX), a power-saving strategy having the primary purpose of enhancing energy-saving at the user equipment (UE). Nevertheless, for the networks that have varying channel quality, it is not possible all the time for fixed DRX parameters to obtain the desired improvement. This research introduces a new model based on CQI (Channel Quality Indicator) that will reduce energy consumption by eliminating unnecessary wakeups of UE's and also achieve reduced latency. As the DRX mechanism saves UE's energy usually by increasing latency, a tradeoff is necessary between these two performance factors. LTE networks can optimize DRX model parameters for minimizing power consumption based on CQI reporting by UEs and MCS (Modulation and Coding Scheme) assignments by eNodeB as network channel quality is not equal. In this research, an adaptive DRX model is developed, namely CQI DRX, that maintains a balance between power saving and latency. The simulation process is carried out using ns3, a discrete event network simulator. This research shows that energy consumption can be decreased by approximately 13%, and latency can be diminished by around 7% compared with static DRX.

KEYWORDS

LTE, DRX, CQI, MCS, Power-saving, wireless networks

1 | INTRODUCTION

The developing 4G/5G wireless communication technology that is called long term evolution (LTE) is showing great opportunity to offer higher data transfer rate and lesser delay with the help of higher-order modulation techniques such as 16/64-quadrature amplitude modulation (QAM) combined with efficient antenna technologies such as multiple-input multiple-output (MIMO), space-division multiple access (SDMA). So, user equipment (UE) circuitry is becoming more complex day by day and also increasing battery energy consumption at UE and

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hence limit the use of LTE services of the networks [1]. LTE networks have increased capacity compared with the other networks, and diverse data applications (DDAs) such as Facebook, Skype, Twitter, and messengers are becoming more and more popular and most accessible reaching technologies. Traffic characteristics of DDA are different from traditional internet applications. These applications generate packets every second though those are shorts in the networks even when they are not being used by users actively but still, that consumes energy. Alongside the fast advancement of sophisticated mobile gadgets, wireless communication technologies advancements, furthermore, different mobile web applications, with interactive media as one of the delegates, have developed and increased gigantic prevalence. This situation calls for a bigger system capacity, higher transmission rate, and better client experience [2].

To accomplish the objective of the LTE system, DRX is used in Cellular networks to save the energy of the battery of the user equipment (UE). For this reason, the LTE standard, which is the Third Generation Partnership Project (3GPP) has indicated a new scheme called discontinuous reception (DRX) [4]. The user equipment (UE) and the eNodeB determine states in which the data transmission process happens. On the other times, besides the active times, the device turns its receiving module deactivated and enters a state that consumes less power of the battery, thus saves energy from draining unnecessarily. DRX parameters much depend on the configuration of the networks. If the feature is on, the receiving module will only read some of the available paging blocks, depending on the parameters defined in the systems. If eNodeB detects no subframes to read, the receiving module will be able to go to a sleep mode that will consume less energy, thus increasing the battery life of the module. The UE powers down most of its circuitry when there are no packets to be transmitted/received. At this time, UE listens to the downlink (DL) for few times and will not keep in touch with uplink (UL) transmission, but that will depend on whether the UE is a part of an evolved node-B (eNB) [3] [4].

As higher modulation techniques use higher bits per symbol, higher MCS (Modulation and Coding Scheme) has the advantages of higher code rate. For most LTE networks, applications such as Facebook, Twitter, YouTube, and Gmail need a fast data rate. However, it is not possible all the time as all network quality is not the same. So, it is desirable that the channel quality that is reported by the UE as CQI (Channel Quality Indicator) is higher and is stable, but this does not happen for all the networks. The reality is that channel quality does not stable for most countries. Thus, the static DRX mechanism cannot be useful for all the systems. So, to use LTE networks effectively, UE must synchronize with the eNodeB. To do so, UE loses a significant amount of energy.

Thus, a dynamic process is needed so that the DRX mechanism of the LTE system can be useful for all kinds of networks. So, LTE systems can use CQI (Channel Quality Indicator) based adaptive DRX (Discontinuous Reception) parameters to get the expected performance in the LTE network from DRX features. In this research, the significant contribution will be to develop a discontinuous reception (DRX) model that will focus on the channel quality of the networks that is reported by the UE to save battery power by dynamically optimizing the DRX parameters based on varying MCS (Modulation and Coding Scheme). It is a feature of the LTE system that UE reports to the eNodeB about CQI. This model will be beneficial for those kinds of channels that are not stable; that is, the MCS assigned by the eNodeB varies with time to time because of the instability of channels. As the varying channel produces more energy problem that cannot be solved using static DRX method, the CQI (Channel Quality Indicator) and MCS (Modulation and Coding Scheme) methods have been taken into account and solve the problem by developing a new DRX model that will concentrate on the CQI and MCS values. This new CQI based model named as CQI DRX takes care of the issue of the static mechanism of DRX to save more battery power.

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In this paper, research is organized as follows: part 2 gives the underlying mechanism of DRX, and the basic mechanism of CQI and MCS will be explained in Part 3. Related work will be discussed in part 4. The proposed DRX model will be described in part 5. The simulation results will be explained in part 6, and finally, part 7 concludes this paper.

2 | BASIC MECHANISM OF DRX

It is alluring for a cell phone to keep its receiver circuitry shut when it is not required so that the UE saves energy. Discontinuous reception (DRX) is a strategy that is utilized in different wireless technologies to enable the device to shut its receiver during times of idleness. During DRX mode, the UE powers down the vast majority of its circuitry when there are no packets to be received. During this time, UE listens to the downlink (DL) once in a while, called DRX active state though the time during which UE does not listen PDCCH (physical downlink control channel) is called DRX sleep state [9][18].

In the LTE system, four main DRX parameters determine when a UE will go into sleep/wake state: DRX inactivity time (IN), on duration time (ON), short DRX cycle (S), long DRX cycle (L) are some of the DRX parameters shown in **Figure 1**. All parameters are explained below:

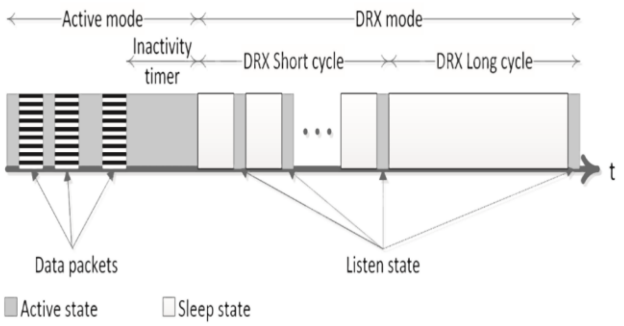

Figure 1 LTE DRX timing diagram for UE [3].

• **Active state:** When a UE is actively monitoring the PDDCH (Physical Downlink Control Channel) for data frames.

Active Time: The time when a UE receives data packets.

DRX Inactivity Timer: It determines the quantity of consecutive PDCCH-subframe(s) for which the UE should be activated after successfully disentangling a PDCCH showing another transmission (UL or DL). This timer is restarted after getting PDCCH for another transmission (UL or DL). Upon the expiry of this timer, the UE should go to DRX mode [3].

• **Sleep state:** When a UE has shut down and not monitoring the PDDCH spectrum.

Listening state: It is a short timeframe when the UE powers up during DRX short cycle to screen the RF spectrum for approaching Physical Downlink Control Channel (PDCCH) transmissions.

Short DRX Cycle: A timeframe when the UE is in a rest state; however, intermittently changes to the listen state to screen the PDCCH for approaching information.

Short DRX Cycle Timer: At the time of the DRX short cycle, the DRX short cycle timer defines the number of consecutive DRX short cycles until switches to an inactive state or long DRX cycle state.

DRX On Duration Timer: At the beginning of every cycle, the UE checks the PDCCH, whether there is any data for the UE, this small timeframe is called DRX on duration timer.

Long DRX Cycle: A timeframe longer than the DRX Short Cycle where a UE stays in the sleep state and wakes up only at the end of the cycle to monitor the PDCCH. The long DRX cycle only starts after the expiration of the short DRX cycle timer and end of this long DRX cycle; it changes to the inactive state [3][10][11].

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DRX inactivity timer tallying down from a specified value after a UE has received a packet. DRX inactivity timer can have any length depending on the network's quality and the network configurations. On the off chance that if a packet arrives before the DRX inactivity timer expires, then the timer restarts in the wake of receiving the new packet so that there are no data to be delayed. However, if the timer expires and there are no new approaching packets at that point, the UE goes into the sleep cycle called DRX short cycle. Nevertheless, those configurations consume more energy, and more extensive the DRX inactivity timer, the UE will waste a large amount of energy. So, at this point, using short DRX inactivity timer can be suggested, but using a very short DRX inactivity timer may suffer severe data delay. Because of this situation, a trade-off is necessary to balance these performance metrics. At the start of every short DRX cycle, UE checks for the subframes in PDDCH, which is on duration timer. At the time of on duration timer, UE checks the PDDCHD, and if eNodeB finds any subframes at that time, the DRX cycles will be omitted, and the UE will go into DRX inactivity sate for monitoring further frames for UE so that the eNodeB can minimize the delay. At the time of the DRX short cycle, the DRX short cycle timer expires too, and UE goes into the listening state to check for the PDCCH. If the PDCCH indicates a new transmission during the listen state, at that point, the UE transitions to an active state and the DRX algorithm starts over once more. If the PDCCH shows no new transmission at the time of the listen states and the DRX short cycle ends, then a deep sleep cycle called DRX long cycle is started to save a large amount of UE energy. At the time of the DRX long cycle, the UE remains shut down until the DRX long cycle timer expires, and at that point, listen state is actuated to check the PDCCH for a new approaching packet again. At long last, when there is another packet in the listen state after completing a DRX long cycle timer, then the UE switches to an active state, and the process restarts [3][11][17]. Now, if the DRX cycles lengths are too long, that may affect the performance of the UE in terms of delay, but if the DRX cycles lengths are too short, that may affect the performance of UE in terms of power consumption. So, a trade-off is necessary between these two performance parameters so that the DRX can be more productive.

3 | BASIC MECHANISM OF CQI AND DRX

CQI, as the channel-quality indicator, gives a gauge of the highest modulation-and-coding scheme that, whenever utilized with the suggested RI (Rank Indicator) and PMI (Pre-coding Matrix Indicator), would bring about a block-error probability for the DL-SCH (Downlink Shared Channel) transmissions of at generally ten percent. The motivation to utilize CQI (Channel Quality Indicator) as a feedback value rather than, for instance, the signal-to-noise ratio, is to account for various receivers' implementations in the terminal. Additionally, putting together the feedback reports concerning CQI rather than signal-to-noise ratio rearranges the testing of terminals. CQI is a 4-bit integer number based on the signal-to-interference-plus-noise ratio (SINR) at the UE. The estimation procedure of The CQI considers the UE capability. Hence, this is significant since, for the equivalent SINR value, the MCS level that can be supported by a UE relies upon these different UE capabilities, which should be considered all together for the eNodeB to choose an ideal MCS level for the transmission. The eNodeB utilizes the CQI's announced for downlink scheduling, which are significant features of LTE [6]. LTE networks have built-in CQI (Channel Quality Indicator) for its performance evaluation as it is the parameter by which eNodeB can understand how good/bad the systems are. CQI is carried by PUCCH (Physical Uplink Control Channel) or PUSCH (Physical Uplink Shared Channel), depending on the situation as follows.

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- CQI is performed by PUCCH if there is no uplink data to be transmitted.
- CQI is performed by PUSCH if there is uplink data to be transmitted.

With the expanding demand for Quality of Service (QoS) of a wireless communication system, progressively powerful strategies are being utilized to improve the power-saving and time proficiency. Modulation and Coding is one of the strategies that are connected in natural systems to expand the throughput [5]. By adaptively choosing the proper modulation requests and coding rates, eNodeB can give a much-improved system execution than fixed modulation and coding plans. Channel Quality Indicators (CQI) should be reported by User Equipment (UE) or Mobile Station (MS) so that the LTE system can perform modulation and coding activity. CQI (Channel Quality Indicator) is the crucial pointer determined by UE for the radio conditions. CQI is transmitted to eNodeB through PDCCH (physical uplink control channel). The Channel Quality Indicator (CQI) contains data sent from a UE to the eNodeB to demonstrate an appropriate downlink transmission information rate, i.e., a Modulation and Coding Scheme (MCS) esteem. In the LTE system, 15 distinct CQI (Channel Quality Indicator) values ranging from 1 to 15 and defined in **Table 1**. Here, it is visible that the higher the CQI index better the modulation technique, and thus the higher the code rate is. Because of this, efficiency is also better for higher CQI values. Now the CQI (Channel Quality Indicator) to MCS (Modulation and Coding Scheme) mapping will also be considered. Methods of mapping show that the lower is the CQI, the lesser the efficiency is. Higher CQI produces a more significant modulation technique. For the CQI index less than 7, eNodeB assigns QPSK (Quadrature Phase Shift Keying) to UE. Having a CQI index greater than 6, eNodeB assigns 16QAM (16-Quadrature amplitude modulation) to the UE. The remaining of CQI index uses 64QAM (16-Quadrature amplitude modulation) to the UE. As can be seen in **Table 2**, the higher the CQI values, the higher the MCS values are; thus, the modulation orders are also higher. Also, the reduction of the CQI values transmitted as a piece of information to eNodeB from UE reduces the MCS values. Thus, it affects the modulation order too. Therefore, it is

Table 1 4-bit CQI table [11].

CQI index	Modulation	Code rate x 1024	Efficiency
0			
1	QPSK	78	0.1523
2	QPSK	120	0.2344
3	QPSK	193	0.3770
4	QPSK	308	0.6016
5	QPSK	449	0.8770
6	QPSK	602	1.1758
7	16QAM	378	1.4766
8	16QAM	490	1.9141
9	16QAM	616	2.4063
10	64QAM	466	2.7305
11	64QAM	567	3.3223
12	64QAM	666	3.9023
13	64QAM	772	4.5234
14	64QAM	873	5.1152
15	64QAM	948	5.5547

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clear that the modulation technique in UE vastly depends on the MCS assignments of the eNodeB.

After analyzing the **Table 2**, the CQI and modulation order has the following relation between them:

• If the channel quality is poor and the UE reports CQI those ranges from 1 to 3, then the eNodeB assigns MCS those ranges from 0 to 2 and will use the modulation technique of QPSK.
• If the channel quality is low and the UE reports CQI those ranges from 4 to 6, then the eNodeB assigns MCS those ranges from 3 to 9 and will use the modulation technique of QPSK, but it will have some improvement of code rate.
• If the channel quality is average and the UE reports CQI those ranges from 7 to 10, then the eNodeB assigns MCS those ranges from 10 to 19 and will use the modulation technique of 16QAM and thus the code rate will be higher than the low-quality channel.
• If the channel quality is excellent and the UE reports CQI those ranges from 11 to 15, then the eNodeB assigns MCS those ranges from 20 to 28 and will use the modulation technique of 64QAM.

Table 2 CQI to MCS mapping [7].

CQI	**Modulation**	**Bits/Symbol**	**MCS**
1-3	QPSK	2	0-2
4-6	QPSK	2	3-9
7-10	16QAM	4	10-19
11-15	64QAM	6	20-28

As a result, the higher the channel quality indicator (CQI), the higher the bits per symbol, so the code rate is also higher that is very effective for the UE in the LTE systems. So, higher the CQI that is reported by the techniques assigned by the eNodeB, thus higher the code rate and will support more battery energy that will help the UE to use LTE network features more efficiently. Here, it is a fact that having a CQI index less than 7 uses the QPSK modulation technique, and the code rate is not more than 600, and the highest efficiency can be approximately 1.17. Having a CQI index of less than 10 uses the16QAM modulation technique, and the code rate is not more than 616, and the highest efficiency can be approximately 2.4. Having a CQI index up to 15 uses the 64QAM modulation technique, and the highest code rate is 948, and the highest efficiency can be approximately 5 [7].

4 | RELATED WORK

To date, several power-saving strategies for DRX have been proposed and studied so that the DRX mechanism can be more useful for all kinds of situations.

At the beginning stage of DRX in [16], the study selected Poisson traffic for studying DRX model performance with the help of the developed analytical and simulation models. In this study, the 2-step UMTS DRX with bursty packet data traffic was proposed using the semi-Markov process.

In [4], a detailed optimization model was proposed for the LTE DRX mechanism under self-similar traffic. A truncated-Pareto-distributed arrival traffic model was introduced. In this research, a discrete-time semi-Markov process (DTSMP) was established along with an online power-saving strategy (OPSS) so that the UE could decrease the energy consumption and

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perform better than the conventional DRX model in terms of energy consumption and packet delay.

In [1], the study proposed a model for optimizing LTE DRX mechanism for mobile internet applications by dynamically selecting the DRX parameters values. In this paper, the proposed model ensured trade-off between power saving and delay, and the study showed that the determination of the DRX cycles for given parameters improves the power saving by over 40%.

In [13], the study described power-saving methods in both network-attached and idle network modes. In this paper, DRX parameters optimization was showed to enhance the power saving without incurring network re-entry and packet delay. The study proved that the model might spare around 40–45 percent of UE battery power without fundamentally affecting video quality by empowering DRX in the active mode.

In [3], 4-state and 5-state 3GPP LTE DRX mechanisms were proposed and explained the trade-off between energy consumption and delay. The proposed mechanisms were developed by increasing (an) active state(s) to deep and/or light sleep cycle of standard 3-state DRX. So, the research bypassed the process of returning to the timer-dependent active mode. The study showed that the augmented DRX models improved power saving by 1% -8% and reduced the delay by 20% - 60%.

In [14], a detailed Counter-Driven Adaptive DRX (CDA-DRX) scheme was proposed and analyzed. This study explained that this DRX model was adaptive, generic, and easy to implement. This study also balanced power consumption and latency.

In [15], the study performed a performance analysis on the Universal Mobile Telecommunications System (UMTS) for the discontinuous reception (DRX) mechanism. This study proposed analytical and simulation models to study the effects of power-saving and latency.

In [2], the study first developed an analytical model to estimate power-saving and latency; then, a trade-off model was proposed to balance between these two-performance metrics. This study also proved that the model's DRX short cycles were successful in diminishing latency for active traffic; also, the shorter inactivity timer is capable of background traffic in terms of energy-saving as this model might save energy up to 48.8%.

In [10], an analysis was showed of the fixed frame DRX cycle and compared it against an adjustable DRX cycle of the LTE/LTE Advanced power saving mechanism. This study used the semi-Markov process to model a system with bursty packet data traffic and also showed the trade-off between latency and power saving. This study also proved that adjustable LTE DRX might perform differently compared to nonadjustable DRX.

5 | PROPOSED DRX MODEL

The study shows that the UE sends CQI (Channel Quality Indicator) to the eNodeB as a feature of the LTE system, and depending on that CQI information, eNodeB assigns MCS (Modulation and Coding Scheme) to the UE. UE selects Modulation techniques based on the MCS values assigned by the eNodeB. This study also informs that the channel quality is not the same for all the LTE systems. It varies with time. However, the LTE network that has the possibility of varying channel quality and having installed with a static DRX mechanism in eNodeB can suffer huge fall-back. It may backfire in the networks that have varying characteristics with sever energy loss and huge latency increase. So, steps should be taken for that kind of LTE networks that have varying characteristics. This research proposes a DRX model based on CQI

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(Channel Quality Indicator) values reported by the UE and MCS (Modulation and Coding Scheme) values assigned by the eNodeB.

Here, DRX parameters have been defined for the proposed algorithm are as follows:

On duration timer (T_{ON}), inactivity timer (T_{IN}), short DRX cycle timer (T_S), long DRX cycle timer (T_L), inactivity time (*IN*), on duration time (*ON*), short DRX cycle (*S*), long DRX cycle (*L*). This algorithm has been divided into four parts, and **Table 3** indicates the partition of the algorithm.

Algorithm: CQI based proposed DRX (Discontinuous Reception) model.

Procedure CQI DRX
Repeat the procedure every T ms.
Foreach user i Do:
    If MCS (i) <=2 Then,
        T_{IN} *+= Step up IN*
        T_{ON} *+= Step up ON*
        T_S *-= Step down*
        T_L *-= Step down L*
    End If
    If MCS (i) >=3 and MCS<=9 Then
        T_{IN} *= IN*
        T_{ON} *-= Step down ON*
        T_S *= S*
        T_L *= L*
    End If
    If MCS (i) >=10 and MCS<=19 Then
        T_{IN} *-= Step down IN*
        T_{ON} *= ON*
        T_S *+= Step up S*
        T_L *+= Step up L*
    End If
    If MCS (i) >=20 and MCS<=28 Then
        T_{IN} *-= Step down IN*
        T_{ON} *= ON*
        T_S *+=2* Step up S*
        T_L *+=2* Step up L*
    End If
End for
End Procedure

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Table 3 shows that the first part of the algorithm is defined for the poor-quality channel where the MCS is less than or equal to 2. Inactivity timer (T_{IN}) has been stepped up by one unit as the channel quality is poor, and it needs the receiving module to turn on as long as possible so that it can monitor PDCCH (physical downlink control channel) for more time. Because of poor-quality channels having a significant setback of data loss, it needs to retransmit the data, and the channel latency is more than the other, so the subframes may be so much late than expected. So, this poor-quality channel that has MCS less than or equal to 2 has higher T_{IN} time than others. Same for the on-duration timer (T_{ON}). As the channel quality is terrible, the receiving module needs to be awake a little bit longer, so the T_{ON} is increased by one unit. The Short DRX cycle timer (T_S) and Long DRX cycle time (T_L) have been stepped down so that the UE can monitor more times for the subframes from eNodeB.

Table 3 The proposed algorithm is divided into four parts.

Part	CQI	MCS	Modulation
Part 1	1-3	0-2	QPSK
Part 2	4-6	3-9	QPSK
Part 3	7-10	10-19	16QAM
Part 4	11-15	20-28	64QAM

The second part of the algorithm is defined for the low-quality channel where MCS is greater than or equal to 3 and less than or equal to 9. Inactivity timer (T_{IN}) has been the same as the channel quality is low. So, this low-quality channel that has MCS less than or equal to 9 has similar T_{IN} time with static DRX. Nevertheless, the on-duration timer (T_{ON}) has been stepped down by one unit as the channel quality is low. If the MCS gets some developments, and the receiving module does not need to search for new frames a little bit longer, so the T_{ON} is decreased by one unit. To save the power of the device, the Short DRX cycle timer (T_S) and Long DRX cycle timer (T_L) have been the same as static DRX for the latency issue.

The third part of the algorithm is defined for the average-quality channel, where MCS is greater than or equal to 10 and less than or equal to 19. Inactivity timer (T_{IN}) has been stepped down as the channel quality has the same increments. So, this average-quality channel that has MCS less than or equal to 19 needs less T_{IN}. Hence, it has been stepped down by one unit. However, for the on-duration timer (T_{ON}), as the channel quality is average and the MCS has some developments, the receiving module does not need to be awake for a long time, so the T_{ON} is similar to static DRX. The Short DRX cycle timer (T_S) and Long DRX cycle timer (T_L) have been stepped down by one unit so that it can save more power compared with the static DRX.

The fourth part of the algorithm is defined for the excellent-quality channel, where MCS is greater than or equal to 20 and less than or equal to 28. On-duration timer (T_{ON}) has been similar to the static DRX because it has a very long range of cycles. As the channel quality has significant increments, this excellent quality channel has MCS less than or equal to 28, so the T_{ON} timer is set similar to static DRX to eradicate from some latency. However, for Short DRX cycle timer (T_S) and Long DRX cycle timer (T_L) has been stepped up by two units. Because this channel is in its best position and it has lesser latency that gives the DRX ample chance to save a tremendous amount of energy by extending the short DRX cycles and long DRX cycles without increasing the latency. So, it can save more power with the comparison of static DRX.

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Also, Inactivity timer (T_{IN}) has been stepped down by one unit as the receiving module does not need to screen for new frames for an extended period.

6 | PERFORMANCE EVALUATION

This section presents the performance study based on Discrete-event simulation models.

6.1 | SIMULATION ENVIRONMENT

The proposed DRX algorithm has been implemented in the ns-3 simulator, a discrete event simulator, along with the LTE-EPC Network Simulator (LENA) module. LENA implements radio resource management, packet scheduling, interference coordination, and dynamic spectrum access. It does not implement the RRC signalling, HARQ mechanism. The main features are implemented as model classes, and helper classes are used to define the overall system using these model classes [12]. In order to implement DRX in ns-3, some changes have been made to the simulator.

6.2 | SIMULATION PARAMETERS

In this research, the proposed algorithm has been divided into four necessary main parts. In those parts, the DRX parameters are set based on CQI reports of UE, and MCS responses of eNodeB. Random bursty data traffic application has been selected with 150 joules energy for single UE, and for simplicity, long DRX and short DRX have been simulated separately so that the results can be more accurate and defined in **Table 4**. Also, for varying channels, total bits per subframes are not fixed too. As the LTE networks are not stable, the total number of bits per subframes also varies and shown in **Table 5**. Overall simulation parameters have been shown in **Table 6**.

Table 4 Energy consumption per bit in a subframe.

DRX Cycle Type	DRX Mode	Consumed Energy Per Bit in A Subframe
Long DRX Cycle	Active	25 micro Jules
	Off	15 micro Jules
Short DRX Cycle	Active	25 micro Jules
	Off	15 micro Jules

Table 5 PDCCH bits per subframe assignment [8].

CQI index	Number of PDCCH Bits Per Subframes
1	576
2	288
3	288
4	288
5	144
6	144
7	144
8	144
9	144
10	144
11	144
12	144
13	72
14	72
15	72

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Table 6 Simulation Parameters.

Parameters	**Values**	**Parameters**	**Values**
Simulation Duration	Until 1024 system frames have been transmitted	Nodes Type	UE nodes
Number of UE	5,10,15,20,25 and 30	Base Station Type	eNodeB
MAC	IEEE 802.11g	Internet Protocol	IPv4
Channel Type	Wireless	Container Type	Net device container
Mobility Model	Constant position mobility model	Traffic	UDP
Short DRX Cycles (ms)	2, 5, 8, 16, 20, 32, 40, 64, 80, 128, 160, 256, 320, 512, 640	Error Detection	Checksum
Long DRX Cycles (ms)	10, 20, 32, 40, 64, 80, 128, 160, 256, 320, 512, 640, 1024, 1280, 2048, 2560		

6.3 | SIMULATION RESULTS AND ANALYSIS

This study has already discussed the four parts of the algorithm. In addition, short DRX scenarios and long DRX scenarios have been explained separately for every four parts of the algorithm.

6.3.1 | FIRST PART OF THE PROPOSED ALGORITHM

The long DRX scenario of the first part of the algorithm shows that the energy consumption of UE is very high for the No DRX system. Also, **Figure 2** shows that the proposed CQI DRX consumes less energy compared with the Static DRX system as there is more remaining energy in which the CQI DRX mechanism is used.

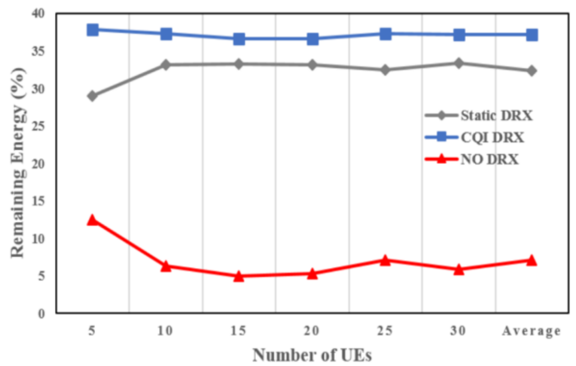

Figure 2 Remaining Energy (%) of the different DRX mechanisms for the long DRX cycle in different numbers of UEs for the first part of the algorithm.

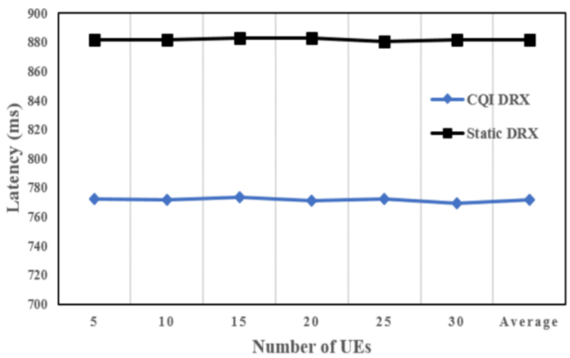

Figure 3 Latency (ms) of the different DRX mechanisms for the long DRX cycle in different numbers of UEs for the first part of the algorithm.

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The CQI DRX consumes approximately 94 joules out of 150 joules, Static DRX consumes about 101 joules, and No DRX consumes about 146 joules. So, CQI DRX performs better compared with the remaining two DRX in this scenario, as the CQI DRX saves up to 10% energy.
Long DRX version of the first part of the algorithm indicates that CQI DRX incurs latency of approximately 771 ms, and Static DRX has a latency of about 882 milliseconds. **Figure 3** shows that the Static DRX has more latency than the CQI DRX in this scenario, as the proposed model has approximately 13% less latency.
The CQI DRX in the short DRX scenario of the first part of the algorithm consumes less energy compared with the Static DRX and No DRX as the CQI DRX consumes approximately 100 joules out of 150 joules, the Static DRX consumes approximately 111 joules, and No DRX consumes approximately 147 joules of energy.
Figure 4 shows that the CQI DRX has more remaining energy compared with the Static DRX and No DRX as the CQI DRX saves up energy approximately 7% compared with the Static DRX in this scenario.

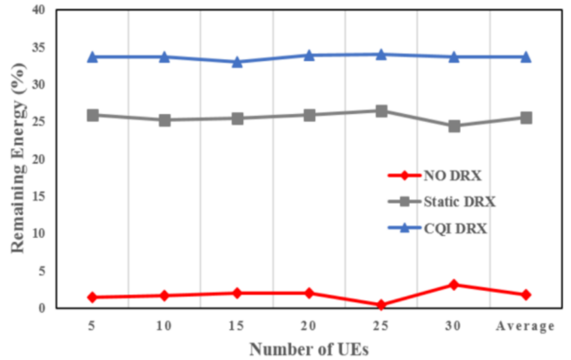

Figure 4 Remaining Energy (%) of the different DRX mechanisms for the short DRX cycle in different numbers of UEs for the first part of the algorithm.

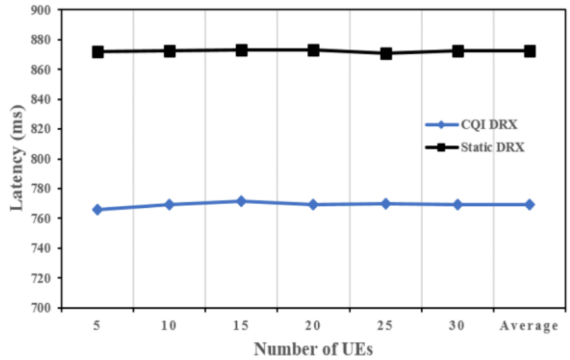

Figure 5 Latency (ms) of the different DRX mechanisms for the short DRX cycle in different numbers of UEs for the first part of the algorithm.

In this scenario, the CQI DRX of the short DRX cycle of the first part of the algorithm shows that the latency of the CQI DRX is approximately 769 ms and the latency of the Static DRX is about 872 ms thus **Figure 5** indicates that the CQI DRX has about 12% less latency compared with the Static DRX.
So, the overall discussion of the first part of the proposed algorithm that is intended for poor quality channels indicates that the CQI DRX outperforms the Static DRX channels in terms of both energy-saving and latency as energy can be saved up to 9% and latency can be decreased by approximately 12% using the CQI DRX.

6.3.2 | SECOND PART OF THE PROPOSED ALGORITHM

Long DRX scenario of the second part of the algorithm in **Figure 6** indicates that the proposed CQI DRX outperforms the Static DRX and No DRX in terms of energy-saving.
The CQI DRX consumes approximately 42 joules out of 150 joules, the Static DRX consumes about 50 joules, and No DRX consumes approximately 75 joules. Understandably, the CQI DRX has a better performance compared with the Static DRX in this scenario, as the CQI DRX saves up to 15% energy.

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In **Figure 7**, the latency of the CQI DRX and Static DRX are not so much different as average latency is almost the same with inconsistent latency in various numbers of UEs.

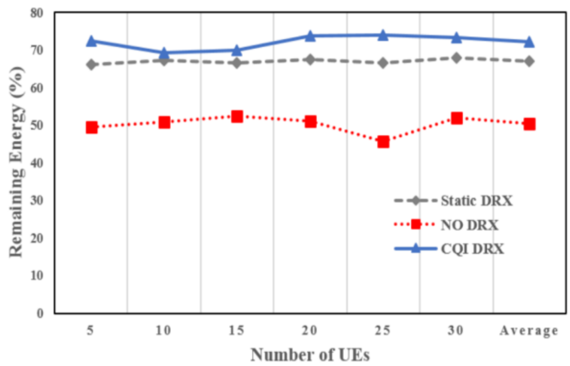

Figure 6 Remaining Energy (%) of the different DRX mechanisms for the long DRX cycle in different numbers of UEs for the second part of the algorithm.

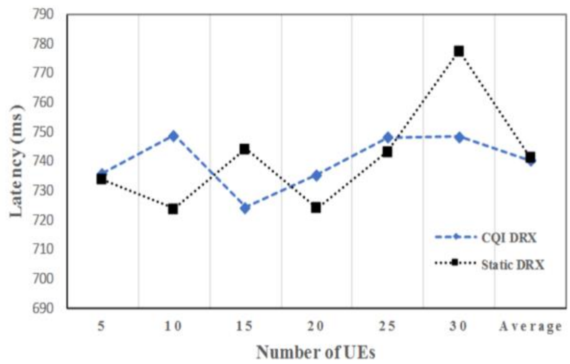

Figure 7 Latency (ms) of the different DRX mechanisms for the long DRX cycle in different numbers of UEs for the second part of the algorithm.

In short DRX scenario of the second part of the algorithm, the CQI DRX consumes less energy compared with the Static DRX and No DRX, because the CQI DRX consumes approximately 43 joules out of 150 joules, the Static DRX consumes about 50 joules, and No DRX consumes approximately 75 joules.

In **Figure 8**, the CQI DRX has approximately 72% of energy left and outperforms the Static DRX in this scenario as the energy saving can be increased up to 14% with proposed CQI DRX.

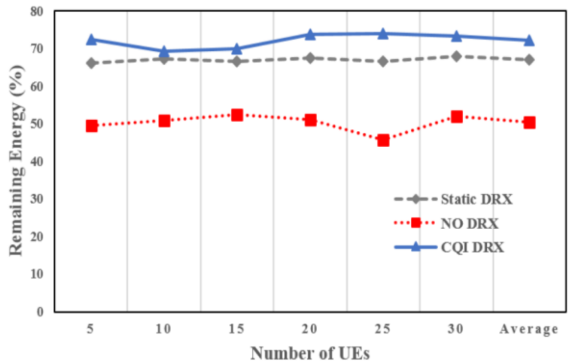

Figure 8 Remaining Energy (%) of the different DRX mechanisms for the short DRX cycle in different numbers of UEs for the second part of the algorithm.

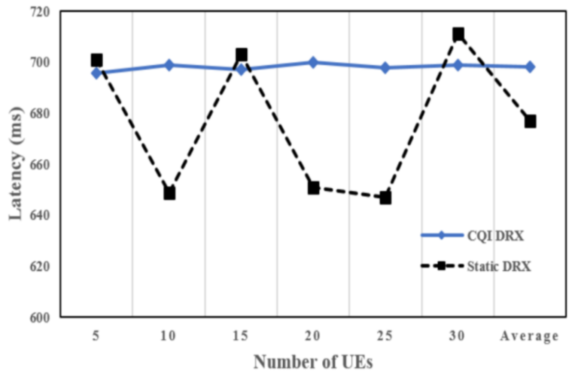

Figure 9 Latency (ms) of the different DRX mechanisms for the short DRX cycle in different numbers of UEs for the second part of the algorithm.

The latency of the short DRX scenario of the second part of the algorithm in the Static DRX is also inconsistent with an average latency of approximately 677 ms (milliseconds). Nevertheless, the CQI DRX suffers some disadvantages with slightly more latency compared with the Static DRX and shown in **Figure 9**.

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After the discussion of the second part of the proposed algorithm, which is intended for low-quality channels shows that the CQI DRX outperforms Static DRX in terms of energy-saving as the energy-saving can be gained up to 15%. However, in case of latency, the CQI DRX incurs slightly more latency compared with the Static DRX.

6.3.3 | THIRD PART OF THE PROPOSED ALGORITHM

Long DRX scenario of the third part of the algorithm indicates that the CQI DRX consumes less energy compared with the Static DRX and NO DRX as understandably, in **Figure 10**, the remaining power of the CQI DRX is approximately 81% compared with the Static DRX and No DRX as both have remaining energy of roughly 77% and 70% respectively.
In this scenario the CQI DRX consumes approximately 28 joules out of 150 joules, the Static DRX consumes about 34 joules, and No DRX consumes about 45 joules, CQI DRX performs better in case of energy-saving compared with the remaining two DRXs in this scenario as the CQI DRX saves up to 16% energy.

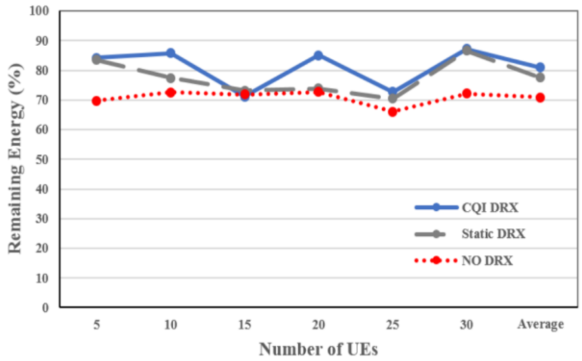

Figure 10 Remaining Energy (%) of the different DRX mechanisms for the long DRX cycle in different numbers of UEs for the third part of the algorithm.

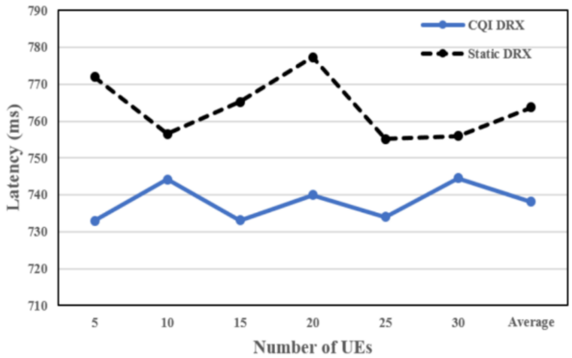

Figure 11 Latency (ms) of the different DRX mechanisms for the long DRX cycle in different numbers of UEs for the third part of the algorithm.

Long DRX of the third part of the algorithm indicates that CQI DRX incurs the system with an average latency of 738 ms and having less latency compared with the Static DRX, as shown in **Figure 11**.
So, in this scenario, the proposed CQI DRX has less latency compared with the Static DRX, as the CQI DRX incurs 3% less latency. The CQI DRX in the short DRX scenario of the third part of the algorithm also consumes less energy compared with the Static DRX and No DRX as the CQI DRX consumes approximately 28 joules out of 150 joules, the Static DRX consumes about 37 joules, and No DRX consumes approximately 46 joules.
In **Figure 12**, the CQI performs better compared with the Static DRX and No DRX as the CQI DRX has remaining energy of approximately 81% and saves up energy by almost 23% compared with the Static DRX.
In this short DRX scenario of the third part of the proposed algorithm, the CQI DRX and the Static DRX have the same latency with inconsistent values with different numbers of UEs, as shown in **Figure 13**.

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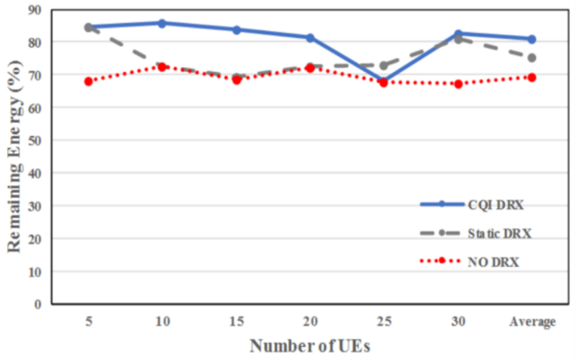

Figure 12 Remaining Energy (%) of the different DRX mechanisms for the short DRX cycle in different numbers of UEs for the third part of the algorithm.

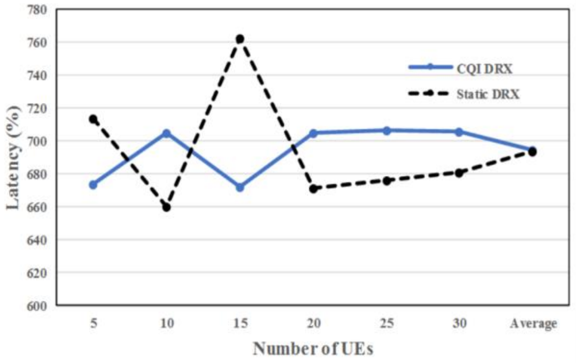

Figure 13 Latency (ms) of the different DRX mechanisms for the short DRX cycle in different numbers of UEs for the third part of the algorithm.

So, the overall discussion of the third part of the proposed algorithm that is intended for average quality channels indicates that the CQI DRX has better performance in case of energy saving. The CQI can save approximately 19% more energy compared with conventional Static DRX. But for latency comparison, the CQI DRX and the Static DRX exhibit the same latency.

6.3.4 | FOURTH PART OF THE PROPOSED ALGORITHM

Long DRX scenario of the fourth part of the algorithm shows that the energy consumption of UEs are higher in the Static DRX and No DRX compared with the proposed CQI DRX as the CQI DRX consumes approximately 10 joules where Static DRX consumes about 16 joules and No DRX consumes approximately 28 joules out of 150 joules. As **Figure 14** suggests that the CQI DRX has more remaining energy compared with the Static DRX, and the proposed CQI DRX model saves up to 36% energy compared with the Static DRX.
Long DRX of the fourth part of the algorithm shows that CQI DRX incurs latency of approximately 583 ms, and the Static DRX incurs latency of about 623 ms. So, in this scenario, the CQI DRX outperforms the Static DRX in terms of latency as the CQI DRX has at least 13.64% less latency compared with the Static DRX and is indicated by **Figure 15**. So, in this

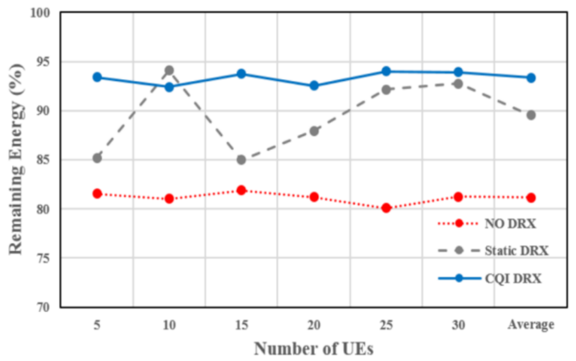

Figure 14 Remaining Energy (%) of the different DRX mechanisms for the long DRX cycle in different numbers of UEs for the fourth part of the algorithm.

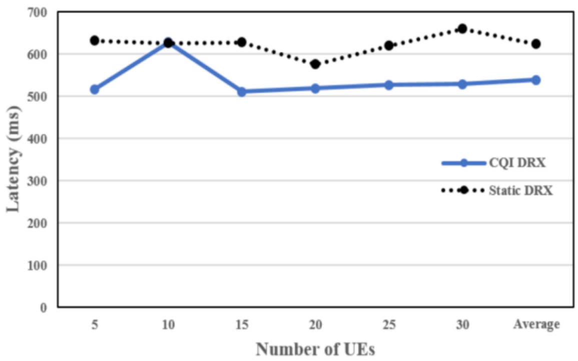

Figure 15 Latency (ms) of the different DRX mechanisms for the long DRX cycle in different numbers of UEs for the fourth part of the algorithm.

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particular scenario of the algorithm, the CQI DRX has a considerable advantage over the conventional Static DRX model; thus, the CQI DRX is better in this version.
Figure 16 shows that the CQI DRX in the short DRX scenario of the fourth part of the algorithm has more remaining energy compared with the Static DRX and No DRX as the CQI DRX consumes approximately 11 joules out of 150 joules, the Static DRX consumes about 13 joules, and No DRX consumes approximately 23 joules.
The short DRX cycle of the fourth part of the algorithm shows that the CQI DRX incurs approximately 483 ms latency, and the Static DRX incurs about 595 ms latency. **Figure 17** exhibits that the CQI DRX has less latency compared with the Static DRX, as UE can diminish about 18.69% latency.

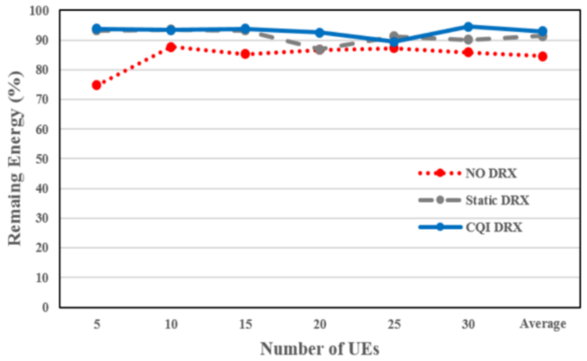

Figure 16 Remaining Energy (%) of the different DRX mechanisms for the short DRX cycle in different numbers of UEs for the fourth part of the algorithm.

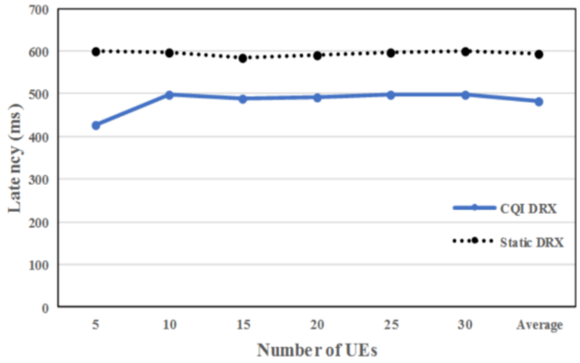

Figure 17 Latency (ms) of the different DRX mechanisms for the short DRX cycle in different numbers of UEs for the fourth part of the algorithm.

After the discussion of fourth part of the proposed algorithm that is intended for good quality channels, shows that the CQI DRX performs better compared with the Static DRX in terms of energy-saving as the energy saving can be gained up to 28% in this scenario also in case of latency the CQI DRX can diminish approximately 16% of the latency compared with the Static DRX. So, in this scenario, the CQI DRX outperforms the conventional Static DRX.
Analyzing all four parts of the algorithm, it is visible that the CQI DRX outperforms the Static DRX and No DRX in terms of energy saving. If an application in a varying characteristics network and participates in all four of the scenarios of the proposed algorithm depending on the MCS assignments by eNodeB, then the application, which is in such a system that has the CQI DRX implemented may consume approximately 44 joules out of 150 joules of energy. On the other hand, in a similar situation, the Static DRX may absorb 52 joules, and No DRX may consume 73 joules out of 150 joules of energy.
In **Figure 18**, understandably, the CQI DRX has an advantage over Static DRX in terms of energy saving in such networks where the network quality is not stable.
In **Figure 18**, in all kinds of scenarios, the CQI DRX outperforms the Static DRX and NO DRX. The CQI DRX has better energy saving compared with the other two DRX models, as energy-saving can be gained up to 13% compared with the Static DRX mechanism.
In **Figure 19**, to gain extra energy-saving, the proposed model does not suffer latency setback even using the proposed CQI DRX model, the latency can be decreased by up to 7%.

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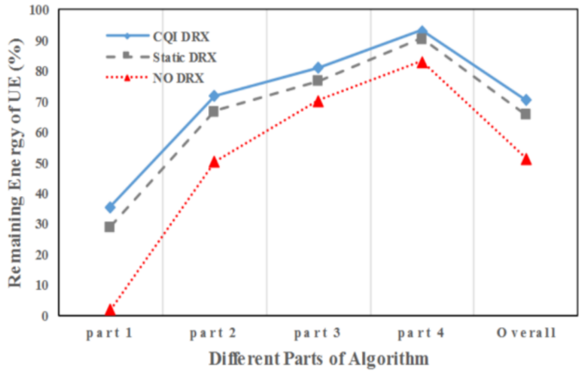

Figure 18 Remaining Energy (%) of UE in different parts of the algorithm.

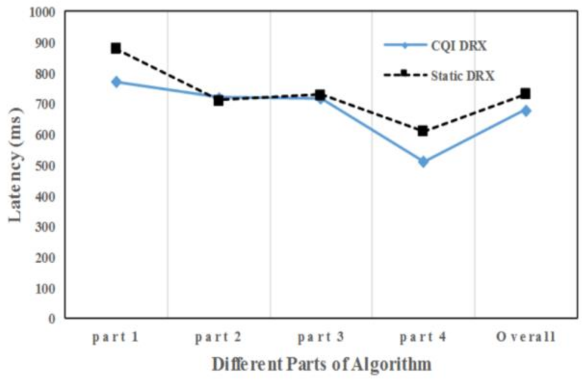

Figure 19 Latency (ms) of UE in different parts of the algorithm.

Figure 20 and **Figure 21** show that the system throughput and PDR (Packet delivery ratio) have not been hampered by the model to achieve the desired goal.
In **Figure 20**, it is noticeable that the throughput of the CQI DRX is almost similar to the throughput of the Static DRX as the throughput does not suffer any setback.

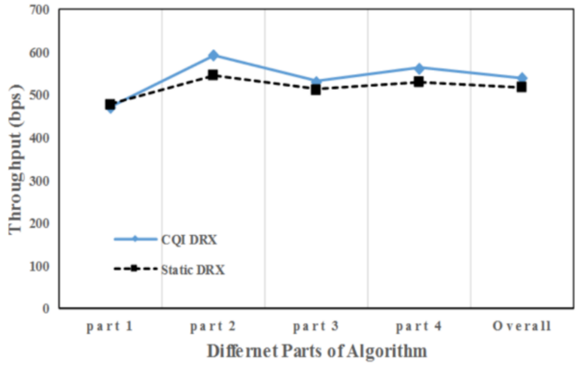

Figure 20 Throughput (bps) of UE in different parts of the algorithm.

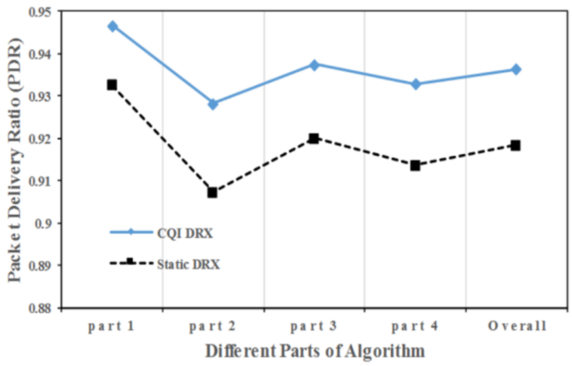

Figure 21 PDR of UE in different parts of the algorithm.

In **Figure 21**, it is also noticeable that the PDR (packet delivery ratio) of the CQI DRX is better compared with the PDR of the Static DRX. So, PDR also does not suffer any setback because of power-saving gain and decreased latency of the CQI DRX.
After all the analysis, it is clear that the CQI DRX model has advantages over the conventional Static DRX model in the networks that have varying characteristics and not stable as the CQI DRX model can increase the power saving by 13.52%. The CQI DRX also decreases the latency by 7% compared with the static DRX model, which indicates that the CQI DRX model outperforms the Static DRX model in terms of both energy-saving and decreased latency.

7 | CONCLUSION

Discontinuous reception (DRX) is expected to play an essential role in future networking as the LTE system is going to be more prevalent in all the countries. However, because of the channels varying characteristics, all the advantages of the LTE system cannot be achieved. To be useful for all kinds of networks, those are not stable; the CQI DRX may be helpful as all the

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country's channel quality will not be the same. So, to improve the power saving mechanism, CQI (channel quality indicator) responses from UE are needed for the DRX mechanism to decide which kind of DRX parameters will be used, such as long DRX cycle length, short DRX cycle length and on duration timer. So, the CQI based discontinuous reception (DRX) model is needed. The algorithm is divided into four parts, such as poor quality channels, low-quality channels, average quality channels, and good quality channels to simplify the simulation and for better understanding. This model has been simulated using network simulator 3 (NS3), a discrete event simulator with the LENA module. Every four parts of the algorithm parameters and conditions have been simulated against the CQI DRX, the Static DRX, and No DRX, along with short DRX cycles and long DRX cycles separately to achieve accurate results. Improvements have been achieved by simulating the CQI DRX as energy saving is achieved 13.52% more compared with the conventional Static DRX. Also, the latency has been decreased by simulating the CQI DRX as the Static DRX has at least 7% more latency compared with the proposed CQI DRX. So, it can be said that the CQI based discontinues reception model has advantages over conventional Static DRX models in those kinds of channels where the quality of the network channels is not stable in terms of both energy saving and reduced latency.

With the evolution of the LTE system, a more power-consuming model can be improved where channels quality is not stable. This simulation can be extended for more sophisticated and more challenging scenarios, including the increased number of UEs and eNodeB. Also, in wireless sensor networks (WSNs), to improve the lifetime of sensors and reduce the energy consumption rate of sensors per rounds, the proposed CQI DRX can be useful for implementation.

CONFLICT OF INTEREST

The authors declare no potential conflict of interest.

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