Discontinuous reception technique for power saving in LTE

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Abstract— **Enhanced discontinuous reception (DRX) mode is supported in long term evolution (LTE) of 3GPP standards to conserve the battery power of user equipment. Furthermore, DRX mode provides additional advantages, such as overall system capacity increment in both uplink and downlink for over-the-air resource saving. One of the improvements over 3G wireless systems is that, even when the user equipment (UE) is registered with the evolved node-B (eNB), LTE DRX mode can be enabled. However, optimization of the DRX parameters is needed resulting in maximization of power saving without disturbing network re-entry and packet delay. However, for real-time services separate care should be taken. The power saving methods under both network idle and network attached mode give scope for research. The optimum criteria for selection of DRX mode for different applications can be developed. Analytical/simulation results will be possible in power saving/connection re-establishment and packet delay.**

Keywords— **(LTE) Long Term Evolution, uplink, downlink (DRX) Discontinuous Reception, Power Saving, Radio resource connected (RRC-Connected), Radio resource Idle (RRC-Idle).**

I. INTRODUCTION

The evolving 4G wireless communication technology called long term evolution (LTE) has shown promise to offer higher data transfer rate over radio access part of the network by using higher order modulation, advanced coding and advanced antenna system [1]. However, the computationally complex circuitry used in user equipment (UE) has also increased battery energy consumption at UE and hence limit the potential use of 4G services.

Among the currently emerging wireless technologies and sophisticated mobile services, the power saving issue is becoming more and more important. This is justified by the fact that most remarkable wireless systems today, such as universal mobile telecommunication system (UMTS), IEEE 802.16e and 3GPP long term evaluation (LTE), have employed several kinds of power saving mechanisms. Actually power saving mechanism has been studied in many papers. In [8], a variant of the M/G/1 vacation model has been introduced to explore the performance of the UMTS discontinuous reception (DRX). The closed-form equations are derived for the output measures based on the Poisson assumption, and a novel semi-Markov process is proposed to model the UMTS DRX with bursty packet data applications in reference will provides a systematic comparison of the energy saving mechanisms of 3GPP and 3GPP2.In [2]and [4], we take an overview of the adjustable feature of the DRX cycle of the LTE DRX and model the mechanism with bursty packet data traffic using a semi-Markov process. There are also some studies of energy management for 802.16e. For all the power saving schemes, downlink packets arriving in the sleep duration will be queued in the buffer temporarily.

Apparently, it will result in unfavorable packet delay, which may degrade the QoS of delay sensitive services. Moreover, the length of the buffer is finite in reality, which will induce packet loss in case of buffer overflow. Therefore, the configuration of DRX mode process deserves in-depth considerations to provide perfect compromise between power saving and service QoS maintenance. In this paper, DRX scheme for LTE system is proposed. The target of this scheme is to capture various packet arrival patterns and scheduling behaviors of system to make a better tradeoff between power efficiency and packet delay by considering the length of the packet queue. Moreover, a mathematical model based on the Markov chain is derived to give comprehensive performance analysis for DRX.

In DRX mechanism, UE wakes up only for a short period called DRX ON period and remains asleep for remaining time in order to monitor PDCCH for every DRX cycle. Every DRX cycle consists of both DRX ON and DRX OFF periods. In this paper, DRX OFF and DRX sleep interchangeably is used. The power saving level depends largely depends on DRX parameters setting. For a predefined DRX ON duration, longer and frequent DRX cycle improves UE power saving with the cost of data packet delay. In practice, trade-off between delay and power saving is unavoidable and hence an efficient DRX scheme is required which adopts its parameters based on instantaneous UE conditions and applications.

II. DISCONTINUOUS RECEPTION TECHNIQUE IN LTE

An UE might operate in either RRC_IDLE or

RRC_CONNECTED state depends on whether it establishes a RRC (Radio Resource Control) connection with an eNB (evolved NodeB). In RRC_IDLE state, UE is registered with the EPS (Evolved Packet System) and MME (Mobility Management Entity) but does not have an active session [3].

The UE releases its connections with the eNB so that the UE no longer receives or transmits traffic. In this state, the UE can be paged for DL (Downlink) traffic and can also initiate UL (Uplink) traffic by requesting RRC connection with the eNB. In RRC_CONNECTED state, the UE persistently connects to the network for long time spans, and may be with a low activity frequency of transmission and reception.

In either states, when an UE does not receive or transmit traffic, it can temporarily shut down its transmitters and receiver for the purpose of energy saving. In order to support energy saving of UE in LTE/LTE-A networks, 3GPP specifications define an ESM (Energy Saving Management) mechanism named DRX in Release 8, and enhance the functions in Release 9 and Release 10. The DRX can be adopted in RRC_IDLE as well as RRC_CONNECTED states:

In RRC_IDLE state, the DRX can be used by the UE to perform the signal quality measurements with respect to the eNB since the network is not aware of the UE existence continuously. The UE does not keep the time synchronization with the UL transmission and only listens to the DL broadcast transmission periodically.

In RRC_CONNECTED state, the DRX may be adopted to save the UE’s energy in the periods that the UE does not receive or send traffic. The UE may power off its transmitters and receivers during this period. It avoids numerous connection establishments and releases and then induces overhead and delay.

The mapping of DRX to a generic traffic model in two states. The DRX can be used in RRC_CONNECTED state during the interval of packet bursts and in RRC_IDLE state during the period of two sequential active sessions. The general operation of DRX in RRC_CONNECTED or RRC_IDLE state.

The UE/eNB starts two timers named as (T1 and T2) after successfully transmitting/receiving a data packet. When there has been no data packet transmission for a period longer than T1, the UE may enter RRC_CONNECTED DRX mode. In this mode the UE still registers with eNB and may turn off most of its RF circuitry to save energy. If there has been no data packet transmission for an extended period of time, say T2 (typically T2 >T1), the UE may enter RRC_IDLE state.

III. Mathematical Analysis And Modeling

In DRX mode, when there are no packets left to be transmitted / received for the UE, the UE circuitry powers down. During this time, UE listens to the downlink (DL) and doesn’t synchronisation with uplink (UL) transmission based on whether the UE is registered with evolved node-B (eNB) Radio Resource Control connected (RRC-connected) or not it goes to Radio Resource Control connected idle state (RRC-Idle).

Furthermore, UE scans the neighbouring eNB during the process of detecting signal quality degradation based on the serving eNB [6, 7]. If the quality of signal is better from one of neighbouring eNBs than the serving eNB, UE should perform handover by coming out of DRX mode while the UE is in RRC_CONNECTED state or if in RRC_IDLE state, UE should perform cell reselection. Once the handover / cell reselection is successfully performed, UE choose to go into DRX. UE has to perform tracking area (TA) update in RRC_IDLE state whenever TA change is detected.

There is significant UL resource optimization and UE power saving through implementation of DRX mode in both RRC_CONNECTED state and RRC_IDLE state. In particular, the power savings and resource utilization are maximized for applications characterized by extended OFF periods. Through careful selection of different DRX parameters, the power saving can be implemented.

In the RRC_CONNECTED state, the DRX mode parameters are selected based on the application type such that the additional delay through DRX mode can be minimized. There is a potential saving power for VoIP applications. When a UE is in the on duration, it keeps monitoring the Physical downlink control channel PDCCH message through PDCCH blind decoding to ensure that the message is received correctly.

This allows a UE to determine which PDCCH messages are destined for it and which are meant for the other UEs. If a UE does not detect PDCCH messages for it, it will enter light sleep in short DRX cycle or deep sleep in long DRX cycle at the end of the on duration and wake up again in the next on duration to monitor the PDCCH messages.

Conversely, if a UE detects a PDCCH message intended for it, it will start the inactivity timer to extend the time during which the UE monitors PDCCH messages in order to allow the reception of more data packets. If a new PDCCH message is detected, the inactivity timer will be re-started. The above actions are repeated until after the expiry of the inactivity timer at which instant UE goes into light or deep sleep.

The parameters used for the mathematical analysis and modeling are defined below :

On duration timer

When UE monitors the PDCCH messages from the eNB it starts it DRX cycle. The value can be 1, 2, 3, 4, 5, 6, 8, 10, 20, 30, 40, 50, 60, 80, 100, or 200 (TTI’s Transmission Time Interval) [8]. The value is denoted by ON.

Inactivity timer

When UE detects a PDCCH message intended for it UE, It will restarts the timer to allow receiving packets from the eNB.

Short DRX cycle

The length of the cycle is specified in transmission time interval (TTI) and it is represented as 2^n, n=1…., 9 or 5×2^n ,n=1…., 6.and it is referred by DRX standard specified by the network.

Long DRX cycle

The length of the DRX cycle is the multiple of short DRX cycle (DRX_s).

Short DRX cycle timer

It is the measure of short DRX cycle a UE can execute before entering Long DRX cycle.

IV. POWER SAVING ANALYSIS

The following symbols are used for the power saving analysis in DRX mechanism. [5,11]

N: The number of packets arriving at eNB for the UE under consideration in one short DRX cycle and Long DRX cycle.

K: The number of packets arriving at eNB during the on duration of the corresponding UE is given by the condition K ≤ ON.

X: The number of packets arriving at eNB while the corresponding UE is in sleep state, X=N−K.

D(K,X): The delay (in TTI) associated with parameters K and X defined above.

q_k : when packet k arrives at eNB and the corresponding UE is in the on duration during the given TTI.

P_{SC}: The probability for the UE to be in a short DRX cycle.

P_{sN}: The probability for N packets to arrive at eNB when the corresponding UE is in a short DRX cycle.

$Q_{K,X}$: The probability for K and X packets to arrive at eNB before and after the end of the on duration of a UE in a short DRX cycle.

P_{LC}: The probability for a UE to be in a long DRX cycle.

P_{lN}: The probability for N packets to arrive at a eNB when the corresponding UE is in a long DRX cycle.

$R_{K,X}$: The probability for K and X packets to arrive at eNB before and after the end of the on duration of a UE in a long DRX cycle.

Let the delay be D(K, X) for various values of K, X and the probability of their occurrence. It is Assumed that the packet arrive at arrivals at the eNB in sequential manner and adopts Poisson distribution having mean arrival rate of λ packets per TTI.

The Probability function for n packet arrival in time interval t is represented as

$$P_n(t)=\frac{(\lambda t)^n}{n!}e^{-\lambda t}, \text{ for } n=0,1,2,\ldots \quad (1)$$

We have DRX mechanism represented as

$$t = \begin{matrix} DRXsTTIs,\ for\ short\ DRX\ cycle \\ \& \\ DRX_L TTIs,\ for\ long\ DRX\ cycle \end{matrix} \quad (2)$$

Let P_s and P_l denote the probabilities that no packet for a UE arrives at eNB in a short and long DRX cycle, respectively. We have

$$P_S=P_0(DRX_S)=e^{-\lambda DRXs} \quad (3)$$

$$P_L=e^{-\lambda\ DRXs} \quad (4)$$

The transition of UE between short and long DRX cycles can be depicted by a Markov model as shown in Figure 2. If no packet for a UE arrives at eNB in a short DRX cycle, UE moves toward the next short DRX cycle.

When no packet for a UE is received by eNB in W consecutive short DRX cycles, UE enters long DRX cycle, where W is the value of the short DRX cycle timer. However, whenever a packet for a UE to be in the with short DRX cycle and PL be the state probability for a UE to be in the long DRX cycle. The probabilities of all the states must sum up to 1:

$$P1+P\ 2+\ldots.. + P_W+ P_L=1 \quad (5)$$

In steady state, we solve for the probabilities as follows:

$$P_L = \left(\frac{P_L + P_S{}^W}{1-P_S} + \frac{P_S{}^W}{1-P_L} \right)^{-1} \quad (6)$$

$$P_L = \frac{P_L P_S{}^W}{1-P_L} = P_{LC} \quad (7)$$

$$P_{SC} = P_1 + P_2 + .. + P_W = 1 - P_{LC} \quad (8)$$

Finally,

$$P_{SN} = \frac{\lambda DRX_S{}^N}{N!} e^{-\lambda DRX_S}, N = 0,1,2,..., \quad (9)$$

$$P_{LN} = \frac{\lambda DRX_L{}^N}{N!} e^{-\lambda DRX_L}, N = 0,1,2,..., \quad (10)$$

Note that with the introduction of DRX_{short} or DRX_{long} for the length of short and long DRX cycles, (1) and (2) are valid for the two different types of cycles. The resulting delay will be denoted by $D_{short}(K, X)$ and $D_{long}(K, X)$, respectively.

Assume only one packet arrives at eNB during on period,

$$Q_{1,0} = \frac{ON}{DRX_S} \quad (11)$$

then If 2 packets arrive at eNB during the on period, then the probability of the arrival is given by

$$Q_{2,0} = \frac{1}{DRX_S - 2 + 1} \sum_{q_1=0}^{ON-2} \frac{ON - 2 - q_1 + 1}{DRX_S - q_1 - 1} = \frac{1}{DRX_S - 1} \sum_{q_1=0}^{ON-2} \frac{ON - 1 - q_1}{DRX_S - q_1 - 1} \quad (12)$$

The same situation can be iterated for any number of packet arrivals.

$$Q_{1,1} = \frac{1}{DRX_S - 1} \sum_{q_1=0}^{ON-1} \frac{DRX_S - ON}{DRX_S - q_1 - 2} \quad (13)$$

$$Q_{1,2} = \frac{1}{DRX_S - 2} \sum_{q_1=0}^{ON-1} \frac{DRX_S - ON - 1}{DRX_S - q_1 - 2} \quad (14)$$

$$Q_{1,X} = \frac{1}{DRX_S - X} \sum_{q_1=0}^{ON-1} \frac{DRX_S - ON - (X-1)}{DRX_S - q_1 - X} \quad (15)$$

The same procedure starting from equation (9) to (15) can be followed to find the finding $R_{K,X}$- The probability for K and X packets to arrive at eNB before and after the end of the on duration of a UE in a long DRX cycle.

when K packets arrive at the eNB before and the end of the on duration of the corresponding UE while the UE is in short and long DRX cycles, then PW_{short} (K) and PW_{long}(K) represents their power consumptions respectively [12].

$$PW_{short}(K)=K\times P_{RE}+(ON-K)\times P_{ID} +(DRX_S-ON-1)\times P_{Short\ sleep}+P_{Wake} \quad (16)$$

$$PW_{long}(K)=K\times P_{RE}+(ON-K)\times P_{Idle}+P_{TL}+P_{WA} \quad (17)$$

Here P_{Idle} , P_{Wake} , $P_{Short\ sleep}$, and $P_{Receiving}$, are the power consumptions by a UE in idle , wake-up , light sleep state and receiving a packet respectively. P_{TL} is the power consumed in transition from deep to light sleep. The different types of power consumption and their values are given in Table 1 [9]. The periodic repetition of DRX On-Duration is represented by the period of inactivity. Two types of DRX cycle, short DRX cycle and long DRX cycle are specified in 3GPP series TS 36.321 V8. The length of a DRX cycle is determined by the Length of On-Duration combined with length of inactivity period.

TABLE 1: POWER TRANSITION FROM DIFFERENT STATES.

STATE	POWER CONSUMED	NEXT STATE
Deep sleep	0 mw/TTI	Light sleep with 1TTI/TTI
Light sleep	11 mw/TTI	Active with no data reception (IDLE state) with 1TTI 39 mw/TTI
Active with no data reception (IDLE state)	255.5 mw/TTI	Light sleep with 11 mw/TTI or Active with data reception with 500 mw/TTI
Active with data reception	500 mw/TTI	Deep sleep 0mw/TTI or light sleep 11 mw/TTI

V. SIMULATION RESULTS OF DELAY

The simulation results of delay are depicted the effect of varying the value of a particular parameter while the values of other parameters are fixed. For comparison, numerical results of theoretical analysis are also shown. Very close match has been observed between the two results, which corroborates the correctness and accuracy of the analysis. In on duration timer *ON* is fixed, the time spent in sleep state grows with the length of the short DRX cycle. Consequently, the probability for a packet to arrive while UE is in sleep state also increases, resulting in a longer average delay. In with a larger value of the on duration, UE stays awake for a longer period.

Hence, packets are more likely to be received without any delay. Thus, the delay falls down almost linearly. In large values λ translate to a greater number of packets, which in turn increase the number of potentially delayed packets. The situation also helps in preventing UE from entering long DRX cycle and reduces delay.

Thus the average delay shows a decline with increasing values of λ. In the short DRX cycle timer is small, it is conducive for UE to enter long DRX cycle. With large values of the timer, UE becomes less likely to enter long DRX cycle and more likely to receive data packets with short delay.

TABLE II: PARAMETERS USED FOR SIMULAITION AND RESULTS.

PARAMETER	VALUES
On duration (TTI) in ms	2,3,4,5,6
Short DRX cycle (TTI) in ms	10,16,20,32,40
Long DRX cycle (TTI) in ms	20,32,40,64,80
Poisson's mean arrival rate λ (packets per TTI)	0.01, 0.03, 0.05, 0.08, 0.1, 0.2, 0.3, 0.4, 0.5, 0.8

VI. SIMULATION OF POWER CONSUMPTION

The simulation results and numerical results of theoretical analysis of power consumption are illustrated in Figure 1,2 [13]. Again, very close match has been observed between the two types of results. In Figure 1, since on duration timer is fixed, the time spent in sleep state grows with the length of the short DRX cycle and that of the long DRX cycle. Thus, greater power saving is achieved. In the case of Figure 2, the length of a DRX cycle is unchanged.

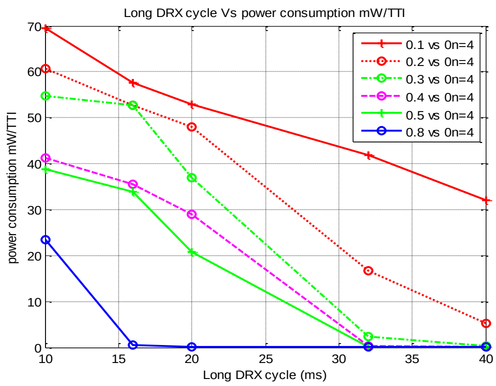

Figure1: comparison of long DRX cycle Vs power consumption in different ON-timer.

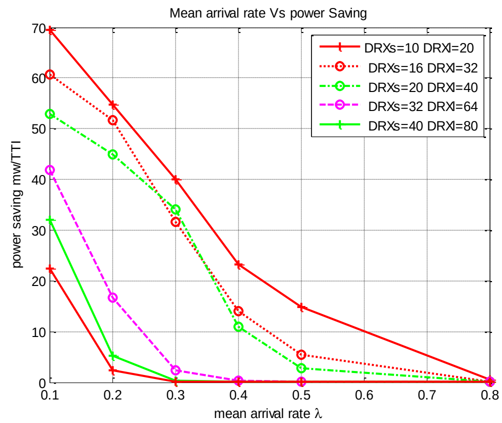

Figure2: comparison of Mean arrival rate Vs power consumption in different ON-timer.

Increasing the on duration forces UE to spend more time waiting for incoming data. Therefore, power consumption also grows. For Figure 2, when the mean arrival rate is increased, more packets are expected. In that case, the likelihood of entering long DRX cycle dwindles and power consumption increases. Similarly, for Figure 1, with a larger value of short DRX cycle timer, it is less likely for a UE to enter long DRX cycle, giving rise to higher power consumption.

CONCLUSIONS

This paper presents an accurate analysis of the DRX mechanism which uses a mix of short and long DRX cycles in terms of delay and power consumption. Poisson packet arrival pattern is assumed, which allows a rigorous analysis. The results of theoretical analysis have been validated via simulations and excellent consistency between the two approaches has been confirmed for both delay and power consumption. By varying the values of the parameters in DRX, we also investigated their effects on performance. The results clearly demonstrated the impacts.

In practice, DRX parameter values can be properly selected based on the QoS and other requirements to render sound user experience. Through this paper we have investigated the effect of varying the values of the parameters in DRX and analysed the results. We also investigated their effects on performance. The results clearly demonstrated the impacts. By proper selection of DRX parameter the QoS and other requirements based on user application can be implemented with minimal power requirements.

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