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User Equipment Power Saving and Delay Optimization in LTE network using DRX mechanism

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Abstract: The growing need for the use of user equipments (UE) has increased the necessity to investigate the power consumed in the switching process and to develop a method to reduce the power loss incurred in the system. Discontinuous reception mechanism DRX is a methodology proposed in Long Term evolution-LTE networks to achieve this desired effect. Although DRX mechanism introduces latency in the system, the power that can be saved in active and background traffic is comparatively good. This work focuses on power saving in UE and latency introduced in the process. Moreover, scheduling the DRX parameters can result in optimization of latency and power. Thereby, better quality of service and enhanced lifetime of the UE can be achieved.

Keywords: LTE, DRX, DRX Cycle, Power saving factor, Latency

I. INTRODUCTION

Nowadays, the use of mobile phones have increased extensively .The development of smart phones has grabbed the attention of the people as data transmission was made easy by the enhanced facilities offered by the phone. Such improvements increased the need to transmit the data as quickly as possible. The growing demand for high speed data transmission has led to the proposal of Long Term Evolution by 3GPP.LTE mainly focusses on increasing the capacity and speed of the wireless data networks. The LTE standard supports high downlink rate of 300 Mbit/s and uplink rate of 74.6 Mbit/s. LTE also provides peak throughput than High Speed Packet Access.

In order to achieve higher data rates using LTE, the User Equipment consumes more power in the process. This results in frequent charging and discharging of the battery. This eventually reduces the battery life. To avoid this problem and to reduce the power consumption a mechanism called Discontinuous Reception (DRX) [1]is introduced. Usually, the UE is turned ON all the time to monitor the network to decode PDCCH. DRX mechanism when there is no traffic, monitoring is not required and the UE can enter into power saving mode. Though DRX mechanism saves power[2], it also induces delay into the system. The delay is tolerable in case of background data traffic but for active data traffic this can result in loss of data.

II. DRX MECHANISM

LTE devices can be in one of the states of either idle state or connected state. As long as there is data activity either uplink or downlink, the device stays in connected state. Once the data transmission ends, the device moves to idle state after the expiry of a timer called RRC Inactivity timer. The timer is reset every time there is a data exchange. There is no transmission or reception of data during idle state. An UE in idle performs selection and reselection of geographic site. Paging is a procedure to wake up the UE for data activity and is triggered by eNB in Radio Access Network to establish a connection between the UE and the base station.

The user equipment monitors the Physical Downlink Control Channel for any data activity. Discontinuous reception is a mechanism to reduce the power loss incurred in the system and at the same time extend the battery life. DRX mechanism also uses a timer to drive the UE into the sleep period. The sleep period is classified into light sleep and deep sleep to employ effective power saving.

Light sleep: The LTE device uses a timer called DRX short cycle timer to wake the device after short sleep to check the PDCCH for any packet activity. If the device detects any downlink data during the ON time, the device moves to connected state and the exchange of data is initiated. In other case, the device sleeps until the next ON time.

Deep sleep: Similarly, the LTE device uses a timer named DRX long cycle timer to check PDCCH for packet activity after long sleep. The Timer starts running after device has been in many cycles of light sleep. The device sleeps if there is no packet activity until the next ON time.

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III. MATHEMATICAL MODEL

The arrival of the data packets [3] is considered to follow semi Markov method and other parameters are opted as indicated in Table .1. The UE stay's in any of the state's S1,S2or S3.

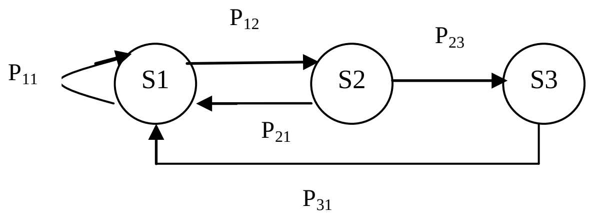

Fig.1

1. S1 is the state in which the UE continuously receives data packets and is the active state where the UE consumes power during data activity.

2. S2 is light sleep state in which the UE is in short DRX cycle .When there is no packet activity for time tinact after the after the reception of data during the state S1.

3. S3 is deep sleep state in which the UE is in long DRX cycle .The UE enters state S3 after several occurrences of short DRX cycles [13] and the UE is said to be in power saving mode.

Table .1

Parameter	Distribution Model	Mean value
Inter-session idle time *is* t_{is}	Exponential	$1/\ L_{is}$
Number of packet calls per session N_{pc}	Geometric	U_{pc}
Inter-packet call idle time t_{ipc}	Exponential	$1/\ L_{ipc}$
Number of packets per packet call Np	Geometric	U_p
Inter-packet arrival time t_{ip}	Exponential	$1/\ L_{ip}$

Let Upc be the number of packets arriving per session, then the probability that next packet belongs to the current session (case 1) is given by

$$P_{pc} = 1 - 1/U_{pc} \tag{1}$$

The probability that the next packet is the initial packet of the subsequent session (case 2) is given by

$$P_s = 1/U_{pc} \tag{2}$$

The probabilities are based on the memory less property of the geometric distribution. The state transition probabilities are given below:

The probability that the packet arrives before the inactivity period (ti) expires for case 1 is given by

$$q_1 = 1 - e^{(-Lipc*ti)} \tag{3}$$

For case 2 it is given by

$$q_2 = 1 - e^{(-Lis*ti)} \tag{4}$$

The probability that the UE in state S1 continues to be in state S1 is given by

$$P_{11} = P_{pc} * q_1 + P_s * q_2 \tag{5}$$

The probability that the UE in state S1 enters into state S2 after inactivity timer has expired is given by

$$P_{12} = P_{pc} * (1 - q_1) + P_s * (1 - q_2) \tag{6}$$

When the DRX inactivity timer expires, the UE enters into state S2 and the DRX short cycle timer is activated [6]. If there is a packet activity before the expiry of the DRX short cycle timer, the timer is cancelled and the UE is pushed back to active state S1. The probability that the packet arrives before the expiry of DRX short cycle timer (tn) [7] is given by

For case 1,

$$q_3 = 1 - e^{(-Lipc*tn)} \tag{7}$$

For case 2,

$$q_4 = 1 - e^{(-Lis*tn)} \tag{8}$$

The probability that the UE in state S2 moves to state S1 is given by

$$P_{21} = P_{pc} * q_3 + P_s * q_4 \tag{9}$$

When the UE in state S2 expires no packet activity for one or several short DRX cycle based on the formulation of parameters, the UE moves into Long DRX cycle i,e state S3.

The probability that the UE in state S2 moves to state S3 is given by

$$P_{23} = P_{pc} * (1 - q_3) + P_s * (1 - q_4) \tag{10}$$

The state transition probability matrix is shown below

$$P = \begin{bmatrix} P_{pc} * q_1 + P_s * q_2 & P_{pc} * (1 - q_1) + P_s * (1 - q_2) & 0 \\ P_{pc} * q_3 + P_s * q_4 & 0 & P_{pc} * (1 - q_3) + P_s * (1 - q_4) \\ 0 & 0 & 1 \end{bmatrix}$$

If Pi represents the probability that the UE is in the state Si, then the

$$\sum_{i=1}^{3} P_i = 1 \tag{11}$$

Let Hi the holding time in the state Si. The holding time in state S2 is given by

$$E_{H2} = (P_{pc} e^{(-L_{ipc}*t_n)} + P_s e^{(-L_{is}*t_i)}) N t_{ds} + (P_{pc} e^{(-L_{ipc}*t_n)} + P_s e^{(-L_{is}*t_n)}) \left(\frac{P_{pc}}{1 - e^{(-L_{ipc}*t_{ds})}} + \frac{P_s}{1 - e^{(-L_{is}*t_{ds})}} \right) t_{ds} \tag{12}$$

The holding time in state S2 is given by

$$E_{H3} = \left(\frac{P_{pc}}{1 - e^{(-L_{ipc} * t_{dl})}} + \frac{P_s}{1 - e^{(-L_{is} * t_{dl})}}\right) t_{dl} \qquad (13)$$

Let t be the ON duration for which the UE checks for packet activity during the DRX cycle. So the effective sleeping time during the short and long DRX cycles is given as tds-t and tdl-t

So the effective sleep time of the UE in short and long DRX cycles are given below equation

$$E'_{H2} = (P_{pc} e^{(-L_{ipc} * t_n)} + P_s e^{(-L_{is} * t_1)}) N(t_{ds} - t) + (P_{pc} e^{(-L_{ipc} * t_n)} + P_s e^{(-L_{is} * t_n)}) \left(\frac{P_{pc}}{1 - e^{(-L_{ipc} * t_{ds})}} + \frac{P_s}{1 - e^{(-L_{is} * t_{ds})}}\right)(t_{ds} - t) \qquad (14)$$

$$E'_{H3} = \left(\frac{P_{pc}}{1 - e^{(-L_{ipc} * t_{dl})}} + \frac{P_s}{1 - e^{(-L_{is} * t_{dl})}}\right)(t_{dl} - t) \qquad (15)$$

The power saving factor P [7] is defined by the ratio of the effective sleep time of UE in short and long DRX cycle to the holding time of[6] UE in short and long DRX cycle .

$$P = \frac{P_2 E'_{H2} + P_3 E'_{H3}}{\sum_{i=1}^{3} P_i E_{Hi}} \qquad (16)$$

The mean wake up delay is also analyzed. The data may arrive during slight sleep or tight sleep .The probability of the packet arriving during the ith DRX cycle is given by equation below:

$$p_i = \{ P_{pc} e^{-\lambda_{ipc} t_I} e^{-\lambda_{ipc}(i-1) t_{DS}} (1 - e^{-\lambda_{ipc} t_{DS}}) + P_s e^{-\lambda_{is} t_s} e^{-\lambda_{is}(i-1) t_{DS}} (1 - e^{-\lambda_{is} t_{DS}}), \quad i \leq N;$$

$$p_i = \{ P_{pc} e^{-\lambda_{ipc} t_I} e^{-\lambda_{ipc} N t_{DS}} e^{-\lambda_{ipc}(i-N-1) t_{DL}} (1 - e^{-\lambda_{ipc} t_{DL}}) + P_s e^{-\lambda_{is} t_s} e^{-\lambda_{is} N t_{DS}} e^{-\lambda_{is}(i-N-1) t_{DL}} (1 - e^{-\lambda_{is} t_{DS}}), \quad i > N.$$

(17)

As the inter packet idle time and the inter packet session time is exponentially distributed, the packet call arrivals are supposed to be Poisson distribution [11].

The mean wake up delay [13] is derived as

$$D = \sum_{i=1}^{N} (p_i \, t_{ds}/2) + \sum_{i=N+1}^{\infty} (p_i \, t_{dl}/2) \qquad (18)$$

IV. SIMULATION RESULTS

The variation of power saves with respect to long and short DRX cycles are shown in the Fig.2. The power saving versus DRX long cycle is a Concave down increasing graph. Power saving increases with increasing values of Long DRX cycle. This is because the ON period for which the UE monitors the Physical downlink control channel-(PPDH) is constant and the time spent by the user equipment in sleep mode is increased as DRX long cycle increases, thus saving more apparent power when compared to active and DRX short cycle.

Fig.3 shows the variation of mean wake up delay with respect to Long DRX cycle. The graph shows that the delay incurred in the system due to the DRX mechanism increases proportionally with DRX long cycle. Delay is introduced in the system by the worst case probability that the call arrives during the Long DRX sleep. As the sleep time increases the time required to establish a call also increases proportionally. This is because the call is detected only in the next ON period of long DRX cycle.

Fig.4 shows the variation of power saving with DRX short cycle [6]. The comparison of power saving versus DRX short and long cycle shows that, UE spends more time in the sleep mode in DRX long cycle than in DRX short cycle. Therefore, the power that be saved in an UE is more in DRX long cycle compared to DRX short cycle. Similar to that of Long DRX cycle, the power saving increases as DRX short cycle increases and the ON duration for which the UE checks for PDCCH is kept constant.

Fig.5 shows the variation of mean wake up delay with respect to DRX short cycle. The graph shows that delay introduced into the system during a DRX short cycle is less compared to that in DRX long cycle. As the DRX short cycle i.e the sleep time increases, the delay also increases. The duration for which the UE monitors the PDCCH is constant, and the delay increases as the sleep time increases. This is because the call arrival is known only during the next ON duration. Therefore, if the sleep time increases the delay also increases.

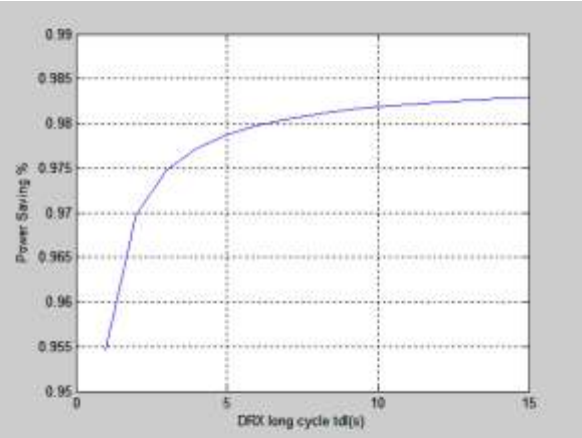

Fig.2 Lip=10,Lipc=1/30,Lis=1/2000,Upc=5,Up=25, tn=40,tdl=20,N=1,t=.1,t1=2

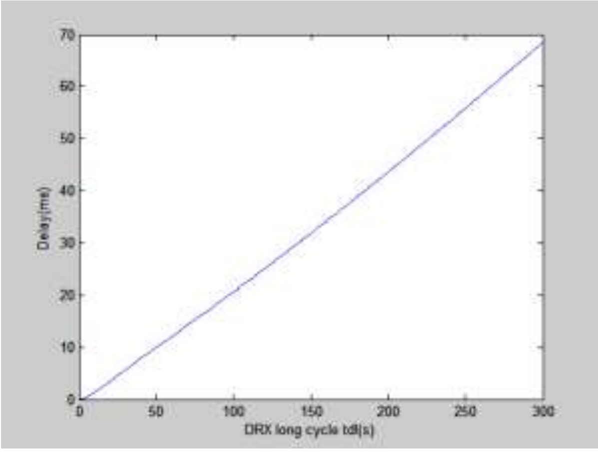

Fig.3 Lip=10,Lipc=1/30,Lis=1/2000,Upc=5,Up=25, tn=10,tdl=2,N=1,t=.1,t1=2

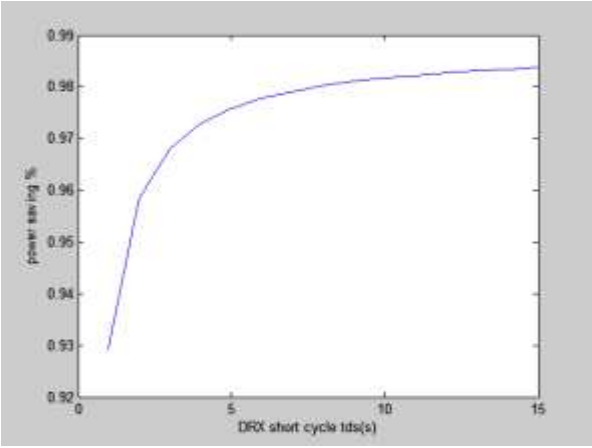

Fig .4 Lip=10,Lipc=1/30,Lis=1/2000,Upc=5,Up=25,tn=10, t1=2,tds=2,N=4,t=.04

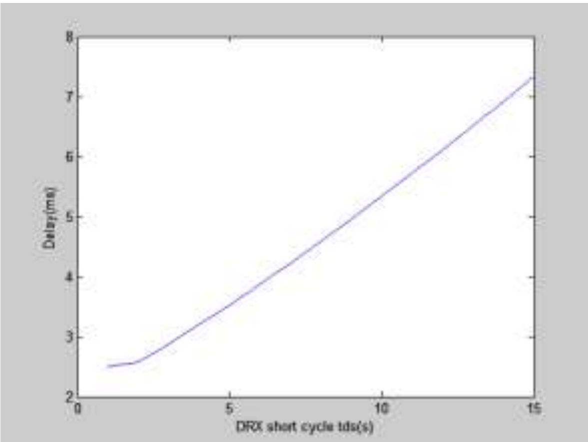

Fig.5 Lip=10,Lipc=1/30,Lis=1/2000,Upc=5,Up=25,tn=120, tdl=20,N=104,t=1,t1=2

V. CONCLUSION

The DRX mechanism in LTE drives the UE into sleep mode if there is no packet activity for long period. It proves to save the battery power to the maximum probable extend. As the charging and discharging of battery is reduced, the battery life is also extended. But the mechanism also induces a delay into the system which is also studied in the paper. In order to compromise between the two obtained characteristics of the system, a relation is developed between power saving factors and the delay incurred in the system.

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