Analytical Modeling of DRX Mechanism to Enhance the Energy Efficiency in LTE

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***Abstract* — One of the major objectives of wireless network is to save energy of UE and radio equipment of Node-B. The discontinuous reception (DRX) is widely used in LTE-A mobile communication system. The recent literature use 3 to 5 state Markov chain to model DRX and show that the performance of N state model is better than N-1 state. This paper provides a generalized 2 state model to measure the performance of DRX in context of probability of entering short and long sleep. Finally, the paper proposes a new analytical model to measure the inclination of sleep and active state of a UE based on entropy of binary state.**

Keywords — Discontinuous Reception (DRX); Discontinuous Transmission (DTX); sleep mode; power saving; Long Term Evaluation (LTE) etc.

I. INTRODUCTION

In recent years, modern life has brought us a new era of mobile communications due to the increasing popularity of all sorts of mobile devices and cloud computing applications. To address the huge demand, the fourth generation (4G)[1] wireless technology of mobile broadband communications is standardized. In 4G, there are 2 prominent systems commercially deployed: Mobile WiMAX [2] and LTE (Long-Term Evolution) [3]. The LTE standard is backward compatible with GSM/UMTS cellular systems. That is why its deployment is easier than the Mobile WiMAX.

There are 2 standards of LTE offered by 3GPP (Third Generation Partnership Project): Long Term Evolution (LTE) and LTE-Advanced (LTE-A). Both are able to achieve high data rates up to 1 Gbps by adopting several advanced modulation schemes, coding and multiple antenna techniques such as MIMO [4]. But this increment capacity for data transmission has also increased the power demands of mobile equipment. To improve user equipment (UE) battery lifetime, LTE supports Discontinuous Reception (DRX) mechanism [5, 6]. When UEs are not receiving any data from their corresponding eNodeB (eNB), DRX allows UEs to monitor the physical downlink control channel (PDCCH) after every certain period of time. UEs can enter the power saving mode when they are not listening to the PDCCH. In power saving mode, UEs turn off most of their circuits. This will reduce the power consumption of UEs significantly. However, UEs wake up periodically to listen to the PDCCH for a while. UEs return to low power mode if there is no packet to receive or transmit, but they go to active mode if there is any packet to receive or transmit.

Nowadays, many scholars are doing their researches on this sleep mode of DRX mechanism. In [7], the authors propose an Active Discontinuous Reception (DRX) mechanism with a sleep-delay strategy for the LTE to reduce the average latency while saving more energy. The key idea is to influence the control of the downlink transmission on that way that the system would go to sleep only when there is no data frame arrival within the sleep-delay timer. The authors in [8] present a mechanism to improve energy efficiency of UEs using DRX that is able to control the average packet delay with any fixed configuration of DRX parameters but not increasing the signaling overhead. Analytical models using a semi-Markov process for bursty packet data traffic with the evaluation against a standard 3-state DRX method has been proposed in [9]. In [10], the power consumption of Evolve Node of LTE (Long Term Evolution) is proposed based on Discontinuous Transmission (DTX) mechanism, *i.e.* the node B is switched off when there is no packet to be served. Some others works of DRX mechanism have been done in [11-14].

In our previous work [15], we have analyzed the sleep mode of 4G mobile network based on two statistical models: Poisson's pdf and Engset pdf and in [16] we have analyzed the probability of attaining at three states: serving state, state of timer inactivity and silent state in a simplified statistical model using traffic parameters of arrival rate, pdf (probability density function) of interarrival time and its threshold value. We developed a new state transition chain of the above three states.

This paper is organized as: section II deals the system model of the DRX mechanism and the Markovian probability state, section III provides the results based on statistical analysis of section II and section IV concludes the entire analysis.

II. SYSTEM MODEL

There might be several packet calls in a single session of data communication. The pdf of the number of packet calls per session follows the geometric distribution. Let, μ_{pc} is the mean packet calls per session.

Let us consider, a session is running. Within this session, the probability of starting a new packet call after completing the previous one (i.e. no new session has been started) is:

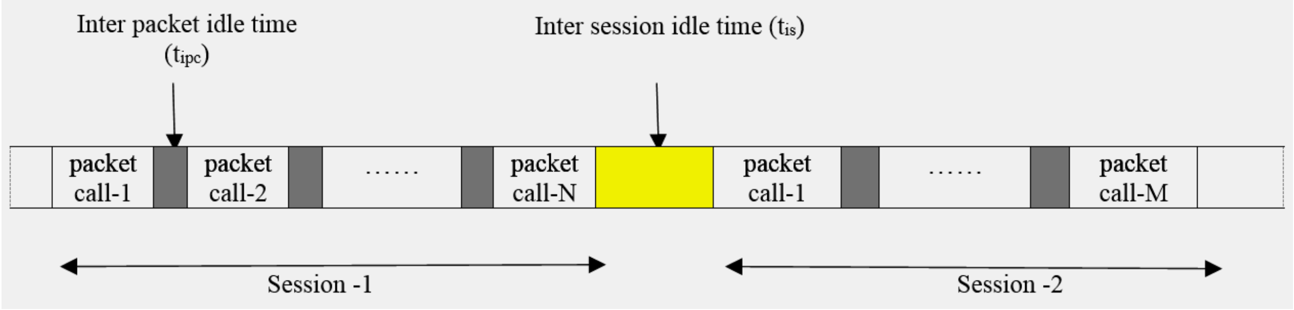

Fig. 1 DRX Mechanism used in LTE-A

$$p_{pc} = 1 - \frac{1}{m_{pc}} \qquad (1)$$

The probability of continuing a packet call within a particular session (no new session is started) is p_{pc}.

Again, the probability of starting a new session after completing the existing one is:

$$p_s = \frac{1}{m_{pc}} \qquad (2)$$

The pdf of inter packet call arrival time t is:

$$f(t) = l_{ipc} e^{-l_{ipc} t} \qquad (3)$$

where, λ_{ipc} is the packet call arrival rate in a session.

Therefore:

$$p_r\{t_{ipc} = t < t_I\} = \int_0^{t_I} \lambda_{ipc} e^{-\lambda_{ipc} t} dt = 1 - e^{-\lambda_{ipc} t_I} = q_1 \qquad (4)$$

The pdf of inter session arrival time t is:

$$f'(t) = \lambda_{is} e^{-\lambda_{is} t} \qquad (5)$$

Therefore:

$$p_r\{t_{is} = t < t_I\} = \int_0^{t_I} \lambda_{is} e^{-\lambda_{is} t} dt = 1 - e^{-\lambda_{is} t_I} = q_2 \qquad (6)$$

Here t_I is the threshold value of inter packet or inter session arrival time.

Let us represent the DRX power saving technique using two state Markov chain as shown in Fig.2 where state 1 (represented as S_1) represent the active state of UE and state 2 (represented as S_2) is the inactive state. The inactive state is the combination of light and deep sleep state.

$$p_{11} = \begin{bmatrix} p_r\{\text{packet calls are continuing in serial in current session}\} \\ \cap\left[p_r\{t_{ipc} < t_I\}\right] \cup p_r\{\text{sessions are in serial}\} \cap p_r\{t_{is} < t_I\} \end{bmatrix}$$

$$= p_{pc} q_1 + p_s q_2 = \left(1 - \frac{1}{\mu_{pc}}\right)\left(1 - e^{-\lambda_{ipc} t_I}\right) + \frac{1}{\mu_{pc}}\left(1 - e^{-\lambda_{is} t_I}\right) \qquad (7)$$

Within a running session, if the interval between 2 consecutive packet calls (inter packet call time) is greater than t_I or if the gap duration between 2 consecutive session (inter session time) is greater than t_I, then the user equipment (UE) moves from state 1 to state 2.

$$\therefore \quad p_{12} = p_{pc} \cdot p_r\{t_{ipc} > t_I\} + p_s \cdot p_r\{t_{is} > t_I\}$$

$$= \left(1 - \frac{1}{\mu_{pc}}\right) e^{-\lambda_{ipc} t_I} + \frac{1}{\mu_{pc}} e^{-\lambda_{is} t_I} \qquad (8)$$

Let us assume that the UE is in state 2 (i.e. inactive state). In this situation, no packet is coming to the UE. But after every certain interval (DRX cycle), the UE will check whether any packet is destined for it.

Let, t_N is the light sleep period. If any packet call comes before the duration of t_N within the current session or a new session starts (after completing the previous session) within t_N, the UE will come back again to state 1 from state 2. The probability of above phenomenon is,

$$\therefore \quad p_{21} = p_{pc} \cap . p\{t_{ipc} < t_N\} + p_s \cap p\{t_{is} < t_N\}$$

$$= \left(1 - \frac{1}{\mu_{pc}}\right)\left(1 - e^{-\lambda_{ipc} t_N}\right) + \frac{1}{\mu_{pc}}\left(1 - e^{-\lambda_{is} t_N}\right) \qquad (9)$$

Similarly,

$$p_{22}=\left(1-\frac{1}{\mu_{pc}}\right)e^{-\lambda_{ipc}t_N}+\frac{1}{\mu_{pc}}e^{-\lambda_{is}t_N} \qquad (10)$$

If the UE retains L times at state 2 then t_N will become $t_{\text{deep-cycle}}$ i.e. the UE enters in deep sleep cycle.

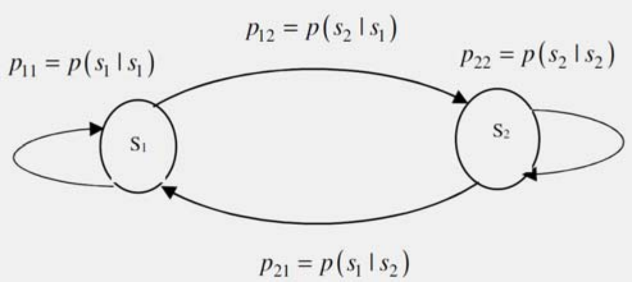

Fig.2 State transition model

From the Fig. 2,

$$\begin{aligned}p(s_1)&=p(s_1|s_2)\,p(s_1)+p(s_1|s_2)\,p(s_2)\\&=p_{11}\,p(s_1)+p_{21}\,p(s_2)\\&=p_{11}\,p(s_1)+p_{21}\{1-p(s_1)\}\\&\Rightarrow p(s_1)\{1-p_{11}+p_{21}\}=p_{21}\\&\Rightarrow p(s_1)=\frac{p_{21}}{1-p_{11}+p_{21}}\end{aligned} \qquad (11)$$

Similarly,

$$p(s_2)=1-p(s_1)=\frac{1-p_{11}}{1-p_{11}+p_{21}} \qquad (12)$$

$$p(s_2s_2)=p(s_2|s_2)\,p(s_2)=p_{22}\cdot\frac{1-p_{11}}{1-p_{11}+p_{21}} \qquad (13)$$

$$\begin{aligned}p(s_2s_2s_2)&=p(s_2|s_2s_2)\,p(s_2s_2)\\&=p_{22}\cdot p_{22}\frac{1-p_{11}}{1-p_{11}+p_{21}}\\&=p_{22}^2\frac{1-p_{11}}{1-p_{11}+p_{21}}\end{aligned} \qquad (14)$$

$$\begin{aligned}p(s_2s_2s_2s_2)&=p(s_2|s_2s_2s_2)\,p(s_2s_2s_2)\\&=p_{22}\cdot p_{22}^2\frac{1-p_{11}}{1-p_{11}+p_{21}}\\&=p_{22}^3\frac{1-p_{11}}{1-p_{11}+p_{21}}\end{aligned} \qquad (15)$$

$$p\left(s_2s_2....s_2.....\text{L}^{th}\ times\right)=p_{22}^{L-1}\frac{1-p_{11}}{1-p_{11}+p_{21}} \qquad (16)$$

$$p(entering\ long\ sleep)=\frac{1-p_{11}}{1-p_{11}+p_{21}}\sum_{i=L-1}^{\infty}p_{22}^i \qquad (17)$$

$$p(entering\ short\ sleep)=\frac{1-p_{11}}{1-p_{11}+p_{21}}\sum_{i=1}^{L-1}p_{22}^i \qquad (18)$$

Let us now derive the entropy of the two state Markov chain to observe the inclination of the UE to state 2. The entropy of a memoryless binary source is,

$$H=P_1\log_2\left(\frac{1}{P_1}\right)+P_2\log_2\left(\frac{1}{P_2}\right) \qquad (19)$$

where, P_1 and P_2 are the probability of occurrence of phenomena 1 and 2 respectively. Since the proposed state transition chain has several conditional probabilities hence it resembles to information source with memory. In this case, the entropy will be evaluated taking individual conditional probability.

The entropy provided that the UE remains in state1,

$$H(X|s_1)=P(s_1|s_1)\log_2\frac{1}{P(s_1|s_1)}+P(s_2|s_1)\log_2\frac{1}{P(s_2|s_1)}\,. \qquad (20)$$

Again, the entropy provided that the UE remains in state 2,

$$H(X|s_2)=P(s_2|s_2)\log_2\frac{1}{P(s_2|s_2)}+P(s_1|s_2)\log_2\frac{1}{P(s_1|s_2)} \qquad (21)$$

The composite entropy,

$$H(X)=P(s_1)H(X|s_1)+P(s_2)H(X|s_2)\,. \qquad (22)$$

The entropy and the Markov chain will be used to evaluate the possibility of inclination of the traffic model towards the state 2.

III. RESULTS

This section deals with the results based on analysis of section-II. Fig.3 shows the profile of ‘probability of entering short sleep’ against ‘threshold interarrival time’ taking ‘packet call arrival rate’ as a parameter. We consider the traffic parameters as: λ_{is}=1/2000 /sec, μ_{pc}= 5/sec and t_N=10 sec. It is common observation that the ‘probability of entering short sleep’ rises when interarrival time increases i.e. an UE gets more idle time between two consecutive arrival. When the threshold value of interarrival time t_I is increased (hurdle is raised for an UE to enter in sleep mode) the probability of an UE to enter in sleep mode will be reduced. The phenomenon is visualized from Fig.3. Here we consider four values of packet arrival rate, λ_{ipc}=1/30, 1/32, 1/35 and 1/38 sec. The curves fall with increase in λ_{ipc} since the opportunity of entering in sleep mode will be reduced with increase in λ_{ipc} (UE will have to handle more packet for larger λ_{ipc}). The similar analysis is shown for the case of 'probability of entering long sleep' shown in Fig.4 taking the same traffic parameters like Fig.3.

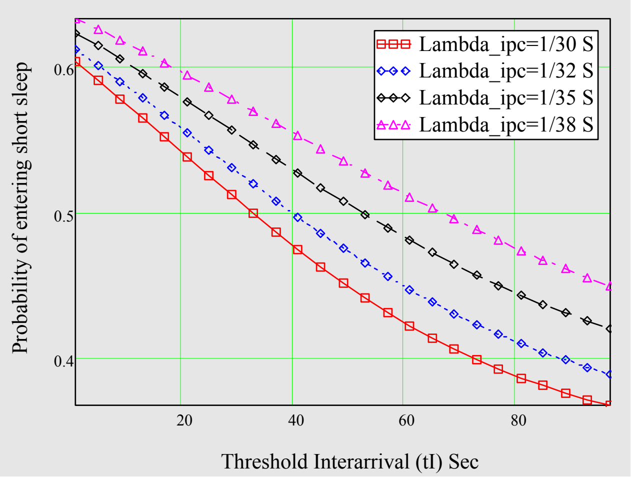

Fig.3 Variation of Probability of entering short sleep against threshold interval of session/packet call

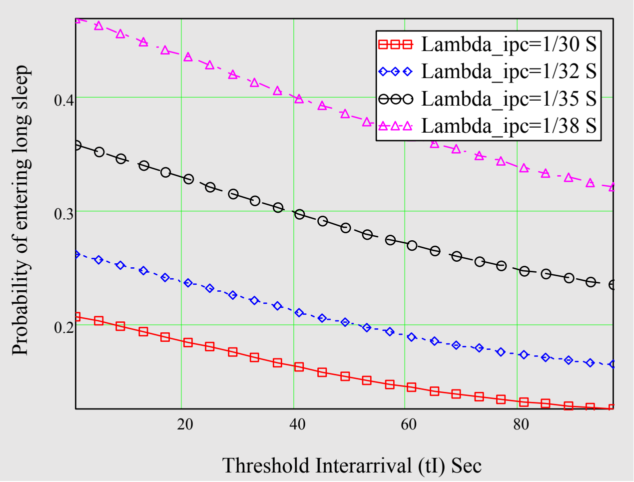

Fig.4 Variation of Probability of entering long sleep against threshold interval of session/packet call

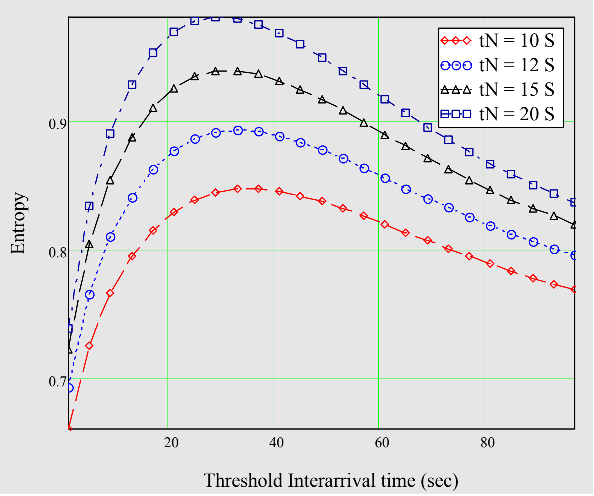

Fig.5 Variation of entropy against threshold interarrival time taking μ_{pc} = 5 and t_N as a parameter

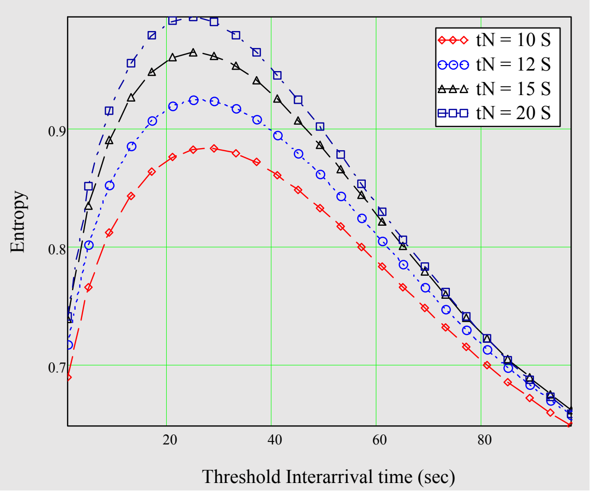

Fig.6 Variation of entropy against threshold interarrival time taking μ_{pc} = 10 and t_N as a parameter

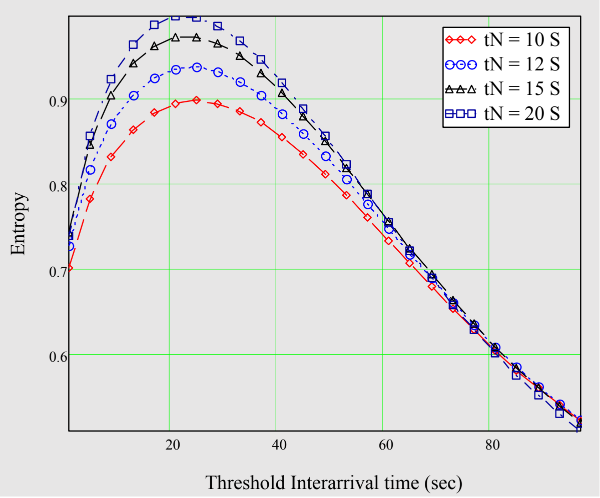

Fig.7 Variation of entropy against threshold interarrival time taking μ_{pc} = 20 and t_N as a parameter

Next, we have shown the profile of entropy of two state Markov chain to observe the inclination of UE towards the idle state. For a binary memoryless information source the entropy is:

$$H = p\log_2\left(\frac{1}{p}\right) + (1-p)\log_2\left(\frac{1}{1-p}\right) \tag{23}$$

where, p is the probability of occurrence of phenomenon 1 and that of 2 is $(1-p)$. The entropy will attain a maximum value of 1 when p =1/2 i.e. for the equiprobable case. For the traffic parameters of the paper the entropy the two state Markov chain is found maximum at t_I = 27 sec visualized from Fig.5-7. When t_I< 27 sec the UE has the tendency of staying at state 1 i.e. in active mode, for t_I = 27 sec the idle (or sleep) and active state are equi-probable, for t_I> 27 sec the UE will stay longer duration on sleep state compared to active state. Here entropy is increased with the increase in short sleep period t_N since the UE has less opportunity to serve packets for shorter t_N which is also visualized from Fig.5-7. It is worth to mention that the instant peak entropy (t_I = 27 sec) is same for t_N = 10, 12, 15 and 20 sec. Finally, increasing the number of packet 'packets calls/sessions' μ_{pc} will keep the UE more inclined to busy state hence entropy curves will rise towards 1 whose are visualized from Fig.5-7. The traffic parameters used for Fig.5-7 are: μ_{pc} = 5, 1 and 20, λ_{is}= 1/2000 and λ_{ipc}= 1/30.

IV. CONCLUSION

The paper provides a simple 2 state Markov chain to evaluate the performance of LTE in context of power saving. The entire work can be extended for generalized N state Markov chain. Finally the impact of timer inactivity on carried traffic needs to be analysed incorporating all traffic parameters on DRX model. Most of the analysis of DRX on recent literature follows the exponential pdf on traffic parameters but the model can be analysed using M/G/1 model.

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