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Performance Comparison of 3 States and 4 State Discontinuous Reception (DRX) Mechanisms with On Time to Short Cycle (OTSC) Ratio for LTE Network

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Abstract: The Standardized 4th Generation Mobile Communication, Long Term Evolution (LTE) Provides High Data Rates To Meet The Growing Demands Of The Users. The High Data Rates Provided By UE Of LTE Introduce Excessive Power Consumption. Power Saving Is The Major Issue In The Present Scenario Of The LTE Due To The Usage Of The User Equipment (UE) For All Applications. Discontinuous Reception (DRX) Mechanism Is One Of The Good Techniques For Tackling This Issue. Delay Constraint And Power Saving Are Two Contrasting Performance Metrics Connected With The DRX Mechanism. In This Paper, The Performance Comparison Between 3 State And 4 State DRX Mechanisms Incorporated With The On Time To Short Cycle Ratio (OTSC) Is Done. Performance Comparison Is Made For Different OTSC Ratios And Found That 4 State Model With OTSC Has Better Performance Than That Of The 3 State Model With OTSC. The Simulation Tool Used Is MATLAB R2014a.

Keywords: LTE; Power Saving; DRX; OTSC Ratio; Delay

I. INRODUCTION

The Trending Wireless Communication Technology Being Deployed Is The Fourth Generation (4G) Mobile Technology, Known As Long Term Evolution (LTE). LTE Is A New Standard For Radio Access Technology Introduced By 3GPP. The Main Objective Of LTE Is To Accommodate Today's Increasing Demands For High-Speed Data Services Such As Conversational Voice, Video And Online Gaming. But The Adverse Effect Is The Quick Draining Of User Equipment (UE) Battery. To Relieve The Knock-On Effect Of Quick Draining And To Outspread The UE Battery Lifetime, The 3GPP Standards For LTE Has Adopted An Upright Technique Called Discontinuous Reception (DRX) Mechanism Which Allows The UE To Enter Into Sleep Mode To Increase The Battery Lifetime. Hence, In This Paper, Performance Comparison Between 3 State And 4 State DRX Mechanism With OTSC Is Done.

The Rest Of This Paper Is Structured As Follows. Section II Deals With The 4 State Model Of DRX Mechanism And DRX Parameters. Section III Discusses About The Performance Metrics Of 4 State Model With OTSC Ratio. The Main Goal of this work Is To Compare The 4 State And 3 State Models And To Explore The Proper Selection Of DRX Parameters Namely On Time Duration And Short Cycle Duration, So That Either Power Consumption Or Delay Can Be Minimized According To User's Choice. Section IV Provides The Simulation Results For Different OTSC Ratios. Section V Reveals The Ultimate Conclusion Of This Paper.

II. 4 STATE MODEL OF DRX

This Section Presents The Details Of The 4 State Discontinuous Reception Mechanism Models[1] Which Have Been Proposed For LTE Network. And Also The Traffic Model Which Is Considered To Represent The Traffic Network Patterns Is Also Dealt.

The 3 State DRX Mechanism Is Also Considered And Its Performance Metrics Are Formulated From The [2,3]

A. 4 - State DRX Mechanism

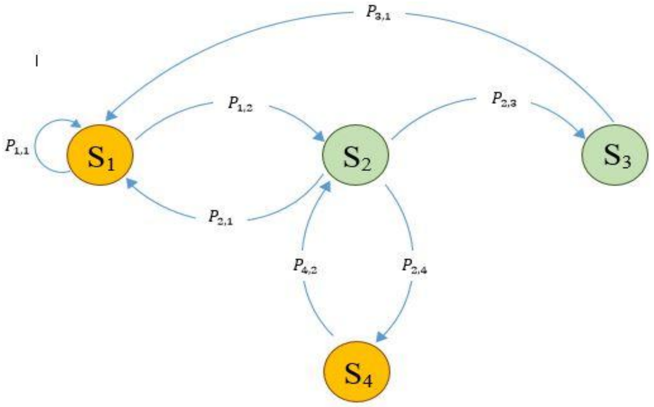

Figure 1. 4- State DRX Model[1]

The 4 State DRX Model Is The Extension To The 3 State DRX Model. With The Help Of This Model, The Power Consumption Of UE Can Be Much More Reduced. The 4 State DRX Model Consists Of Four States Such As S_1, S_2, S_3 And S_4. The Additional 4th State Is Called As The Single Packet Active State Attached To The Light Sleep State. This State Is Useful Because When The DRX Model Is In Light Sleep State, It Will Not Move To The Active State On The Arrival Of Single Packet, Instead It Moves To The Single Packet Active State Where The DRX Model Is Not Needed To Wait For The Expiration Of The Inactivity Timer. So, In This Way, Some Power Will Be Saved By Not Moving To The Active State For Less Packets Indicated By The PDCCH. The Transitions Between The States And The Probabilities Of Each State On The Arrival Of The Packets Will Be Discussed In The Next Section.

The Possible Values Of The $t_I, t_{DS}, t_N, t_{DL}, \tau$used In This Paper Are Taken From The Research Work [7] And Listed In The Following TABLE I

TABLE I. POSSIBLE VALUES OF DRX PARAMETERS [7]

Parameter	Values (In TTI Or Ms)
t_I	1,2,3,4,5,6,8,10,20,30,40,50,60,80,100,200,300,500,750,1280,1920,2560
t_{DS}	2,5,8,10,21,40,64,80,128,160,256,320,512,640
t_N	1-16
t_{DL}	10,20,32,40,64,80,128,160,256,320,512,640,1024,1280,2048,2560
τ	1,2,3,4,5,6,8,10,20,30,40,50,60,80,100,200

B. ETSI Packet Traffic Model

The ETSI Packet Traffic Model Is Chosen Based On The Previous Studies Inorder To Represent The Network Traffic Patterns For Analyzing The DRX Mechanism [4, 6, 9]. Hence The Same Traffic Is Adopted In The Proposed Model. For ETSI Packet Traffic Model, The Statistical Distributions Of The Parameters Are Summarized As Follows:

- $1/\lambda_{is}$ Is Mean Of Inter-Session Idle Time (t_{is}) Which Is Modeled As An Exponential Distribution.
- μ_{pc} Is The Mean Of Number Of Packet Calls Per Session (N_{pc}) Which Follows Geometric Distribution.
- $1/\lambda_{ipc}$Is The Mean Of Inter-Packet Call Idle Time (t_{ipc}) Which Is Assumed To Be An Exponential Distribution.
- μ_p Is The Mean Of Number Of Packets Per Packet Call (N_p) Which Is Modeled As A Geometric Distribution.
- $1/\lambda_{ip}$Is The Mean Of Inter-Packet Arrival Time (t_{ip}) Which Is Drawn From An Exponential Distribution.

III. PERFORMANCE ANALYSIS WITH OTSC RATIO

A. Performance Measure

The Performance Metrics [5] Which Are Being Measured Are:

- Power Saving Factor (PS): It Is The Percentage Of Time UE Spends In Sleeping Within A DRX Mechanism.
- Wake-Up Delay (E(D)): It Is The Delay Experienced By The UE Before It Enters Into Active Mode.

B. Incorporation Of OTSC Ratio

In This Proposed Work, A 4 State DRX Model With OTSC Ratio Is Modeled And Compared With The Existing 3 State Model With OTSC [8]. The Advancement In 4 State Apart From The Conventional 3 State DRX Model Is The Addition Of Single Packet Active State. The Active State Is Attached To The Light Sleep State As Shown In The Figure 1.The Implementation Considered In This Paper Is The Incorporation Of OTSC Ratio In 4 State DRX Model.

Based On The ETSI Traffic Model, The Probabilities For All The Statistical Parameters Of The ETSI Traffic Model Which Are Listed Above Are Considered. Interpacket Call Idle Time (t_{ipc})Is Possibly The Inter-Arrival Time Between Two Successive Packet Calls With The Probability $P_{pc} = 1 - 1/\mu_{pc}$Or The Probability Of Inter Session Idle Time (Tis) Is $P_s = 1/\mu_{pc}$.

In The 3 State Model, S_1Is The Active State, S_2 Is The Light Sleep State And The S_3 Is The Deep Sleep State.In The 4 State Model, S_1 And S_4 Are The Active States And S_2 Is The Light Sleep State And The S_3 Is The Deep Sleep State. The Transitions between the States in the 3 State and 4 State Model Are Almost Similar except Transitions From S_3ToS_4.The Transition Probabilities Of These Models Are Discussed Below[10]. Initially, The Active State Or $S_1$is the stateWhere The UE Stays In Power Active Mode Monitors The Physical Channel For The PDCCH And Remains Awake During The Complete Packet Transmission. In This State, After Successfully Receiving Each Packet, The UE Initiates A DRX Inactivity Timer (t_I). If Any Packet Appear Before The Expiration Of t_I The UE Remains In S_1And Receives All Packets Delivered From Enodeb. During An Ongoing Session, Before The Expiration Of t_I, $q_1 = \Pr[1/\lambda_{ipc} < t_I] = 1 - e^{-\lambda_{ipc} t_I}$Is The Probability Of A New Packet Call And The Probability Of A New Session Starting Is $q_2 = \Pr[1/\lambda_{is} < t_I] = 1 - e^{-\lambda_{is} t_I}$Before The Expiration Of t_I.Thus, If There Are No New Sessions Or Packet Calls During A Session And t_I Expires Then The UE Switches From State S_1To State S_2As Shown In Figure 1.Eventually There Can Be Only Two Transitions That S_1Will Have.The Probabilities For These Transitions Described As:

$P_{1,1} = P_{pc} q_1 + P_s q_2$ (1)

$P_{1,2} = P_{pc}(1 - q_1) + P_s(1 - q_2)$ (2)

Then The UE Moves To The Light Sleep State Which Is Called State 2 (S_2). In This State, The UE Will Be In Sleep Period For A Particular Short Period Of Time, That Is The UE Follows The DRX Short Cycle. On Switching Over To The DRX Short Cycle, The Short Cycle Timer (t_N) Will Be Initiated. The Number Of DRX Short Cycle Is N_{DS}=t_N/t_{DS}. In This State 2 If There Are Arrival Of Packets In The Listen State Of The DRX Short Cycle Then It Moves To State 1 Or State 4 Based On The Range Of Packets, If The Number Of Packets Are More Then It Will Move To The Active State S_1 And Again Inactivity Timer Will Be Initiated And After Expiration It Comes To The StateS_2. But If The Packets Are Less In Number, Then It Will Move To StateS_4, Based On The Threshold Value. The Advantage In The Added Active State S_4Is That It Receives The Packets With In Threshold Value And Return To The State S_2And There Will Be No Inactivity Timer. And Even After The Expiration Of Short Cycle Timer If There Are No Packets Arrived Then State S_2Will Move To The State S_3. Similar To The Active State, The Probabilities For A New Packet Call During A Session And For A New Session Initiation Can Be Also Expressed In The Light Sleep State Which Are Given As$q_3 = \Pr[1/\lambda_{ipc} < t_N] = 1 - e^{-\lambda_{ipc} t_N}$And $q_4 = \Pr[1/\lambda_{is} < t_N] = 1 - e^{-\lambda_{is} t_N}$ Respectively.So The Possible Transitions For StageS_2 Are: S_2ToS_1; S_2 To S_4 And S_2 To S_3And The Probabilities For Those Transitions Are:

$P_{2,1} = P_{pc} q_3^{(Thr_{2,4}+1)} + P_s q_4^{(Thr_{2,4}+1)}$(3)

$P_{2,3} = P_{pc}(1 - q_3) + P_s(1 - q_4)$ (4)

$P_{2,4} = 1 - P_{2,1} - P_{2,3}$ (5)

The Next State In The DRX Process Is The Deep Sleep State Or State S_3 As Shown In The Figure 1. In This State The UE Goes To Sleep For Longer Period Of Time (t_{DL}) I.E. UE Follows The Long DRX Cycles.After Completing A Cycle In S_1 If A Packet Is Scheduled To Arrive An UE Moves Straight ToS_1. As Like The Previous States,The Probability For A New Packet Call During A Session In The Deep Sleep State Defined As$q_5 = \Pr[1/\lambda_{ipc} < t_{DL}] = 1 - e^{-\lambda_{ipc} t_{DL}}$And The Probability Of A New Session Is$q_6 = \Pr[1/\lambda_{is} < t_{DL}] = 1 - e^{-\lambda_{is} t_{DL}}$. In Similar To State S_2The Possible Transition Probabilities Of S_3 And S_4 Are :

$P_{3,1} = 1; P_{4,2} = 1$ (6,7)

Putting All Transition Probabilities Together From Above Equations, The Probability Matrix For The 4 State DRX Mechanism Is Expressed As Follows:

$$P_{4-state} = \begin{bmatrix} P_{1,1} & P_{1,2} & 0 & 0 \\ P_{2,1} & 0 & P_{2,3} & P_{2,4} \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix} \quad (8)$$

By Using The Equations $\sum_{i=1}^{4} \pi_i = 1$And The Balance Equations$\pi_i = \sum_{i=1}^{4} \pi_j P_{j,i}$From [1]$\pi_j$As Follows:

$$\Pi = \begin{cases} \pi_1 = \frac{1-p_{24}}{1-p_{24}+p_{12}+p_{12}p_{24}+p_{12}p_{23}} \\ \pi_2 = \frac{p_{12}}{1-p_{24}+p_{12}+p_{12}p_{24}+p_{12}p_{23}} \\ \pi_3 = \frac{p_{12}p_{23}}{1-p_{24}+p_{12}+p_{12}p_{24}+p_{12}p_{23}} \\ \pi_4 = \frac{p_{12}p_{24}}{1-p_{24}+p_{12}+p_{12}p_{24}+p_{12}p_{23}} \end{cases} (9)$$

In The Holding Times Of The 4 State DRX Model, The Proposal Of Incorporation Of The OTSC Ratio Is Done As Shown Below. OTSC Ratio Means Ontime Duration (τ) To The Short Cycle Duration (t_{Ds}) Ratio. This Ratio Indicates How Much Time The UE Can Able To Listen To The Arrival Of Packets Within The Short Cycle. Based On This Ratio, The Power Saving And Delay Will Be Varied According To The Variation Of The OTSC Ratio. So The Modified Holding Time H_j For$j\epsilon\{1,2,3,4\}$Is As Follows:

Alpha (A) $= (\tau/t_{DS})$; $t_{DS} = \left(\frac{\tau}{\alpha}\right)$ (10,11)

$$E[H_1] = \frac{\mu_p - 1}{\lambda_{ip}} + \frac{P_{pc}}{\lambda_{ipc}}\left[1 - e^{-\lambda_{ipc} t_I}\right] + \frac{P_s}{\lambda_{is}}\left[1 - e^{-\lambda_{is} t_I}\right] \quad (12)$$

$$E\left[{H_2}^{4\,state\alpha}\right] = P_{2,3}\left(N_{DS} + Thr_{2,4}\right)\left(\frac{\tau}{\alpha}\right) + P_{2,4}\left[\frac{P_{pc}}{1 - e^{-\lambda_{ipc}\left(\frac{\tau}{\alpha}\right)}} + \frac{P_{pc}}{1 - e^{-\lambda_{is}\left(\frac{\tau}{\alpha}\right)}}\right]\left(\frac{\tau}{\alpha}\right) + P_{2,1}\left[\frac{P_{pc}}{1 - e^{-\lambda_{ipc} t_N\left(\frac{Thr_{2,4}+1}{Thr_{2,4}+N_{DS}}\right)}} + \frac{P_s}{1 - e^{-\lambda_s t_N\left(\frac{Thr_{2,4}+1}{Thr_{2,4}+N_{DS}}\right)}}\right]\left(\frac{\tau}{\alpha}\right) \quad (13)$$

$$E[H_3] = \left[\frac{P_{pc}}{1 - e^{-\lambda_{ipc} t_{DL}}} + \frac{P_s}{1 - e^{-\lambda_s t_{DL}}}\right] t_{DL} \quad (14)$$

$$E\left[H_{2\,eff}^{4state\alpha}\right] = E\left[{H_2}^{4\,state\alpha}\right]\left((\tau/\alpha) - \tau\right) \quad (15)$$

$$E\left[H_{3\,eff}\right] = E[H_3](t_{DL} - \tau) \quad (16)$$

The Power Saving For The 4 State DRX Model With Incorporated OTSC Ratio Is As Follows

$$PS_4^{\alpha} = \frac{\pi_2 E\left[H_{2\,eff}^{4state\alpha}\right] + \pi_3 E\left[H_{3\,eff}\right]}{\sum_{i=1}^{4} \pi_i E[H_i]} \quad (17)$$

Even If UE Is In Deep Sleep Or Light Sleep, A Packet Call Transmission Begins In One Of The States. The Probability That A Packet Call Delivery Begins At The Ith DRX Cycle Is Formulated For 4 State With OTSC Ratio As Follows:

$$P_i^{4state-\alpha} = \begin{cases} \underbrace{P_{pc} e^{-\lambda_{ipc}\left\{t_I + [i-1+(m-1)]\left(\frac{\tau}{\alpha}\right)\right\}}\left(1 - e^{-\lambda_{ipc}\left(\frac{\tau}{\alpha}\right)}\right) + P_s e^{-\lambda_{is}\left\{t_I + [i-1+(m-1)]\left(\frac{\tau}{\alpha}\right)\right\}}\left(1 - e^{-\lambda_{is}\left(\frac{\tau}{\alpha}\right)}\right)}_{m=\sum_{j=1}^{Thr_{2,4}} k[k=1,2,3,.....],\ 1\leq i<N_{DS}} \\ \underbrace{P_{pc} e^{-\lambda_{ipc}\{t_I + t_N + [i-N_{DS}-1]t_{DS}\}}\left(1 - e^{-\lambda_{ipc} t_{DL}}\right) + P_s e^{-\lambda_{is}\{t_I + t_N + [i-N_{DS}-1]t_{DL}\}}\left(1 - e^{-\lambda_{is} t_{DL}}\right)}_{i\geq N_{DS}} \end{cases} \quad (18)$$

Wake Up Delay Of3state And 4 State DRX Model With OTSC Ratio (α) Is Obtained As Follows:

$$E[D_4^{\alpha}] = \sum_{i=1}^{N_{DS}} P_i^{4state-\alpha}\frac{(\tau/\alpha)}{2} + \sum_{i=N_{DS}+1}^{\infty} P_i^{4state-\alpha}\frac{t_{DL}}{2} (19)$$

IV. SIMULATION RESULTS

The Performance Comparison Is Done Between The 4 State Model With OTSC Ratio And The Existing 3 State Model With OTSC Ratio Using MATLAB R2014a Simulator. The Performance Is Analyzed In Terms Of The Wakeup Delay, Power Saving Factor. The Simulation Results Are Obtained For Different OTSC Ratios. The Parameters Used In The Simulation Are Given In TABLE II And TABLE III.

TABLE II. VALUES OF OTSC RATIOS USED FOR SIMULATION

(α)OTSC Ratio; τ/t_{DS}	$\tau(TTI)$	$t_{DS}(TTI$
0.02	1	50
0.05	2	40

TABLE III. DRX PARAMETERS FOR SIMULATION

Parameter	**Details(TTI Or Ms)**
Inactivity Timer(t_I)	20 – 120
Short DRX Cycle(t_{DS})	20– 50
DRX Short Cycle Timer(t_N)	2 – 16
Long DRX Cycle(t_{DL})	40 – 140
On Duration Timer(τ)	1 – 5
Thr_{24}	3

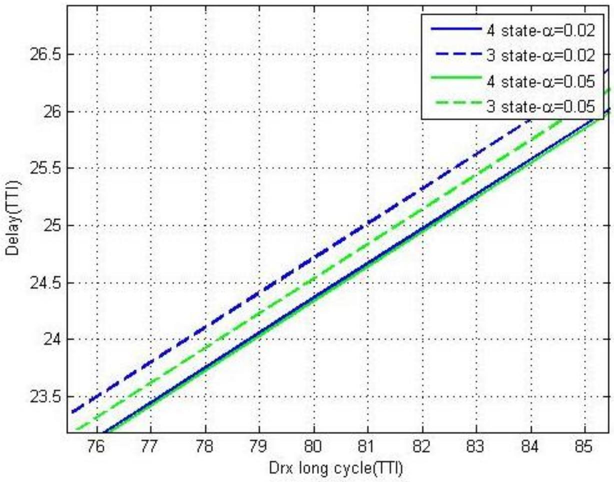

Figure 2(A). Wakeup Delay As A Function Of DRX Long Cycle

It Is Observed Through The Simulation Result Shown In Figure 2(A) That Wakeup Delay Is Increased With The Increased Values Of The Long DRX Cycle. It Is Also Inferred That If The Value Of α Is Increased Then Wakeup Delay Decreases. The Reason For Increase In Delay For Lower α Value Is That As α Decreases, The t_{DS} Value Is Increased Which Results In The Increase Of The Wakeup Delay. It Is Noticed That 4 State achievesBetter Performance Than That Of The 3 State.

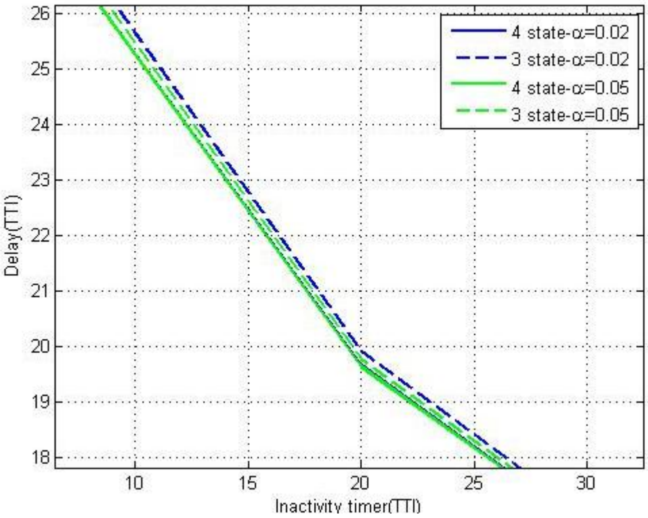

Figure 2(B). Wakeup Delay As A Function Of Inactivity Timer

It Is Inferred Through The Figure 2(B) That The Wakeup Delay Decreases With The Increase In Inactivity Timer Irrespective Of The α Value. With The Increase Of α Value, The Delay Is Decreased Because The τ Increases With Increase Of α, Which Provides More Time For Arrival Of Packets. And Also It Resembles From The Figure 2(B) That 4 State Model Achieves Lesser Delay Than That Of The 3 State Model.

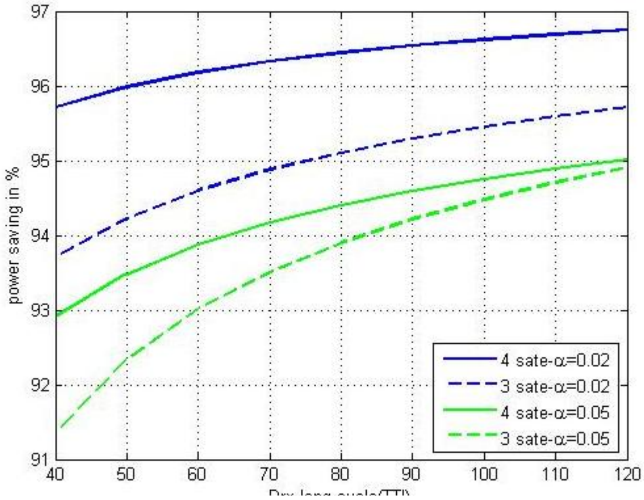

Figure 3(A). Power Saving As A Function Of DRX Long Cycle

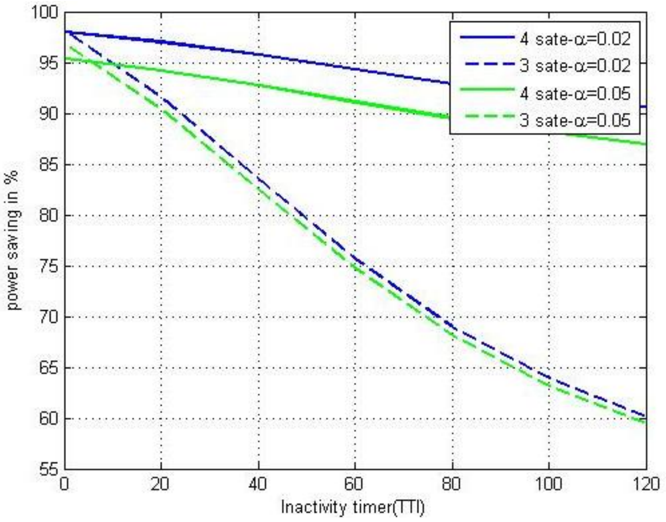

Figure 3(B). Power Saving As A Function Of Inactivity Timer

From Figure 3(A), It Is Observed That The Power Saving Is Increased As DRX Long Cycle Is Increased Initially And it is Constant As It Reaches Higher Values Irrespective Of α It Is Also Depicted Through The Figure3(A), That For α =0.02, 4 State Model Achieves Good Power Saving Factor When Compared With The 3 State Model, Which Is Due To The Presence Of The Single Packet Active State In The 4 State DRX Model. From Figure 3(B), It Is Inferred That The Power Saving Factor Decreases With Gradual Increase Of The Inactivity Timer. For α =0.02, 4 State Model With OTSC Ratio Has Higher Power Saving Factor Than That Of The 3 State Model With OTSC Ratio For Increased Inactivity Timer.

V. CONCLUSION

In This Paper, The 4 State DRX Model Of LTE Incorporated With OTSC Ratio Is Compared With The 3 State DRX Model Incorporated With OTSC Ratio Considering The Performance Metrics Such As Power Saving Factor And Wakeup Delay. These Performance Metrics Are Determined For The Different OTSC Ratio (α) Values By Varying DRX Long Cycle And Inactivity Timer. Hence From This Paper, It Is Concluded That The 4 State Model With OTSC Ratio (α) Provides Better Performance Than That Of The 3 State Model With Incorporated OTSC Ratio (α). In Future Work, OTSC Ratio Can Be Incorporated In The 5 State DRX Mechanism And Performance Can Be Analysed For The Other Traffics.

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