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# The Effect of $T_{max}$ in Energy Consumption in IEEE 802.16e with Traffic Load

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***Abstract*****—**Energy consumption is an important design issue for Mobile Subscriber Station (MSS) in the standard IEEE 802.16e. Because mobility of MSS implies that energy saving becomes an issue so that lifetime of MSS can be extended before re-charging. Also, the mechanism in efficiently managing the limited energy is becoming very significant since a MSS is generally energized by battery. For these, sleep mode operation is recently specified in the MAC (Medium Access Control) protocol. In order to reduce the energy consumption, we focus on the sleep-mode and wake-mode of the MAC layer, which are included in the IEEE 802.16 standards [1-2].

***Keywords*****—**IEEE 802.16e, Sleep-mode, Wake-mode, Downlink, Mobile Subscriber Station.

## I. INTRODUCTION

IEEE 802.16 is a wireless network technology and has been developed recently. The first version of this standard was created in 2001. IEEE 802.16e, which is the last version of IEEE 802.16 was introduced in 2005 and it should support mobile users [3].

Energy consumption is an important design issue for mobile users. In order to reduce the energy consumption of the IEEE 802.16e standard, we focus on sleep-mode and wake-mode. This is because these parts are important components in energy consumption of this standard. In this papers a new method based on variable $T_{max}$, which is obtained by changing the length of $T_{max}$ window in sleep-mode is proposed. The proposed technique calculates the $T_{max}$ based on $\lambda$ (frames per unit time) variations with the changes of network load to reach the best situation of energy consumption. The length of $T_{max}$ interval in this technique is not fixed. The domain of $T_{max}$ value is set between 2 and 1024 with traffic load [4-5].

This paper is organized as follows. In section II, the general architecture of IEEE 802.16, sleep-mode, and wake-mode is described. The proposed technique in related work is discussed in section III followed by the new proposed technique in section IV. Finally, the obtained results and conclusions are discussed in sections V and VI, respectively.

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## II. ARCHITECTURE, SLEEP-MODE, AND WAKE-MODE

As shown in Figure1. IEEE 802.16 structure includes of Based Stations (BSs) and Subscriber Stations (SSs). The BS makes connection for data transmission between other SSs and BSs,. Users connect to network directly by the SS. This structure can support other standards. If data send to the SS via the BS this process is called Downlink, otherwise this process is called Uplink [6–7].

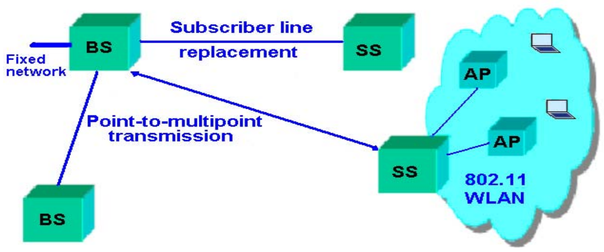


Fig. 1 IEEE 802.16 Architecture

Fig. 2 depicts the timing of the sleep-mode and wake-mode. These modes are included by MSS. The MSS includes one period in the wake-mode and one period in the sleep-mode. The MSS has to send a sleep request frame to the BS and waits for BS's approval before goes to sleep. After getting approval, the MSS goes into the sleep-mode, gets sleep for an interval, and then wakes up to check whether there are frames for it. Otherwise, the MSS is still in the sleep-mode and gets sleep for another interval. If the frames are available for the MSS, it goes to wake-mode. The MSS keeps performing the above procedure until it goes to the wake-mode again. After each sleep interval, the MSS temporarily wakes up for a short interval, called listen interval, to listen the traffic indication message broadcasted from the BS. The message includes information about MSSs to whom the BS has frames waited for. Such a procedure should be negotiated beforehand between the MSS and the BS [1].

Parameters such as $T_{min}$ and $T_{max}$ are included in the sleep request frame, which are sent by the MSS to the BS before sleeping. In addition,, the MSS can terminate the sleep-mode if there is an out-going frame, mostly because of the user's manual interaction [8-9].

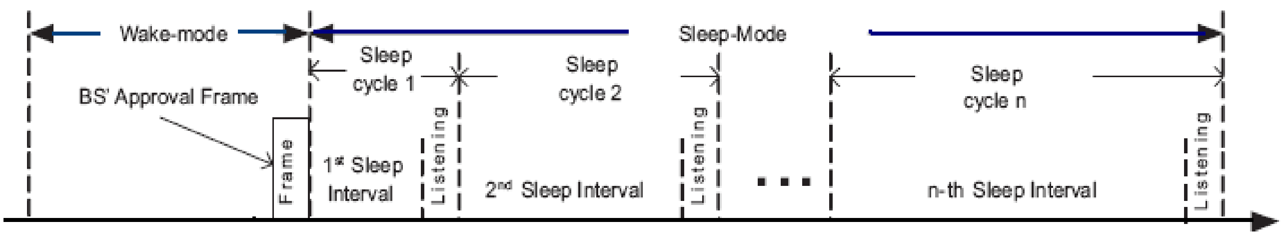


Fig. 2. Sleep-mode and Wake-mode

A MSS goes to sleep-mode when the MSS is not active (it's idle), and has got no frame for sending and receiving. Small part of MSS is on for quick restarting and others are off. So, the energy consumption decreases**.** Assume that frame arrival rate to a MSS follows Poisson distribution with rate $\lambda$ (frames per unit time). Then the inter frame arrival a time of follows an exponential distribution with mean $1/\lambda$ (unit time).

In the 802.16e, sleep intervals are defined as follows. At the first sleep interval, a minimum sleep interval $T_{min}$, is used. Then each sleep interval is doubled ($2^j T_{min}$), until a maximum sleep interval $T_{max}$ is reached, and then the sleep interval keeps $T_{max}$, where $j$ stands for the j-th sleep interval. Consider that $T_j$ denote the length of the *j-th* sleep interval. $T_j$ domain is between *1* and *1024*, and doubled, according to the equation (1). For example $T_1=1$, $T_2=2T_1$, $T_3=4T_1$… Let $L$ denote the length of a listening interval.[8-12]

$$T_j \begin{cases} 2^{j-1} T_{min}, & if\ 2^{j-1}T_{min} < T_{max} \\ T_{max}, & if\ 2^{j-1}T_{min} \geq T_{max} \end{cases} \tag{1}$$

$N$ is defined as the number of sleep cycles in sleep-mode before the MSS changes the mode and goes to wake-mode. Let $\lambda$ denotes frames per unit time, the length of the *J-th* sleep cycle is computed using the following equation [10]:

$$\boldsymbol{T_{cycleJ}} = L + T_J \tag{2}$$

The equation (3) expresses the computed energy consumption. Let $E_S$ and $E_L$ denote the energy consumption units per unit of time in the sleep interval and the listening interval, respectively. Then we can obtain the energy consumption in the sleep-mode as follow [11]:

$$\boldsymbol{Energ\ y} = \sum_{j=1}^{\infty} e^{-\lambda \sum_{i=1}^{j-1}(Ti+L)} \sum_{k=1}^{j}(TkEs + LEL) - \sum_{j=1}^{\infty} e^{-\lambda \sum_{i=1}^{j}(Ti+L)} \sum_{k=1}^{j}(TkEs + LEL) \tag{3}$$

The equation (4) expresses the response time. Where $R$ is the response time. Since frame arrivals follow Poisson distribution, the arrival events are random observers to the sleep intervals. Therefore, it is obtained using equation (4) [11]:

$$\boldsymbol{E[R]} = \sum_{j=1}^{\infty} \Pr(n=j)(Tj+l)/2 = \frac{1}{2}\sum_{j=1}^{\infty} e^{-\lambda \sum_{i=1}^{j-1}(Ti+L)} (Tj+l) - \frac{1}{2}\sum_{j=1}^{\infty} e^{-\lambda \sum_{i=1}^{j}(Ti+L)} (Tj+l) \tag{4}$$

We have the following parameters: $L=1$, $T_{Max}=1024$, $E_S=1$, $T_{min}=1$ and $E_L=10$. The $E_l$ is ten times of $E_s$. So, if we can change the wake interval in wake-mode instead of sleep interval for each unit time in the sleep interval, then the energy consumption almost will be decreased to *0.1* of its previous edition. So this is the best reason that we check sleep-mode more than before [10-13].

## III. The Suggested Design for Decreasing the Energy Consumption in 802.16E Standard in Our Pervious Work

$T_{min}$ should be chosen somehow to be performable in each network traffic and have the most optimum condition. So, using an innovative method (using the variant $T_{min}$) has been suggested. By studying the diagrams, an optimum $T_{min}$s with the lowest consumption of energy has been obtained, $T_{min}=2$ $\lambda>=0.2$. Now by using an innovative method, the variant $T_{min}$ can be changed in *1* to *16* span along with $\lambda$, that means by decreasing $\lambda$, $T_{min}$ increases and vice versa.

The parameters used in this algorithm do not have general meaning and just specialized for this algorithm. $X_i$ is the time of MSS awaking in sleep cycles from the $I_{th}$ sleep-mode. $T_{Nmin}$ is the new $T_{min}$ and is the length of first sleep window in the first sleep cycle of sleep-mode. $T_{Omin}$ is the old $T_{min}$ showing the length of first sleep window in the first previous sleep cycle. $N$ is the window number of sleep cycle that MSS has been awaken in that window at the last time. $P$ is the increased coefficient of $T_{Omin}$, which permanently the changes and is energy of two.

The execution steps procedures of the innovative algorithm as follows [14].

**1-** $X_i$ and $T_{Nmin}$ are inputs.

**2-** Sleep cycle windows are made. Repeat this job till sum of sleep cycle windows are less or equal to $X_i$.

**3-** For each window made from sleep cycle "*I*" parameter is increased by 1.

**4-** "*I*" parameter is the number of last sleep-mode window, in which MSS has changed mode and is put in *N* and sent to next step

**5-** If N>1, it means that MSS changed mode in windows except the first sleep window, so the traffic decreases. So,

$$P=N \textbf{ division } 2-1 \quad (5)$$

$T_{Nmin}$ is obtained from below formula (so the $T_{min}$ must increase because traffic is light).

$$T_{Nmin}= 2^P * T_{Omin} \quad (6)$$

**6-** If $N=<1$ and $T_{Omin}>1$ (for $T_{min}>1$ it can be decreased), so

$$T_{Nmin}= T_{Omin} /2 \quad (7)$$

Otherwise the division function is not done because $T_{min}$ has the min value for starting window in sleep-mode.

The presented algorithm is depended on *N* and $T_{min}$, which shows the decrease and increase of network traffic. If *N* is low it shows the increase of network load and vice versa. When $X_i$ is high, the change has been applied in farther windows from $T_{min}$, so *N* will increase because of network load decreasing and MSS Sleeps more than before. It is better that first sleep cycle time be higher to have decrease in the number of listening time windows. By progress this process; $T_{min}$ must be increased step-by-step till $T_{min}$ approaches to *16*, which is the most optimum $T_{min}$. If $X_i$ decreases in comparison to $X_{i-1}$ and $X_{i-1}$ in comparison to $X_{i-2}$, and so… The network traffic increases and $T_{min}$ also decrease and always is an energy of two till $T_{min}=1$. $T_{min}$ increases in a jumping way, but decreasing is done relatively.

## IV. Studying Consumption of the MSS Energy in Sleep-Mode

At first, system energy is calculated in lieu of all *λ's* by the use of the presented formula, also at the same time, $T_{min}$ is change in order to compute the energy consumption value in lieu of variant $T_{max}$. In the previous formula, the $T_{max}$ has been fixed about *1024*, but $T_{max}$ has been applied in correspondence to domain change of sleeping cycle with different values. This job is done for distinguishing $T_{max}$ optimum function for ending point of sleep-mode. Table.1 shows different $T_{max}$ functions and has applied from *2* to *1024*. As it is know, the *λ* increases, the MSS remains more in wake-mode and less in sleep-mode. So, the energy consumption for sleep-mode is decreased. When $T_{max}$ increases, firstly consumption diagram has a downswing then upswing. It must be noted that the most optimum $T_{max}$ which has the least energy consumption value should be chosen for starting point in the sleep-mode

TABLE I THE ENERGY CONSUMPTION WITH DIFFERENT $T_{max}$

| λ \ Tmax | 2 | 4 | 8 | 16 | 32 | 64 | 128 | 256 | 512 | 1024 |
|---|---|---|---|---|---|---|---|---|---|---|
| **0.01** | 408.99 | 295.82 | 225.31 | 189.8 | ***178.12*** | 180.83 | 190.15 | 197.18 | 198.49 | 198 |
| **0.02** | 208.98 | 155.65 | 124.66 | 111.62 | ***110.03*** | 113.75 | 117.01 | 117.63 | 117.64 | 117 |
| **0.03** | 142.3 | 108.81 | 90.706 | ***84.49*** | 85.085 | 87.539 | 88.52 | 88.567 | 88.568 | 88.5 |
| **0.04** | 108.96 | 85.31 | 73.449 | ***70.25*** | 71.342 | 72.775 | 73.05 | 73.055 | 73.055 | 73 |
| **0.05** | 88.951 | 71.149 | 62.899 | ***61.239*** | 62.326 | 63.12 | 63.196 | 63.196 | 63.196 | 63.2 |
| **0.06** | 75.609 | 61.659 | 55.689 | ***54.897*** | 55.827 | 56.254 | 56.27 | 56.274 | 56.28 | 56.3 |
| **0.07** | 66.076 | 54.839 | 50.421 | ***50.114*** | 50.864 | 51.09 | 51.09 | 51.09 | 51.09 | 51.1 |
| **0.08** | 58.924 | 49.691 | 46.368 | ***46.348*** | 46.923 | 47.04 | 47.04 | 47.04 | 47.04 | 47 |
| **0.09** | 53.359 | 45.675 | ***43.132*** | 43.27 | 43.7 | 43.76 | 43.76 | 43.77 | 43.77 | 43.7 |
| **0.1** | 48.906 | 42.405 | ***40.474*** | 40.696 | 41.02 | 41.05 | 41.05 | 41.05 | 41.05 | 41.05 |
| **0.2** | 28.828 | 27.191 | ***27.11*** | 27.231 | 27.243 | 27.24 | 27.24 | 27.24 | 27.24 | 27.3 |
| **0.3** | 22.097 | ***21.606*** | 21.67 | 21.693 | 21.7 | 21.7 | 21.7 | 21.7 | 21.7 | 21.7 |
| **0.4** | 18.715 | ***18.583*** | 18.625 | 18.63 | 18.63 | 18.63 | 18.63 | 18.63 | 18.63 | 18.6 |
| **0.5** | 16.682 | ***16.666*** | 16.686 | 16.69 | 16.69 | 16.69 | 16.69 | 16.69 | 16.69 | 16.7 |
| **0.6** | ***15.33*** | 15.347 | 15.356 | 15.36 | 15.36 | 15.36 | 15.36 | 15.36 | 15.36 | 15.35 |
| **0.7** | ***14.372*** | 14.395 | 14.399 | 14.399 | 14.399 | 14.399 | 14.399 | 14.399 | 14.399 | 14.4 |
| **0.8** | ***13.664*** | 13.683 | 13.685 | 13.68 | 13.68 | 13.68 | 13.68 | 13.68 | 13.69 | 13.68 |
| **0.9** | ***13.126*** | 13.14 | 13.141 | 13.14 | 13.14 | 13.14 | 13.14 | 13.14 | 13.14 | 13.2 |

For $\lambda=0.01$, $T_{max}$ from *16* to *256* has low energy consumption whit comparison to $T_{max}=1024$. However, the lowest value for the energy consumption is when $T_{max}=32$. This procedure has been done for $\lambda=0.02$, *although*, $T_{max}$ between 16 and 64 is lower than $T_{max}=1024$. (Figure 3)

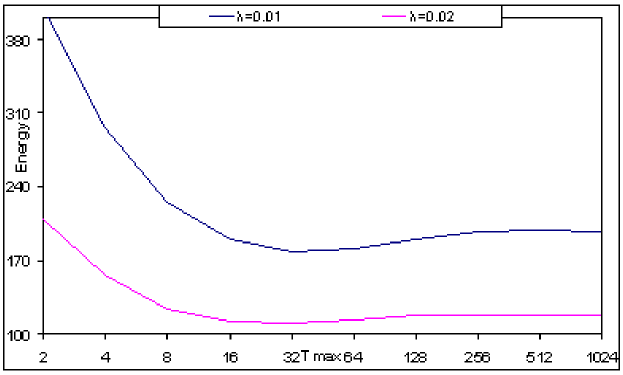


Fig. 3 The energy consumption for $\lambda<0.03$

In studying of $0.03=<\lambda<=0.08$, the energy consumption decreases suddenly and go up again slowly. So $T_{max}$=16 is very optimum for energy consumption (Figure 4).

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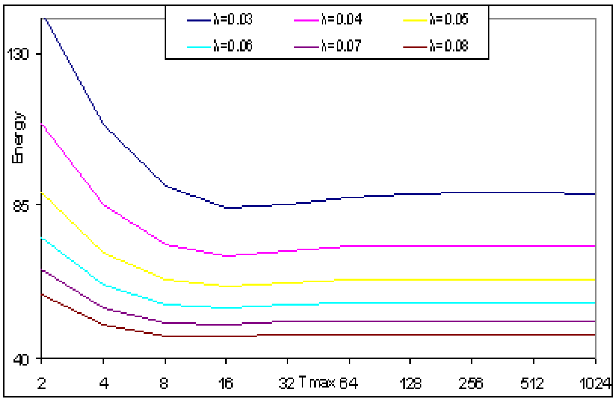


Fig. 4 The energy consumption for 0.03=<$\lambda$<=*0.08*

For $\lambda$ from *0.09* to *0.2*, this follows the previous similar pattern but the changes of energy consumption are very slightly. Therefore, the best $T_{max}$ is equal to 8 (Fig. 5).

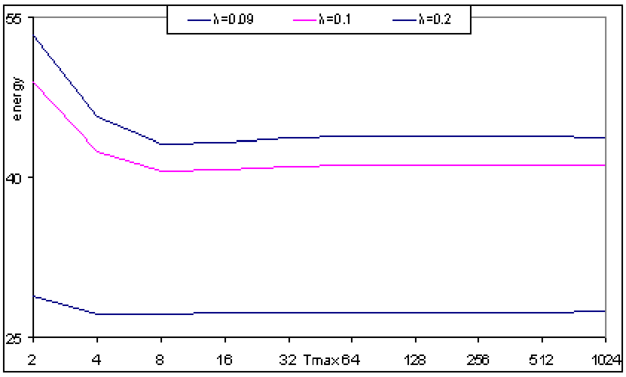


Fig. 5 The energy consumption for 0.09=<$\lambda$<=*0.2*

In this situation, 0.3=<$\lambda$<=*0.5*, the increasing of $\lambda$ causes the optimum $T_{max}$ ($T_{max}$=4) happens in the smallest windows (Figure 6). The Figure 7 illustrates the domain of $\lambda$ between 0.6 and *0.9* in high traffic load that the energy consumption is very lower if $T_{max}$ is equaled to 2.

*Note:* The results show that there is a optimum $T_{max}$ among *9* values in sleep cycle range (*2,4,8,16,32,64,128,256,512,1024*) by considering the working condition (decrease and increase in network traffic), we can use these values as sleep-mode $T_{max}$.

## V. FINAL TEST AND RESULTS

To test the performance of this method, the MSS was changed from sleep-mode to wake-mode about *10000* times and the wake times were chosen between *1* and *4000* randomly. Finally the domain was changed from *1* to *64* and all wake times (random selected times) for all domains repeated and their energy were compared with others. (Table.2)

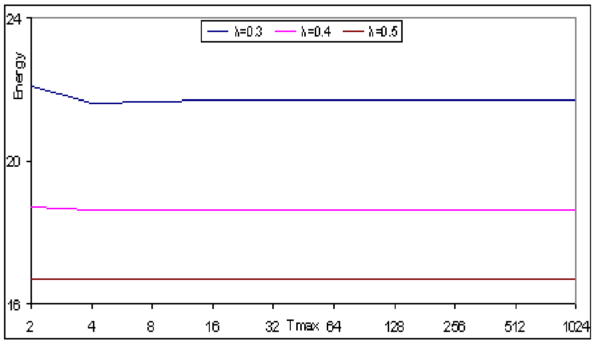


Fig. 6 The energy consumption for 0.3=<$\lambda$<=*0.5*

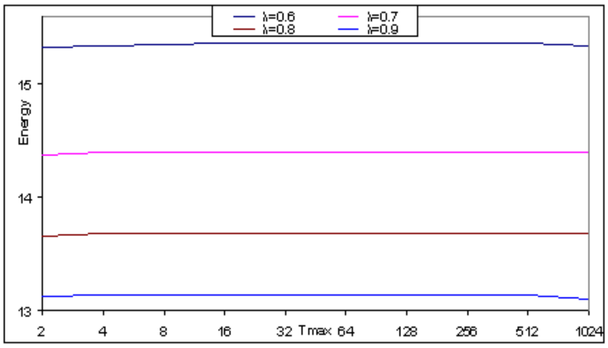


Fig. 7 The energy consumption for 0.6=<$\lambda$<=*0.9*

TABLE II THE ENERGY CONSUMPTION WITH RANDOM NUMBERS

| λ \ Tmax | 2 | 4 | 8 | 16 | 32 | 64 |
|---|---|---|---|---|---|---|
| **0.01** | 68.91 | 86.044 | 94.629 | 90.167 | ***85.707*** | 87.36 |
| **0.02** | 71.995 | 69.144 | 60.807 | 54.914 | ***54.248*** | 56.172 |
| **0.03** | 61.561 | 52.611 | 44.644 | ***41.659*** | 41.996 | 43.227 |
| **0.04** | 51.201 | 41.878 | 36.193 | ***34.653*** | 35.218 | 35.93 |
| **0.05** | 43.156 | 35.094 | 31.067 | ***30.281*** | 30.834 | 31.225 |
| **0.06** | 37.198 | 30.525 | 27.592 | ***27.216*** | 27.684 | 27.895 |
| **0.07** | 33.039 | 27.49 | 25.295 | ***25.158*** | 25.535 | 25.647 |
| **0.08** | 29.239 | 24.687 | 23.053 | ***23.052*** | 23.24 | 23.34 |
| **0.09** | 26.298 | 22.517 | ***21.282*** | 21.356 | 21.571 | 21.6 |
| **0.1** | 24.334 | 21.11 | ***20.156*** | 20.27 | 20.431 | 20.446 |
| **0.2** | 14.447 | 13.629 | ***13.592*** | 13.651 | 13.657 | 13.657 |
| **0.3** | 11.03 | ***10.785*** | 10.817 | 10.829 | 10.829 | 10.829 |
| **0.4** | 9.3835 | ***9.3174*** | 9.3387 | 9.3406 | 9.3406 | 9.3406 |
| **0.5** | 8.3571 | ***8.3493*** | 8.3593 | 8.3595 | 8.3595 | 8.3595 |
| **0.6** | ***7.6802*** | 7.6891 | 7.6934 | 7.6934 | 7.6934 | 7.6934 |
| **0.7** | ***7.144*** | 7.1555 | 7.1571 | 7.1571 | 7.1571 | 7.1571 |
| **0.8** | ***6.8447*** | 6.8555 | 6.8551 | 6.8551 | 6.8551 | 6.8551 |
| **0.9** | ***6.6074*** | 6.6148 | 6.6148 | 6.6148 | 6.6148 | 6.6148 |

Table 2, in the column *No.1*, the range of $T_{min}$ is changed just between 1 and 2. In column *No.2*, the range of $T_{min}$ can be changed from *1* to 4 and $T_{max}$ is fixed to 4. In column *No.3*, $T_{min}$ could be *1, 2*, 4 or 8 according to its algorithm. In column *No.*4, $T_{min}$ could be *1,2,4,8* or *16* in place of inputted $X_i$. In table 2, this procedure has been done for all $\lambda$*'s* and energy consumption for MSS sleep-mode has been calculated. According to table 2, the energy consumption for yellow boxes are lower in comparison to $T_{max}$ =*1024*.

Fig. 8 confirms energy consumption decrease by the use of this new method, so using variant $T_{max}$ is a basic solution for reducing consumption of energy in the network MSS of *802.16e.* This solution decreases consumption of the MSS energy about *4.5%* in this condition. This new method is very useful for a standard during research step. For the next step and more studies, we can reduce the energy consumption, as it is possible, and reach to a better and improved value by mixed optimum $T_{max}$ *and* $T_{min}$.

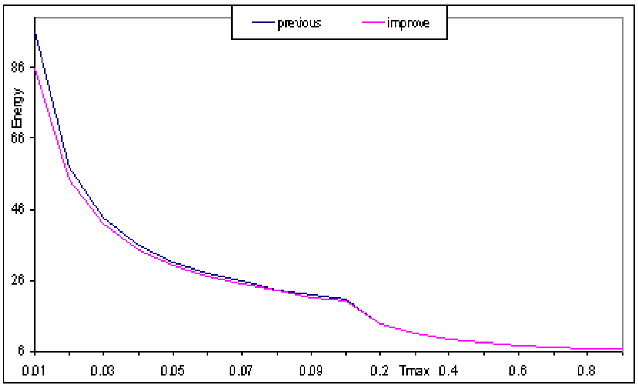


Fig. 8 The energy consumption of previous method in comparison to optimum $T_{max}$

## VI. Conclusion

The IEEE 802.16e Standard is one of famous applicable standards in the world, which fulfilled different user's demand. This is an investigative standard presented in the field of mobile networks called IEEE 802.16e. This research has proposed a new technique to reduce energy consumption in the 802.16e standard. The obtained results from studying total energy consumption are as below:

-The more increase in $T_{max}$, the much more decrease in consumption of energy after $T_{max}$ optimum wildly.

-If $T_{max}$ decreases, MSS can respond to the requests with higher speed.

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