Energy Efficient Communication for IEEE 802.16e/m Networks

Arun M Bhaskaran

Abstract—Energy efficiency is progressively important for wireless cellular systems due to the limited battery resources of mobile devices. As mobile devices are becoming smaller, users are desiring a longer battery life. To address this issue, an advanced Sleep Mode Mechanism (SMM) is introduced in IEEE 802.16e/m network. Which is an enhanced version of the legacy WiMax system’s sleep mode. The new sleep mode mechanism’s listening window may be extended and the sleep cycle length is adjustable. In this paper to increase the energy efficiency a Modified Sleep Mode Mechanism (MSMM) is proposed, which will adjust the sleep interval according to the packet arrival rate of the serving base station.

Keywords—Energy Efficiency, IEEE 802.16e/m, Modified Sleep Mode Mechanism, Sleep Mode Mechanism, WiMax.

I. INTRODUCTION

WiMAX based on IEEE 802.16e/m is a part of Fourth Generation (4G) communication technology. With the proliferation of wireless services, mobile devices are getting smaller and smarter. Therefore, 4G wireless standard IEEE 802.16e/m should provide very efficient energy conservation mechanisms to achieve longer battery life while providing enhanced user experience and quality of service (QoS). IEEE 802.1e/6m standard provides a Sleep Mode Mechanism for Mobile Stations (MS) to address the energy efficiency.

Recently, there have been lots of studies conducted on sleep mode mechanism. Sunggeun [1] conduct an analytical study on the power consumption and average packet delay for 802.16m MSs. Based on the analytical results, they proposed a sleep mode management scheme called Adaptive Sleep Mode Management (ASMM) to minimize the power consumption. Hwang [2] introduce an analytical model for the 802.16m sleep mode operation. However, their numerical analysis is based on an estimation obtained from an observation of simulation results, and hence, the numerical model may not be accurate. Nguyen [3] proposed a new energy saving mechanism without sleep request/response message (MOB-TRF-REQ/RSP).

The proposal mechanism does not reduce the tasks of MS in sleep mode but also it reduces overheads and waste time to get sleep approval. Jin [4] provided a model for the case that real time and non-real time packets are serviced simultaneously. The 802.16e/m sleep mode has been well-studied in the previous works [5–7]. Zhu [8] presented a heuristic algorithm to determine the initial sleep window dynamically according to given traffic loads. Kim [9] introduced an efficient power management mechanism which takes into account the remaining power.

In Sleep mode, the energy consumption of MS may be reduced by introducing a sleep cycle. However, it is not considering the traffic arrival rate. In this paper Modified Sleep Mode Mechanism is proposed (MSMM). Unlike in the legacy system, the length of the sleep interval is determined according to the traffic arrival rate of the serving Base Station (BS). Here the serving BS consider the inter arrival time into account to calculate the sleep interval so that the modified sleep mode mechanism consumes less energy compared with the original standard of sleep mode.

II. SLEEP MODE MECHANISM

Sleep mode is used to minimize MS power consumption and to decrease the use of serving BS radio resources. The Sleep Mode may also be used to support co-located multi-radio coexistence. A single power saving class for each mobile station is managed in order to operate the active connections associated with the MS. The Sleep Mode may be invoked when an MS is in the Connected State. When Sleep Mode is activated, the MS is provided with a series of alternate listening window and sleep intervals. The listening window is the time in which the MS is available to exchange control signaling, as well as data, in the uplink or downlink.

Sleep Mode entry is initiated either by the MS or the BS. When the MS is in Active Mode, sleep parameters are negotiated between the MS and BS. The serving BS determines when the MS can transition to Sleep Mode. MAC control signaling is used for sleep mode request and response. The start of the listening window is aligned with the frame boundaries. A sleep cycle is the sum of sleep and listening windows.
The MS or BS may request change of sleep cycle through MAC control signaling. The BS maintains synchronization with the MS at the sleep/listening windows’ boundary. The synchronization can be conducted implicitly with a predetermined procedure. There are 16 distinct sleep patterns or sleep cycle settings specified in IEEE 802.16e/m where each is denoted by a unique Sleep Cycle Identifier (SCID). If an MS requests changes to the sleep pattern to one of the previous patterns using AAI_SLP-REQ including the associated SCID, the BS will respond with an AAI_SLP-RSP containing the same or a different SCID. There is only a single sleep cycle setting that is applied across all MS active connections.

During the sleep window, the MS is unavailable to receive any DL data and MAC control signaling from the serving BS. For the duration of the listening window, the MS can receive DL data and MAC control signaling from the serving BS. The MS can also send data, if any uplink data is scheduled for transmission. After termination of a listening window, the MS may return to sleep for the remainder of the current sleep cycle.

The energy consumption of an 802.16e/m MS may be reduced via prolonging its sleep cycle or sleep interval. At the first sleep interval, a minimum sleep interval Tmin is used. After the first sleep interval, an MS switches into a listening interval to wait for a AAI-TRF-IND message. This message indicates addressed traffic that BS buffered for the MS during previous sleep interval.

The value of AAI-TRF-IND determines next MS’s reaction. The negative AAI-TRF-IND message means that there is no packet serving BS want to send. When an MSS receives a negative AAI-TRF-IND message, it goes to the next sleep interval whose duration is double from the preceding sleep interval. This process repeatedly continues until the sleep interval reaches to Tmax and then next sleep interval keeps unchanged. In j-th listening interval, if serving BS sends the MS a positive AAI-TRF-IND message, the MS leaves sleep mode and wakes up to process packets. We call the duration of first sleep interval T1=Tmin, then the duration of j-th sleep interval is

$$T_j = \min\{2^{j-1} T_{\text{min}}, T_{\text{max}}\}$$

Let n and D denote the number of sleep intervals and the duration of a successive sequence of sleep intervals in sleep mode, respectively. L denote the listening interval. ES, EL denote the energy consumption units per unit time in the sleep interval and the listening interval, respectively. R denotes the frame response time which is defined as the delay a frame destined to an MS has to wait before it is delivered.

Suppose that the arrival of frames destined to an MS follow a Poisson distribution with rate λ. It means, the interarrival time is distributed according to an exponential law with parameter 1/λ. Let ej denote the event that there is at least one packet arrival during the monitor period j. Note that in definition, listening intervals are also belong to the sleep mode.

$$Pr[e_j = \text{true}] = 1 - e^{-\lambda(T_j + L)}$$

The term Pr[n=j] represents the probability of success in the exact j-th iteration, which is also the probability of failure in iteration 1 to j -1 and success in the j-th. The number of sleep cycles is an independent random variable.

$$Pr(n = 1) = Pr(e_1 = \text{true}) = 1 - e^{-\lambda(T_j + L)}$$

For n≥2, Pr(n = j)

$$= Pr(e_1 = \text{false}; \ldots; e_{j-1} = \text{false} ; e_j = \text{true}) = \prod_{i=1}^{j-1} Pr(e_i = \text{true})Pr(e_j = \text{true})$$

$$= e^{-\lambda\sum_{i=1}^{j-1}(T_i+L)}(1 - e^{-\lambda(T_j + L)})$$

$$+ \sum_{j'=1}^{j-2} e^{-\lambda\sum_{i=1}^{j'-1}(T_i+L)}\sum_{j''=1}^{j'} e^{-\lambda\sum_{i=1}^{j''}(T_i+L)}$$

From the equations (3) and (5), we can calculate the mean or average value of number of sleep intervals. Here n ranges from 0 to ∞, so the expected value of n is given by

$$E[n] = \sum_{j=1}^{\infty} j Pr(n = j)$$

$$E[n] = \sum_{j=1}^{\infty} e^{-\lambda\sum_{i=1}^{j-1}(T_i+L)} - \sum_{j=1}^{\infty} e^{-\lambda\sum_{i=1}^{j}(T_i+L)}$$
Each sleep cycle has length of $T_j + L$. Therefore, the expected duration of a sequence of sleep mode cycles is calculated by:

$$ E[D] = \sum_{j=1}^{\infty} Pr(n = j) \cdot (j - \text{th cycle duration}) $$

$$ = \sum_{j=1}^{\infty} Pr(n = j) \sum_{k=1}^{j} (T_k + L) $$

$$ = \sum_{j=1}^{\infty} e^{-\lambda(T_j+L)} \sum_{k=1}^{j} (T_k + L) $$

$$ = \sum_{j=1}^{\infty} e^{-\lambda(T_j+L)} \sum_{k=1}^{j} (T_k + L) $$

$$ = \sum_{j=1}^{\infty} e^{-\lambda(T_j+L)} \sum_{k=1}^{j} (T_k + L) $$

The energy consumption for j-th cycle is $E_j = \sum_{k=1}^{j} (T_k E_3 + LE_2)$. Hence, the expected energy consumption of a sequence of sleep mode cycles is:

$$ E[\text{Energy}] = \sum_{j=1}^{\infty} Pr(n = j) E_j $$

$$ = \sum_{j=1}^{\infty} Pr(n = j) \sum_{k=1}^{j} (T_k E_3 + LE_2) $$

$$ = \sum_{j=1}^{\infty} e^{-\lambda(T_j+L)} \sum_{k=1}^{j} (T_k E_3 + LE_2) $$

$$ = \sum_{j=1}^{\infty} e^{-\lambda(T_j+L)} \sum_{k=1}^{j} (T_k E_3 + LE_2) $$

It’s assumed that the frame causing escape from the sequence of sleep mode cycles will arrive at any moment during the last cycle with uniform probability. The length of j-th cycle is $(T_j + L)$. The expected frame response time is defined as:

$$ E[R] = \sum_{j=1}^{\infty} Pr(n = j) \sum_{k=1}^{j} (T_j + L) / 2 $$

$$ = \frac{1}{2} \sum_{j=1}^{\infty} e^{-\lambda(T_j+L)} (T_j + L) $$

$$ = \frac{1}{2} \sum_{j=1}^{\infty} e^{-\lambda(T_j+L)} (T_j + L) $$

III. PROPOSED MODIFIED SLEEP MODE MECHANISM

In the standard sleep mode mechanism (SMM) sleep cycle is not adjusting according to the packet arrival rate. So we propose a new sleep mode mechanism named Modified Sleep Mode Mechanism (MSMM). The main characteristic of MSMM is to the length of sleep interval is calculated based on the serving traffic rate. The serving BS takes traffic inter arrival time into account to choose the value of sleep interval so that the MS consume minimum energy in sleep mode.

The parameters Tmin, Tmax are main factors affecting on the energy consumption and frame response time (delay).

In general, each pair of $(T_{\text{min}}, T_{\text{max}})$ gives different results of energy consumption. So, if the value of $T_{\text{min}}$ and $T_{\text{max}}$ are limited in a given range, it choose a pair $(T_{\text{min}}, T_{\text{max}})$ which causes energy consumption is minimal correspond to a certain $\lambda$. The algorithm to choose $(T_{\text{min}}-\lambda, T_{\text{max}}-\lambda)$ is below:
By using the Tmin and Tmax values it will calculate the energy consumption, expected number of sleep intervals, expected values of sleep duration and the response time. The new proposed modified sleep mode mechanism dynamically changing the sleep cycle according to the packet arrival rate.

(i) Energy Saving

The energy saved by the proposed Modified Sleep Mode Mechanism compared to the Sleep Mode Mechanism can be calculated by the following formula:

\[
\text{Energy Saving (100\%)} = \frac{\text{Energy}_{\text{PSM}} - \text{Energy}_{\text{MSMM}}}{\text{Energy}_{\text{PSM}}} \times 100\%
\]  

(13)

The effectiveness of the proposed Modified Sleep Mode Mechanism can be determined by how many percentage of energy is saved.

IV. RESULTS AND DISCUSSION

The sleep mode mechanism (SMM) and the proposed Modified Sleep Mode Mechanism are implemented using Matlab 2012b. The expected values of sleep intervals, duration, response time and energy consumption are simulated for the existing and the proposed methods and the results are compared. The parameters used in simulation are: Tmin=1, Tmax=1024, L=1, ES=1, EL=30.

Fig 3 shows the expected value of number of sleep intervals versus packet arrival rate of the sleep mode mechanism and Modified Sleep Mode Mechanism.

The number of sleep intervals is decreases while the packet arrival rate increases. It is because when packet arrival rate increase the sleep interval will reconfigure to a minimum value, so the number of sleep interval will decrease. Here the simulation results indicates that the proposed method having less number of sleep intervals compared with the existing sleep mode mechanism.

Fig 4 shows the comparison expected value of sleep duration versus packet arrival rate of the SMM and MSMM. The sleep interval is reconfigured according to the packet arrival rate. If the packet arrival rate increases, the sleep interval reduces. So when the packet arrival rate is high, the duration of sleep interval will be less. Here, the sleep duration of proposed method is higher than the existing method.
Fig 5 shows the comparison of energy consumption versus packet arrival rate of the SMM and MSMM. It shows that when packet arrival rate increases the energy consumption decreases. Here it shows that the proposed mechanism having less energy consumption compared to the existing Sleep Mode Mechanism. In the proposed MSMM technique the sleep cycle dynamically changes according to the packet arrival rate. Here, for each $\lambda$ we are finding out the minimum and maximum value of sleep interval which will give the lesser energy consumption. So the energy consumption of the proposed method will give better energy conservation.

If the packet arrival rate increases the sleep duration decreases, then the response time also decreases. It infers that if the packet arrival rate is high the response time will be less in the Sleep Mode Mechanism. Here the proposed MSMM having increased frame response time than the existing Sleep Mode Mechanism.

Figure 7 shows the energy saving obtained by the proposed Modified Sleep Mode Mechanism. It shows that the MSMM saved more than 31% of energy compared with the standard Sleep Mode Mechanism.

V. CONCLUSION

The Modified Sleep Mode Mechanism for IEEE 802.16e/m dynamically changes the sleep interval based on traffic rate of serving Base Station. The simulation results indicate that the proposed mechanism gains more than 31% of energy saving compared with the current standard of sleep mode management scheme.

REFERENCES