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QPS: QUEUING MODEL BASED POWER SAVING SCHEME FOR IEEE 802.16e NETWORKS

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Abstract: **Energy-saving is vital in a mobile network as mobile terminals are energy contingent and is one of the most important features that extends the lifetime of portable devices. Mobile WiMAX (IEEE 802.16e) addresses the issues related to energy conservation at a Mobile Subscriber Station (MSS). In this paper, a power saving mechanism involving sleep mode operation is proposed for IEEE 802.16e networks. A Queuing model based Power Saving Scheme (QPS) that dynamically alternates the sleep interval for different traffic classes is presented. The window size of the sleep interval is calculated dynamically based on the packet arrival time and the type of traffic. A proper sequence of power saving classes is obtained and a trade-off is achieved between power consumption and packet delay. Average delay is greatly reduced and power is saved to a great extent.**

Index Terms: **IEEE 802.16e, Queuing model, packet delay, power saving, sleep interval.**

1. Introduction

The IEEE 802.16 broadband wireless access system also referred to as World-wide interoperability for Microwave access (WiMAX) is a promising standard for next-generation Broadband Wireless Access (BWA) networks.

It provides last-mile wireless access and supports high-speed multimedia services with a data rate comparable to that of traditional wired access. This standard is a promising technology that can provide a cost-effective broadband access solution for connecting local area networks to the internet and for supporting mobile applications like fourth generation mobile systems.

Originally, IEEE 802.16 was designed for fixed Subscriber Stations (SSs). The recently-developed IEEE 802.16e is an extension targeting at the service provisioning to the Mobile Subscriber Stations (MSSs). The IEEE 802.16e mobile WiMAX technology aims to provide an energy efficient communication platform for various mobile applications.

In mobile computing, the energy consumption of an MSS is an important index for measuring device performance because of the limited battery life of MSS. Therefore communicating devices should be designed with the consideration of power conservation in mind. In general, the best way to reduce the energy consumption of MSSs is to switch them OFF, but obviously, this method is impractical because it prevents communication.

An 802.16e MSS that registers with a specific BS can be in one of two operational modes, namely, awake mode and sleep mode. In the awake mode, an MSS can send or receive data according to the Base Station (BS)'s scheduling. But in the sleep mode it may stop sending or receiving data from the BS for a pre-determined time interval.

Most wireless networks adopt a Power-Saving Mode (PSM).The basic principle of a power saving mechanism is to implement sleep mode operation to minimize MSS power consumption. For efficient utilization of power, the sleep mode feature in IEEE 802.16e is designed with different power saving classes. The sleep mode in 802.16e MSS is standardized taking into account various situations like, moving into sleep, listening or wake-up modes as shown in Fig 1.

The sleep mode involves two operational windows (i.e., time intervals), namely, sleep window and listening window, and an MSS in the sleep mode basically switches between these two windows. During a sleep window, an MSS turns off most of its circuits to minimize the energy consumption, and hence cannot receive/transmit any message. If any packet(s) destined to the MSS in the sleep mode arrive at the BS during the sleep window of an MSS, these packets are placed in a buffer and they can be delivered to the MSS when it is awake in the future.

During a listening window, a MSS synchronizes with its serving BS' downlink (i.e., BS-to-MSS) and listens to a traffic indication message which indicates whether there is any buffered packet(s) for that MSS. On the basis of this message, it decides whether to stay awake to receive the pending packet(s) or go back to sleep [6].

An MSS in sleep mode wakes up at predefined wake-up intervals to verify whether there are any buffered packets waiting for it. If there are packets waiting, the MSS receives them. A MSS thus conserves much of its energy as the energy consumed by a MSS in sleep mode is much lower than in wake-up mode [1].

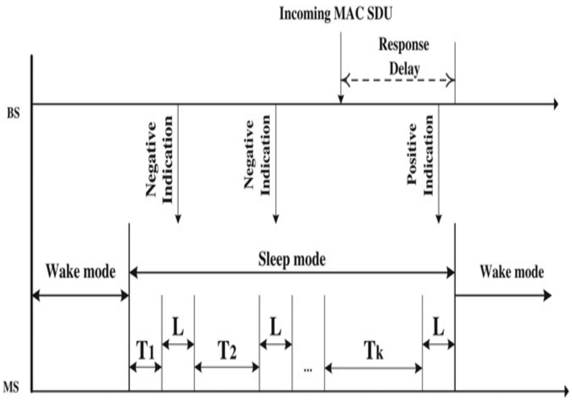

Fig. 1 Example of sleep mode operation in IEEE 802.16e

IEEE 802.16e adopts a Binary Truncated Exponent (BTE) algorithm to determine sleep intervals. The first sleep interval is of minimum duration, and thereafter, each sleep interval is doubled until a maximum is reached. If there are packets to be transmitted to it, the MSS moves from sleep mode to always-active mode. Otherwise, it sleeps for another interval [2].

The power consumption and packet delay are the two key factors in the power saving mechanism. The main challenge in the design of an efficient power saving scheme is to balance the conflicting requirement of these two factors. Therefore, a trade-off between them should be achieved to reduce the power consumption, while maintaining the packet delay at an acceptable level.

In IEEE 802.16e, three power saving classes are defined: The type I power saving class is recommended for connections of Best-Effort (BE) and non-real time variable rate (NRT-VR) traffic; type II power saving class is recommended for connections of Unsolicited Grant Service (UGS) and real-time variable rate traffic (RT-VR); and type III is recommended for managing the operations and multicast connections [3] - [6].

Here a new power saving algorithm that is suitable for IEEE 802.16 BWA systems is explained. This scheme calculates a suitable sleep window size for the MSS. The sleep interval for alternate scheduling is calculated according to the packet arrival time, the time interval between the two packets and the packet types (real-time data service and non-real-time data service) such as video-phone and e-mail traffic.

This algorithm uses dynamic and historical information to adjust previously made decisions and system parameter values. This scheme has the ability to provide efficient control over network condition fluctuations. This is important for estimating the amount of energy consumed and the packet delay involved.

2. Related Work

Several power saving schemes have been proposed to reduce the power consumption in the IEEE 802.16e environment.

In [2], a probabilistic sleep interval decision algorithm is proposed to deal with the power saving problem. The PSID algorithm is used to determine the length of each sleep interval, T_j, by considering the fixed and variable delays. The time at which the probability of a response packet arriving at the BS is high is predicted and the MSS is waked up at that moment. Here the sleep window placement is determined by using the distribution function of the response packet's arrival time so that the response packet may have the same probability of arrival at the BS during each sleep window.

In [3], the sleep-mode operation of IEEE 802.16e and parameters related to this operation such as initial sleep window size, final sleep window size, listening window size and power saving threshold size are presented. The authors have adaptively applied different values to these parameters according to the traffic types like Constant Bit Rate (CBR) and the File Transfer Protocol (FTP) with different QoS.

A power efficient sleep mode operation for IEEE 802.16e is proposed in [4]. The authors have presented a heuristic algorithm to tune the initial sleep window dynamically according to the traffic load to get a proper trade off between power consumption and delay.

In [5], the authors have proposed an adaptive sleep-mode interval control algorithm for IEEE 802.16e taking into account the Downlink (DL) traffic pattern. Here the minimum allowed sleep interval based on DL traffic pattern is used to predict the succeeding time of arrival of DL frame.

In [6], the authors analyzed and evaluated the sleep mode operation of type I power saving class of IEEE 802.16e for downlink traffic by using a semi-Markov chain.

The remaining energy-aware power management mechanism to adjust the initial and final sleep windows according to the remaining energy state is proposed in [8].

In [9], a power saving mechanism with periodic traffic indications in the IEEE 802.16e/m is proposed. In the power-saving mechanism with periodic traffic indications, the BS periodically sends Traffic Indication (TRF-IND) messages at every constant interval called the TRF-IND interval and discards sleep request and sleep response (MOB-SLP-REQ/RSP) messages.

However, all these schemes only consider the type I power saving class

With respect to the type II power saving class, in [7], the authors proposed an energy conservation scheme, Maximum Unavailability Interval (MUI) by using Chinese Remainder algorithm. The computational complexity is reduced by a Table based algorithm.

In [11] authors proposed a Universal Power Saving Mechanism, namely UPSM, which adopts a constant sleeping window to reduce the negotiation overhead and alleviate the possible degradations of sleep ratio, energy saving and mean packet delay caused from irregular packet inter-arrival gaps.

These previously developed schemes do not take into account the power saving model for service connection of the types I and type II power saving classes at the same time.

This work proposes a queuing model based power saving model for both types of service classes, I and II. A proper sequence of power saving classes is also provided that reduces the number of listening windows and improves the power saving achieved, while a suitable packet delay is maintained.

3. System Model

The system model is developed for the power saving classes of types I (Non-real time traffic) and type II (Real time traffic) in IEEE 802.16e. Fig. 2 illustrates an example of sleep-mode for the type I power saving class.

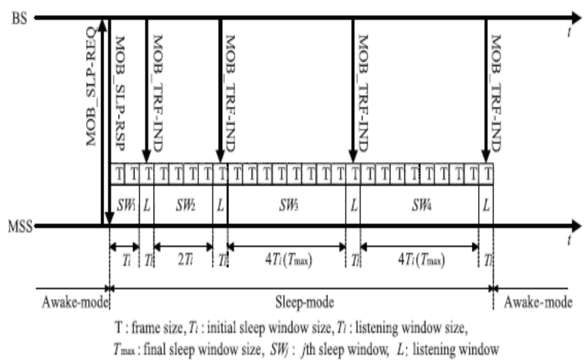

Fig. 2 Example of sleep-mode for the type I power saving class.

An MSS communicates with a BS by using the Sleep-Request message (MOB_SLP-REQ), Sleep-Response message (MOB_SLP-RSP), or Traffic-Indication message (MOB_TRF-IND). To enter into the sleep mode, the MSS first sends a MOB_SLP-REQ message to the BS and waits for the approving MOB_SLP-RSP message from the BS. When the MSS gets the MOB_SLP-RSP message it goes into sleep-mode for an interval defined by the initial sleep window.

After the first sleep interval, the MSS transits into listening state and listens to the traffic indication message MOB-TRF-IND broadcasting from BS. The message indicates whether there was any traffic addressed to the MSS during its first sleep interval T1. If MOB-TRF-IND is a negative indication, then the MSS continues to be in sleep mode after the listening interval. The next sleep window size is twice the previous sleep window. When the sleep window size reaches the maximum size, it does not increase further. If the message MOB-TRFIND indicates a positive indication, the MSS will return to awake mode. The sleep interval and its subsequent listening interval is termed as a cycle [10].

Let SW_j denote the j^{th} sleep window size. It is calculated as follows:

$$SW_j = \begin{cases} T_i & \text{if } j = 1 \\ \min\{2^{j-1}T_i, T_{max}\} & \text{if } j \geq 2 \end{cases} \qquad (1)$$

where T_i is the initial sleep window size and T_{max} is the final sleep window size. This expression is defined to determine the sleep window for the power saving class of type I.

The operation of type II power saving class is similar to that of the type I power saving class. The type I and II power saving classes differ in the size of the sleep window in sleep-mode. Unlike the power saving class of type I, the power saving class of type II uses a constant sleep window size instead of doubling the size of the sleep window.

When the MSS enters sleep-mode, the BS buffers all the packet frames addressed to the MSS until the listening window appears. However, the power saving class of type II results in more listening windows and high power consumption than the type I power saving class (Fig. 3).

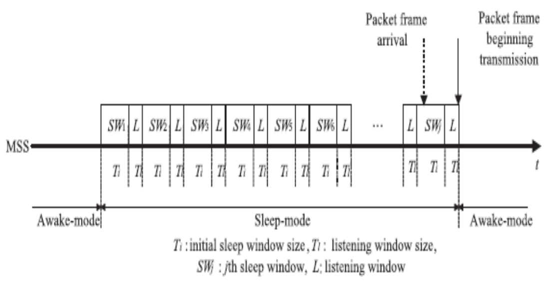

Fig. 3 Operation of power saving class of type II in IEEE 802.16e

The dynamically changing network traffic environment gives the motivation to choose the power saving class at random as the service connection may involve real-time or non-real-time traffic. Hence, in this paper, an MSS with any type of traffic connection is considered and the performance of the Queuing model based Power Saving (QPS) scheme is examined.

4. BTE Algorithm

The Binary Truncated Algorithm is a standard algorithm used to calculate the sleep interval size in IEEE 802.16e. Using this algorithm the length of sleep intervals in IEEE802.16e is determined by the following equation.

$$T_1 = T_{min}$$
$$T_j = \max\{T_{max}, 2^j T_{min}\} \text{ for } j \geq 2 \quad (2)$$

where T_{max} and T_{min} denote the maximum and minimum (initial) length of sleep interval, respectively. The value of T_j increases as j increases, but is truncated to T_{max} when T_j is larger than T_{max} to avoid an excessively large ON–OFF delay [2].

5. Dynamic Power Saving Scheme

The Dynamic power saving scheme in [12] classifies the data traffic into type I (non-real-time data service) and type II (real-time data service) and designs a Dynamically Alternating Sleep Interval Scheduling Algorithm (DASISA) for such wireless network systems. This algorithm schedules a proper sequence of power saving classes. Two power saving classes are alternatively included in the power saving sequence. The listening windows should be placed close to the packet arrival frames. In other words, the listening windows should follow the packet frames [12]. DASISA is discussed in this section.

C_{L_i}, the initial sleep windows cycle length is calculated as follows:

$$C_{L_i} = T_i R_n^{\log_2\left(\frac{T_{max}}{T_i}\right)} \quad (3)$$

where R_n is the rank number ($R_n \geq 1$) in the n^{th} awake state. The value of R_n is changed according to the traffic load in the system.

The initial sleep window cycle length is divided into several sections according to R_n. Let S_{L_k} denote the k^{th} section length, for k = 1, 2,...,R_n, and is expressed as,

$$S_{L_k} = \left\lceil \frac{C_{L_i}}{R_n} \right\rceil \quad (4)$$

Each section includes two subsections. A power saving class of types I or II operates in each subsection. The main goal is to alternate the types I and II power saving classes in each section.

t_d is the time delay and t_u the duration of transmission of the packet frame i. As the MSS cannot receive any packet frames in sleep-mode, the BS buffers the entire packet frames addressed to the MSS until it moves to the listening window. This results in a time delay before the packet frame is received in the MSS.

Let τ_c denote the time interval between the completion of the transmission time of packet frame i and the arrival time of packet frame j for class c data traffic, which is calculated as,

$$\tau_c = t_{p_j,c} - \left(t_{p_i,c} + t_d + t_u\right) \quad (5)$$

where $t_{p_j,c}$ is the arrival time of packet frame j of class c data traffic and $t_{p_i,c}$ is the arrival time of packet frame i of class C data traffic.

The arrival time of packet frames can be included in the MOB_TRF-IND message from the serving BS to the MSS and the MSS can calculate τ_c in the awake-mode. By calculating the length of τ_c and the number of τ_c, the duration between the arrival of packets can be found and the sleep window can be adjusted dynamically. The time interval τ_c is an important parameter for calculating the sleep window size.

Let $N_{\tau C}$ be the number of τ_cs for class C data traffic. For each traffic class, a sequence queue is established according to $N_{\tau C}$in descending order. In the sequence queue, the parameters $N_{\tau C}$and τ_c for each item are included, which is expressed by (τ_c, $N_{\tau C}$).

(τ_{c_1}, $N_{\tau_{c_1}}$) denotes the class I data traffic information of each item for different τ_{c_1} and $N_{\tau_{c_1}}$. In addition, (τ_{c_2}, $N_{\tau_{c_2}}$) denotes the class II data traffic information of each item for different τ_{c_2} and $N_{\tau_{c_2}}$.

Let $P_{I,k}$ be the subsection length for the power saving class of type I and let $P_{II,k}$ be the subsection length for the power saving class of type II in the k^{th} section, which is calculated as,

$$P_{I,k} = S_{L_k} \frac{F_I}{F_I + F_{II}} \quad (6)$$

$$P_{II,k} = S_{L_k} \frac{F_{II}}{F_I + F_{II}} \quad (7)$$

where $F_I = \tau_{c_1} N_{\tau_{c_1}}$ and $F_{II} = \tau_{c_2} N_{\tau_{c_2}}$.

The k^{th} item is selected to calculate $P_{I,k}$ and $P_{II,k}$ from the first to the last item in the sequence queue for each traffic class. Repeat this for all k = 1, 2,..,R_n.

The power saving class of type I will operate in the predecessor subsection and the power saving class of type II will operate in the successor subsection if F_I is larger than F_{II}. Otherwise, the power saving class of type II will operate in the predecessor subsection and the power saving class of type I will operate in the successor subsection.

If data frames arrive at the BS for the MSS during the sleep window cycle, the MSS switches to the awake-mode. Otherwise, the MSS remains in sleep-mode. When a cycle of sleep windows finishes, a new sleep window cycle length is created.

Let C_{L_j} denote the length of the j[th] sleep window cycle, which can be expressed as follows:

$$C_{L_j} = \begin{cases} C_{L_i}, & \text{if } j = 1 \\ \min\{2^{j-1} C_{L_i}, T_{max} R_n\}, & \text{if } j \geq 2 \end{cases} \quad (8)$$

The new sleep window cycle length is double the previous sleep window cycle length. The new sleep window cycle length is also divided into several sections according to R_n. The section length and subsection length are readjusted according to the new sleep window cycle length according to the information in the sequence queue.

When the sleep window cycle length reaches $T_{max} R_n$, the cycle length of the sleep window is no longer increased so as to reduce the packet delay.

To reduce the packet delay further, the concept of a queuing model can be applied. The MSS can be made to switch to listening mode by predicting the time at which a packet may arrive based on the Sleeping Barber model.

6. Queuing model based Power Saving Scheme (QPS)

In the sleeping barber model, the barber sleeps when there are no customers in the shop and if a new customer comes he should wake up the barber. Likewise, if the MSS is in sleep mode and if any packet frame arrives at the serving BS for that particular MSS, it should wake up the MSS.

The time at which there is a high probability for the packet to arrive at the MSS can be predicted based on packet arrival rate and service rate.

Here in IEEE 802.16e simulated model the barber is analogous to MSS and the customers are similar to packets. The MSS, after servicing the current data packet frames, it checks whether there are any frames waiting for it at the BS. If there are any, it receives the frames and services them. If there are no frames waiting for it at the BS, it switches to sleep mode for a predefined time interval. In the normal case, it wakes up and listens to the BS after every sleep window.

If a new packet frame comes during the sleep interval it has to wait until the MSS switches to the listening window. This will cause packet delay.

If the most probable time for the packet to arrive can be predicted, the delay can be reduced significantly. This can be done by setting the listening window at that time. In the proposed system, the prediction is done by calculating sleep window size dynamically based on packet arrival rate and service rate, as mentioned afore.

7. Implementation

The Queuing model based Power Saving Scheme (QPS) was implemented for IEEE 802.16e using ns-2.31 and the performance of the scheme was evaluated in terms of delay and energy consumption. Table 1 lists the simulation parameters.

Table 1: Simulation Parameters

Parameter	Value
MAC	Mac/802_16
Beacon interval	0.5
Queue Length	512
Queue Type	Queue/DropTail/ PriQueue
Routing	GPSR
No. of Nodes	15
Simulation time	40.0
Initial Energy	100.0
Transmission Power	0.6
Receiving Power	0.2

Fig. 4 shows the energy consumption of MSSs at different arrival times for both QPS and DASISA.

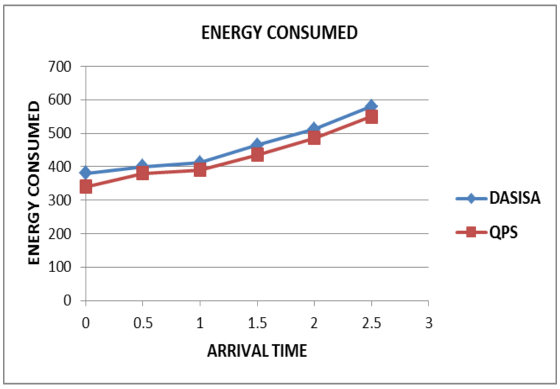

Fig.4 Energy consumption

Fig. 5 shows the average packet delay of MSSs for different arrival times for both QPS and DASISA.

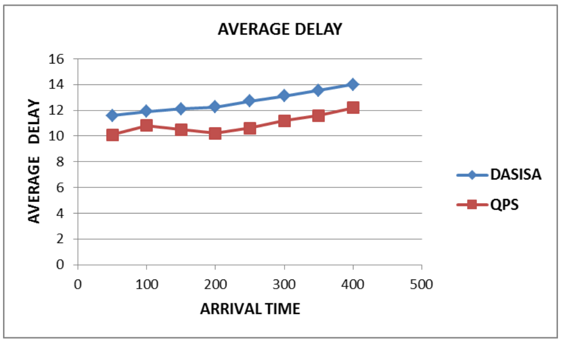

Fig.5 Average delay

8. Conclusion

Power saving is the major concern in a wireless network. To extend the lifetime of the MSSs in IEEE 802.16e, a novel and efficient power saving scheme is developed. The sleep window size is dynamically adjusted based on the traffic information. This method sets the listening window close to the arrival of packet frames. Simulation results show that QPS reduces the power consumed significantly. It also maintains a suitable packet delay.

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