Modeling and Simulation of Power Saving Mechanism for IEEE 802.16e Mobile WiMAX

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Abstract
In order to reduce the power consumption of a mobile station, IEEE802.16e introduced the sleep mode to extend the standby time of battery-powered mobile stations. However, existing mainstream simulation platforms do not yet support the sleep mode. Since simulation tools play increasingly important role in the design, research of network protocols, products and applications, it is of high importance to also have sleep mode support in the popular simulation platforms. This paper describes the design and implementation of a simulation module for sleep mode of IEEE 802.16e mobile WiMAX based on OPNET WIMAX module. Simulations on downlink web business of sleep mode under wireless communications scenario are performed. Simulation results show that the sleep mode can greatly reduce energy consumption of a mobile station while maintaining its quality of service.

Keywords: IEEE 802.16e, Power Saving, Sleep Mode, OPNET Modeler

1. Introduction
With the rapid development of computer networking technology as well as the widespread application of portable devices and mobile communications equipment such as mobile phone, PDA, notebook, etc, wireless users wish that these wireless devices be used as conveniently as possible in daily life and business environment [1]. Wireless Metropolitan Area Network (MAN) based on IEEE 802.16 standard family has provided a new solution for the broadband access. The IEEE 802.16e standard is designed to provide a solution that delivers high-speed mobile data services with broadband wireless access. IEEE 802.16e, mobile WiMAX, is based on orthogonal frequency division multiple access (OFDMA) technology and can support fixed and mobile users simultaneously. As one of the 3G standards, IEEE 802.16e standard is growing faster than even before and become the most famous and competitive technology in the telecommunications industry due to its large coverage area, low cost of deployment and high speed data transfer rate [2-4].

In mobile networks, how to control the energy consumption to prolong the standby time is one of the most important issues for battery-powered mobile stations. Since a mobile station (MS) does not always have packet transmission with its base station (BS), thus both ends could negotiate in advance so that the MS can temporarily power down one or more physical operation components in order to reduce power consumption at the designated interval, namely unavailability interval, when there is no need to send or receive packets. As such, a sleep mode mechanism has been introduced by IEEE 802.16e standard to reduce the power consumption of an MS and the air interface utilization of serving base station to prolong the battery lifetime of the mobile terminal.

Since simulation tools play increasingly important role in the design, research of network protocols, products and applications, it is of high importance to also have sleep mode support in the popular simulation platforms. As the IEEE 802.16e standard was published lately, there is less support for power saving mechanism in current mainstream simulation platforms. Most of researches on power management in mobile WiMAX are still mainly concentrating on performance analysis and algorithm optimization by theoretical analysis [5-10]. Therefore a unified yet standardized simulation model for energy saving mechanism of mobile WiMAX based on mainstream simulation platform (such as OPNET) is necessary to test the validity of the proposed power saving mechanism and to help improving them.

This paper models and implements the power saving mechanism in a simulation module by
extending WiMAX process model of OPNET. The rest of this paper is organized as follows. Section 2 gives a brief description of the power saving mechanism in IEEE 802.16e standard. Section 3 provides the analysis and design of proposed simulation module. Section 4 presents the simulation setup and results analysis for the Power Saving Class of Type I with web browsing business by proposed simulation module. Finally, section 5 concludes the paper.

2. Power saving mechanism of IEEE 802.16e standard

In order to reduce the power consumption to extend the lifetime of battery-powered Mobile Stations, IEEE 802.16e has introduced the sleep mode and the idle mode to decrease the usage of air interface resources of serving Base Stations. In the sleep mode, an MS enters into a sleep cycle after negotiating with serving BS and stops its traffic service temporarily. The idle mode allows even more power saving. Once enters into the idle mode, a subscriber mobile station periodically receives downlink broadcast messages (such as paging message and MBS business) in discrete interval. In addition, no handoff or re-registration is needed while a mobile station travels across multiple base stations. Thus the idle mode is simpler than the sleep mode. Currently research work on idle mode is pretty limited. The mobile WiMAX working group has listed these two modes as power saving mechanism that must be implemented by electronic terminals. Paper [6] presented the design of these two power saving modes respectively in electronic products. Paper [7] found out that the idle mode has better support for mobility than the sleep mode. Paper [8] applied both the sleep mode and the idle mode in Push to Talk (PTT) service. Considerable energy reduction was achieved.

Sleep mode is a state in which an MS conducts pre-negotiated periods of absence from the serving BS air interface. These periods are characterized by the unavailability of the MS, as observed from the Serving BS, to DL or UL traffic. Sleep mode is intended to minimize MS power usage and decrease usage of Serving BS air interface resources. Implementation of sleep mode is optional for the MS and mandatory for the BS. A key feature of IEEE 802.16e is that it is connection-oriented at the MAC layer. Connections established between an MS and a BS can have different quality of service (QoS) parameters in terms of service categories. A BS performs sleep state management for all MSs registered to it, buffers all data destined to the registered MSs during the sleep interval, and notifies MSs by sending indication message to switch to wakeup mode for normal operation. At the sleep mode, a mobile station continues to retain the management connection and perform periodic ranging. For each involved MS, the BS keeps one or several contexts, each one related to certain Power Saving Class. Power Saving Class is a group of connections that have common demand properties. There are three types of power saving classes named Power Saving Class (PSC) of Type I, II and III, which differ by their parameter sets, procedures of activation/deactivation, and policies of MS availability for data transmission. These three PSCs entail different power saving strategies to suit for different businesses. Briefly, the PSC of type I is recommended for connections of Best-Effort Service (BE) and Non-Real-Time Polling Service (nrtPS). The PSC of type II is used for connections of the Unsolicited Grant Service (UGS), real-time Polling Service (rtPS) and extended real-time Polling Service (ertPS). While the PSC of type III is designed for multicast connections as well as for management operations, for example, Periodic Ranging, DSx operations, MOB_BFM-ADV etc.

Before entering into sleep mode, an MS sends request to its BS requesting to enter into sleep mode. It enters into sleep mode once the message to grant the request has been received. A sleep mode is comprised of one or more sleep cycles. Each sleep cycle consists of a sleep interval (T) and a listening interval (L). During a sleep interval, an MS closes communication in order to reduce power consumption, while in the listening interval, an MS checks whether there is packet transmission to determine whether to keep sleep or to wake up.

The operating mechanism of sleep mode is illustrated in figure 1. After the first sleep interval (T₁), the mobile station enters into listening interval (L₁) monitoring broadcast messages from the base station to determine whether there have been messages destined to the mobile station in the last sleep interval. If there have been messages, the mobile station returns to wake mode after this listening interval. Otherwise, it enters into the next sleep cycle until the MS receives the indication messages at listening interval (Lₙ) that show there have been packet transmissions from the BS at the Nᵗʰ sleep cycle. During the whole sleep process, it alternates periodically between sleep mode and wake mode.
3. Design for Sleep Mode Simulation

3.1 Analysis of Sleep Mode Simulation

Widely recognized by the industry as the most popular network simulation design and application platform, OPNET modeler is used to design and study communication networks, devices, protocols and applications. It provides a graphical editor interface to build models for various network entities from physical layer modulator to application processes. OPNET boasts with advanced modeling mechanism, comprehensive model library and excellent external interface. It fully manifests network characteristics by effectively integrating each stage of network simulation including model design, simulation, data collection and analysis, using discrete event driven simulation mechanism, applying packet based communication mechanism and adopting three layer modeling mechanism and real protocols that match with real-world network [11-13].

![Figure 1. The operation mechanism of sleep mode in IEEE 802.16e](image)

![Figure 2. BS-MS communication with sleep mode](image)
The OPNET WiMAX specialized model is available for OPNET Modeler® Wireless Suite and OPNET Modeler® Wireless Suite for Defense. It supports the IEEE 802.16-2004 and IEEE 802.16e-2005 standards. OPNET modeler 14.5 has implemented almost entire features of the IEEE 802.16e standard except for power management, network-assisted handover and base station-initiated periodic ranging. Based on the operation mechanism of sleep mode, we design a sleep controller at the existing OPNET WiMAX simulation module that is responsible for management and maintenance of sleep mechanism. The communication process in sleep mode between a BS and an MS is shown in figure 2. When the MS has no traffic to receive or transmit during a specified period, it sends MOB-SLP-REQ message via the sleep controller to the BS requesting to switch to sleep mode. It then starts to enter into the sleep mode after receiving MOB-SLP-RSP message returned by the BS. MS state list maintained in BS is designed to record each MS’s current sleep state. After the MS enters into sleep mode, the BS sets MOB-TRF-IND to negative indication and modifies state list at the same time. If a packet destined to the MS arrives at the BS during this period, the packet will be buffered and the MOB-TRF-IND is set to positive indication. When the MS enters into listening interval and finds that the MOB-TRF-IND message indication is positive, the BS will modify the MS state to wake-mode and send packets normally.

3.2 Design for Sleep Mode Simulation

In IEEE 802.16e sleep mode is mainly implemented at the MAC layer which corresponds to the process model in OPNET simulation modeling implementation. The process model of sleep mode is represented by finite state machine, which is the most important part of simulation implementation. We add the sleep_ctrl forced state to control sleep process in the existing MAC process model of WiMAX node provided by OPNET. The process model is shown in figure 3.

At the beginning of simulation, each node first enters into initialization stage (including init_1, init_2, init_3, wait_for_ip_1 and wait_for_ip_2) to obtain running parameters. After initialization, a node enters into idle state that is surrounded by forced states (as shown in green states). Forced states deal with the event handling when interrupt occurs. It enters into the hl_pk state when there is packet coming from the higher layer, into the ll_pk state when there is packet coming from lower layer or into the control_pk state when there is control packet arrived. If the sleep mode trigger condition is satisfied at idle state, self-interrupt with interruption code SLEEP_CODE is generated, which brings the node into the sleep_ctrl state to set the sleep mode parameters and enter into sleep mode. Then sleep cycle timer is started according to sleep algorithm. After the sleep cycle is finished, it returns to idle state. The sleep cycle timer produces self-interrupt at the end of sleep cycle in order to decide whether to enter the next sleep cycle or not. The forced states (hl_pk, ll_pk, control_pk and tx_schedule) in process model handle the data transfer or buffering based on the sleep state of the mobile station.

Core simulation functions of the sleep mode, such as check_no_packet_time (), slp_pk_buffer (), slp_next_interval_get() and lp_pk_buffer_send() are designed in the Function Blocks (FB) of WiMAX.
MAC process model. Function `check_no_packet_time()` obtains the duration of awaked mobile station that has no packet service in order to decide whether it triggers the `SLEEP_MODE` condition from wake mode to sleep mode. Function `slp_pk_buffer()` buffers the packets destined to an MS in sleep mode. The buffered packets are sent to a mobile station via function `slp_pk_buffer_send()`, and function `slp_next_interval_get()` obtains the next sleep interval of sleep mode.

The variables in the OPNET process model can be defined in TV (Temporary Variable) block or SV (State Variable) block. The variables in TV block are not retained between two interrupts while the variables in SV block are. Table 1 shows the variables used for sleep mode triggering and sleeping process in SV block.

<table>
<thead>
<tr>
<th>Variable Name</th>
<th>Type</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>slp_ms_is_sleep</td>
<td>Boolean</td>
<td>Whether MS is in sleep mode</td>
</tr>
<tr>
<td>slp_current_interval</td>
<td>Double</td>
<td>Sleep interval of current sleep cycle</td>
</tr>
<tr>
<td>slp_current_cycle</td>
<td>Double</td>
<td>Current sleep cycle</td>
</tr>
<tr>
<td>slp_current_cycle_time</td>
<td>Double</td>
<td>Start time of current sleep interval</td>
</tr>
<tr>
<td>slp_ms_trf_ind</td>
<td>Boolean</td>
<td>Has the MS buffered packets</td>
</tr>
<tr>
<td>slp_last_pk_arrived_time</td>
<td>Double</td>
<td>Arrived time of latest packet</td>
</tr>
<tr>
<td>slp_no_pk_time</td>
<td>Double</td>
<td>No traffic service duration at MS</td>
</tr>
</tbody>
</table>

Figure 4. The call of sleep mode module in process model

Based on the above design, the core algorithm of simulation handling at the MAC process in the sleep mode is shown in figure 4. Sleep mode process mainly involves three forced states, namely `idle`, `sleep_ctrl` and `hl_pk`. The `idle` state is mainly used to produce self-interrupt to enter into `sleep_ctrl` state by checking the state transition trigger condition when the no-packet-serving duration of the awaked MS (by `check_no_packet_time()`) is larger than the threshold `SLP_T_TRIGGER`. The `sleep_ctrl` state is mainly used to control sleep mode based on sleep increase algorithm. If an awaked MS enters into this
state, it turns the MS into sleep mode and produces self-interrupt to enter into this state again after the end of sleep interval, or it indicates that the MS is in the listening interval of sleep cycle. If the variable slp_ms_trf_ind is TRUE at the listening interval, indicating that there are buffered packets destined to the MS at the sleep cycle, the MS will exit the sleep mode after the end of listening interval and the function slp_pk_buffer_send() is called to transfer buffered packets. Otherwise the function slp_next_interval_get() is called to obtain the next sleep interval to continue next sleep cycle. At hl_pk state, if the destination of a received packet is an MS in sleep mode, the packet is buffered, and the indication slp_ms_trf_ind is set to TRUE, otherwise the packet is forwarded to the MS normally.

4. Simulation Experiments

4.1 Simulation setup

The network model of simulation experiments is that a web server is connected to a BS node by a wired network, and an MS node is registered to the BS to receive packets from the web server. The physical layer of simulation module takes OFDM (set to 5 frames/ms) modulation mode and BE scheduling method. To simplify the simulation experiments, we mainly observe the simulation performance on two-times exponential increase sleep algorithm recommended in IEEE 802.16e standard for downlink business of mobile WiMAX. The value of each parameter configured in this simulation is shown in Table 2.

Table 2. Parameters setting in the simulation experiment

<table>
<thead>
<tr>
<th>Constant Name</th>
<th>Comments</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLP_T_MIN</td>
<td>the minimum of sleep interval</td>
<td>5 ms</td>
</tr>
<tr>
<td>SLP_T_MAX</td>
<td>the maximum of sleep interval</td>
<td>1024 ms</td>
</tr>
<tr>
<td>SLP_T_LISTEN</td>
<td>the listening interval</td>
<td>5 ms</td>
</tr>
<tr>
<td>SLP_T_TRIGGER</td>
<td>the threshold of trigger condition</td>
<td>50 ms</td>
</tr>
<tr>
<td>SLP_ENG_SLEEP</td>
<td>energy consumption per unit time during sleep interval</td>
<td>10 mW</td>
</tr>
<tr>
<td>SLP_ENG_LISTEN</td>
<td>energy consumption per unit time during listening interval</td>
<td>750 mW</td>
</tr>
<tr>
<td>SLP_ENG_AWAKE</td>
<td>energy consumption per unit time during wake mode</td>
<td>750 mW</td>
</tr>
<tr>
<td>SLP_ENG_SWITCH</td>
<td>Energy exhaust during state switch</td>
<td>1 mJ</td>
</tr>
</tbody>
</table>

4.2 Business Modeling

The accuracy of business modeling is the key to the success of communication system performance evaluation. To obtain effective results for real network design, the business source of simulation must accurately reflect the statistical characteristics of real business. To mainly examine the complicated power saving mechanism PSC I, we choose web browsing service as the representative of best effort business modeling service. A typical packet session consists of a group of packet callings. Several packets are generated at the packet calling period, i.e. packet calling includes a group of bursting packets. In web browsing session, a packet calling corresponds to downloading a web document that is read by users for a period of time called reading time. According to wireless packet business unified reference model, we adopt three layer businesses modeling based on user behavior [14]. Table 3 shows the model parameters configured for session level, web level and object level in OPNET.

Table 3. Parameters setting of business modeling

<table>
<thead>
<tr>
<th>OPNET Parameter</th>
<th>Distribution</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Session Interarrival Time</td>
<td>Exponential</td>
<td>1429</td>
</tr>
<tr>
<td>Session Duration</td>
<td>Weibull</td>
<td>(0.027, 0.529)</td>
</tr>
<tr>
<td>Page Interarrival Time</td>
<td>Weibull</td>
<td>(0.672, 0.511)</td>
</tr>
<tr>
<td>Objects per page</td>
<td>Pareto</td>
<td>(0.384, 0.846)</td>
</tr>
<tr>
<td>Object Size</td>
<td>Exponential</td>
<td>1261</td>
</tr>
</tbody>
</table>
4.3 Simulation Result Analysis

There are two significant performance factors in sleep mode operation, one is power consumption, and the other is response delay. The sleep mode operation in power management helps to extend the lifetime of a mobile station by saving energy consumption while it increases the MAC SDU response delay.

Simulation results of the average power consumption and the average power saving rate is shown in Figure 5 using the implemented sleep mode module with 2 times exponential increase algorithm. Considering the simulation stability, the sleep mode is observed after 100s from the start of the simulation. Due to the trigger condition that requires no packet within 50 ms, the energy consumption fluctuates pretty radically when the node first enters into sleep cycle. The average power consumption of the mobile station quickly decreases from 750 mW at awaking state to 170 mW. However, after about 5 minutes, the average power consumption quickly stabilizes at around 300 mW and about 60% energy consumption is achieved.

![Figure 5. Effects on energy consumption](image)

![Figure 6. Effects on response time (ms)](image)

In the sleep mode packets sent to an MS in sleep cycle are buffered until the MS turns into wake mode, which would increase the packet delay inevitably. The extra packet delay and the average response time as well as the average packet delay are shown in Figure 6. The response time of buffered packets in sleep interval fluctuates at around the maximum sleep interval (1024s). This result conforms to the result calculated by algorithm. After a short sleep start-up period, the average response time of the buffered packets in BS takes about 80 ms. The sleep mode increases by about extra 50 ms of end-to-end delay. In terms of BE service, the sleep mode just increases the packet delay by about 50 ms on the average while saves 60% power consumption, which could have a wide application for mobile terminals powered by battery.

5. Conclusion

By extending the WiMAX process model of the OPNET simulation platform, we have adopted the three-layer modeling mechanism, designed and implemented the simulation module of IEEE 802.16e sleep mode. Moreover, we applied the three layer business model based on users’ behavior to model WWW business service under wireless communication and simulated the WWW browsing business using 2 times exponential increasing sleep algorithm. The simulation results validated the effectiveness of sleep mode to the energy-saving. We believe this work could benefit and promote the future research work on power saving of mobile station in mobile WiMAX.
6. Acknowledgments

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7. References