國立交通大學

網路工程研究所

碩 士 論 文

在 802.11 和 802.16e 共存的異質網路下的省電機制

Power Saving Mechanism in Wireless Heterogeneous Networks

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摘要

無線技術是目前網路的潮流。像是藍芽和 Wi-Fi 已經普及化了，而且幾乎已經成了現在行動裝置的基本配備了。除了藍芽和 Wi-Fi 之外，WiMax 是另一項目前發展迅速的技術之一。不久之後，WiMax 也將成為行動裝置的基本配備。

對於行動裝置來說，電源一直是很重要的一個問題。不過 Wi-Fi 和 WiMax 都有針對電源因素提出解決的省電機制。但是它 Wi-Fi 們的省電機制並沒有考慮到對方。對於同時擁有 Wi-Fi 和 WiMax 的行動裝置來說，要真正進入省電模式必須 Wi-Fi 和 WiMax 都進入省電模式才行。目前 Wi-Fi 和 WiMax 都沒有考慮如此。

本篇論文針對上述問題，修改原本的省電機制，使得既可以考慮到對方又可以保持省電機制的效果。透過模擬，我們可以看到這樣的方法的確有效。

Abstract

Wireless technology is the current trend of Internet. Like Bluetooth and Wi-Fi, they have already been popular and are basic equipments in mobile devices. Except Bluetooth and Wi-Fi, WiMax is another technology that develops rapidly in current. In the feature, WiMax will be basic equipment in mobile device too.

For mobile devices, power is always a important issue. Wi-Fi and WiMax have power saving mechanisms to solve the power issue. But their power saving mechanisms don’t consider each other. For mobile devices with Wi-Fi and WiMax, it will enter power saving mode if and only if Wi-Fi and WiMax both enter power saving mode. Currently, Wi-Fi and WiMax don’t consider this way.

Focus on this problem, in this thesis we revise the original power saving mechanisms to consider other side and keep the effect of power saving mechanisms. From simulation, we can see this method works.

致謝

經過了兩年的時間，終於到了完成論文的這一步了。去年看著實驗室學長姐這樣走過，當時覺得非常了不起，現在輪到自己了。

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Chapter 1 Introduction

1.1 Preface

Wi-Fi is universal recently. You can access the Internet through Wi-Fi in Starbucks, McDonald's, airport, etc. Wi-Fi technology uses the IEEE 802.11 standard [1-3]. IEEE 802.11 calls wireless local area network, WLAN. IEEE 802.11 contains two different frameworks, ad hoc mode and infrastructure mode. In ad hoc mode, users change their information each other by transmitting message to their neighbors directly. For infrastructure mode, it is unlike ad hoc mode that transmits message to neighbors directly. In infrastructure mode, users transmit/receive information to/from access point (AP). And access points connect with Internet normally. Infrastructure mode is common, so we only consider infrastructure mode in this thesis.

But IEEE 802.11 is local area network. The coverage of wireless waveform is at most three hundred meters. Recently, there is a new network. Its coverage of wireless waveform and broadband are more widely. It calls worldwide interoperability for microwave access, WiMax. WiMax is based on IEEE 802.16 standard [5] and proposed for wireless metropolitan area network, WMAN. The coverage of WiMax is about 2-10 kilometers depending on different environments. IEEE 802.16 also institutes two frameworks, point-to-multipoint (PMP) mode and mesh mode. PMP mode is more commonly than mesh mode, so we only consider PMP mode in this thesis. PMP mode in IEEE 802.16 is like infrastructure mode in IEEE 802.11. In PMP mode, users transmit/receive information to/from base station (BS). And normally, BS will connect with Internet, too. Although PMP mode in IEEE 802.16 is like infrastructure mode in IEEE 802.11, there still is something different. IEEE 802.16 supports quality of service (QoS) and IEEE 802.11 don't. In IEEE 802.16d [5], it defines four different service types but doesn't support mobility. The future version IEEE 802.16e [6] combines previous version with mobility and adds one more service type. In this thesis, we focus on IEEE 802.16e.

Wi-Fi and WiMax are applied to hand-held devices mostly, like mobile phones, PDAs and laptops. The powers of these hand-held devices are usually supplied by batteries. The lifetime of battery is limited. So the power issue is very important. IEEE 802.11 and IEEE 802.16e both propose power saving mechanism to solve the problem. In next two sections, we will introduce the power saving mechanism.

1.2 Power management in IEEE 802.11

In order to increasing the lifetime of battery, IEEE 802.11 proposes a power management to decreasing the consumption of power. In infrastructure mode of IEEE 802.11, users (normally called mobile stations, MS) must connect with access point and transmit/receive information to/from access point. But IEEE 802.11 only proposes power management for downlink (DL) traffic. For uplink (UL) traffic, if mobile stations want save their power, they just stop transmitting any messages to access point and keep the messages in queue. So IEEE 802.11 doesn't propose any power management for uplink traffic.

Before introducing the power management for downlink traffic, we first introduce two terms, active mode and power-save mode. Active mode means mobile station keeps transmit/receive information to/from access point. Power-save mode means mobile station will turn off the antenna or decrease the power intensity of radio.

If a mobile station having downlink traffic wants to enter power-save mode, it must alert access point. Otherwise access point will keep attempting to transmit messages. Mobile station will use the power management bit within the frame control field of transmitted frames to inform the access point. And access point will not transmit message to mobile station and buffer the messages. Then mobile stations will know if having any buffered messages in access point through traffic indication map (TIM) which is included within all beacons generated by access point. In order to conserve more power, mobile station shall not have to receive TIM every beacon. During power-save mode, mobile station only shall periodically listen for beacon. The period of listening (listen interval) is determined by mobile station.

	B0 B1	B2 B3	B4 B7	B8	B9	B10	B11	B12	B13	B14	B15
	Protocol Version	Type	Subtype	To DS	From DS	More Flag	Retry	Pwr Mgt	More Data	WEP	Order
Bits :	2	2	4	1	1	1	1	1	1	1	1

Figure 1-1 Frame control field

After receiving and interpreting TIM, mobile station will know having buffered messages in access point or not. If yes, mobile station will transmit a PS-Poll frame to access point and access point will response the corresponding buffered messages immediately. Figure 1-2 is a simple example. In figure 1-2, access point sends TIM during every beacon. The listen interval of mobile station is two beacons. So mobile station receives TIM in 1st and 3rd beacon interval and sends PS-Poll frame. After receiving PS-Poll frame, access point sends corresponding buffered messages to mobile station.

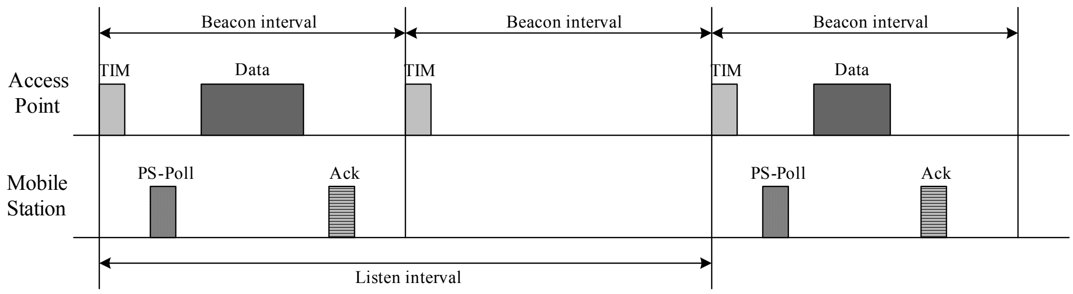

Figure 1-2 Power management operations

1.3 Power saving mechanisms in IEEE 802.16e

IEEE 802.16e proposes three kinds of power saving mechanisms which calls power saving class of type I, type II and type III for different service types. Before introduction these power classes, we will introduce the five service types first.

In order to support QoS, IEEE 802.16e proposes five different service types which are Unsolicited Grant Service (UGS), Real-time Polling Service (rtPS), Extend Non-real-time Polling Service (nrtPS), Best Effort (BE) and Real-time Polling Service (ertPS). The descriptions of each service type are in the following:

(a) UGS: support real-time service which having fixed data packets and period, like voice over Internet Protocol (VoIP) service.

(b) rtPS: support real-time service which having variable-sized data packets and data flow is bigger than UGS, like real-time video service.

(c) nrtPS: support services with delay-tolerant and variable-sized data packets, like FTP service.

(d) BE: support service without any requirements.

(e) ertPS: newly added in IEEE 802.16e. It combines with UGS and rtPS. The data flow is small, but the size of data packets is variable.

The QoS requirement of each service type is different which is showed in table 1-1.

Table 1-1 QoS requirement of each service type

	UGS	rtPS	nrtPS	BE	ertPS
Grant interval	●				●
Maximum latency	●	●			●
Minimum reserved rate	●	●	●		●
Maximum sustained rate		●	●	●	●

After knowing the character of each service type, we can introduce the power saving mechanisms in IEEE 802.16e. Like IEEE 802.11, IEEE 802.16e also proposes some method to solve the power issue. Like the power-save mode in IEEE 802.11, mobile station in IEEE 802.16e can enter sleep mode to conserve power. If mobile station want enter sleep mode, it must alert the base station. Mobile station will send a MOB_SLP-REQ message within some parameters to base station. Then base station will reply to mobile station with a MOB_SLP-RSP message within some parameters. Both MOB_SLP-REQ and MOB_SLP-RSP are both management messages. Then we will describe the character of each power saving classes.

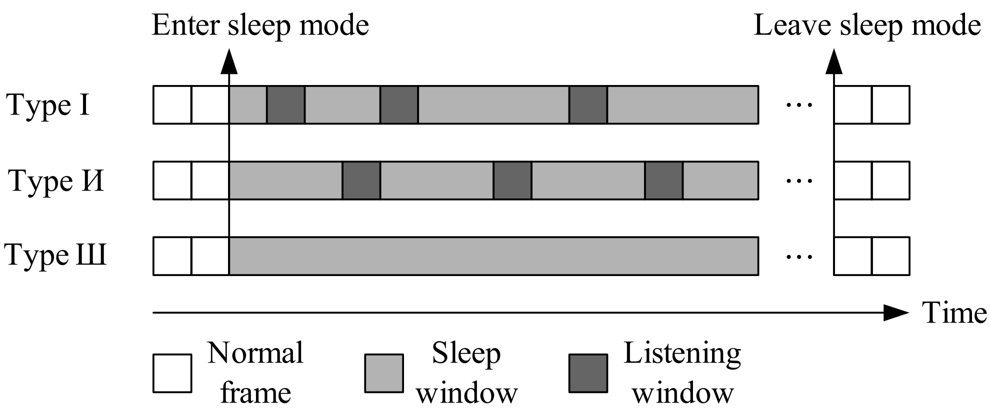

Figure 1-3 Examples of each type of power saving classes

In IEEE 802.16e, power saving classes of type I is recommended for connections of BE or nrtPS type, power saving classes of type II is recommended for connections of UGS or rtPS type and power saving classes of type III is recommended for multicast connections as well as for management operations. Figure 1-3 are examples of power saving classes of type I, type II and type III. In normal frame, mobile station is not in sleep mode and mobile station might receive or transmit packets. Sleep window and listening window are consisted of frames. In sleep window, mobile station does nothing and mobile station can turn off the antenna to conserve power. In listening window, mobile station has different operations in each type. But there is no listening window in type III because power saving of classes of type III is used for management operations. For type I, the listening frame will include a traffic indication message, MOB_TRF-IND. If positive, mobile station will leave sleep mode, otherwise, mobile station will sleep until next listening window. Normally, the length of listening window in type I is one frame. Different with type I, mobile station will receive or transmit packets in listening window in type II. And from figure 1-3, we can find the length of sleep window of each type is different. For type I, the sleep window is twice as before. Avoiding sleep window becoming too long, mobile station will decide a maximum sleep window. If next sleep window is greater than maximum sleep window, it will adjust to be same as maximum sleep window. For type II, the sleep window is constant.

After introducing the power saving classes of type I, II and III, there is still an important thing need to know. In fact the power saving classes in IEEE 802.16e standard is determined per connections. It means a mobile station might have different power saving classes of type I, II and II at the same time. Figure 1-4 is an example of two power saving classes in a mobile station. Mobile station can conserve power only in intervals of unavailability.

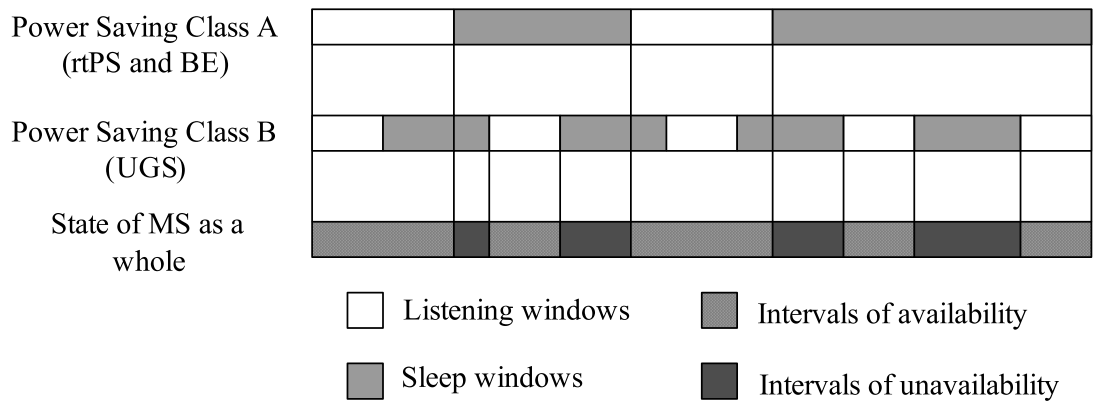

Figure 1-4 Example of sleep mode operations with two power saving classes

1.4 Motivation

With the rapid development of WiMax, it will become basic equipment in mobile devices like Wi-Fi. At that time users can determine which way to connect with Internet between Wi-Fi and WiMax. Or some users might connect with Internet through Wi-Fi and WiMax at the same time. Although IEEE 802.11 and IEEE 802.16e both propose its own power saving mechanisms, they don’t consider other standards. In this situation that a user having wireless traffics from IEEE 802.11 and IEEE 802.16e, this user can conserve the power of mobile device only when both wireless traffics are idle. Figure 1-5 is an example of this situation. From figure 1-5, we can find the power-saving states of wireless traffic of IEEE 802.11 and IEEE 802.16e are independent. For this mobile device, the actual time of conserving power is intervals of unavailability. The time is less compare with IEEE 802.11 or IEEE 802.16e traffic. So we want to let the sleep states of IEEE 802.11 and IEEE 802.16e appear synchronously. We will revise the power saving mechanism in IEEE 802.11 and IEEE 802.16e to reach the goal.

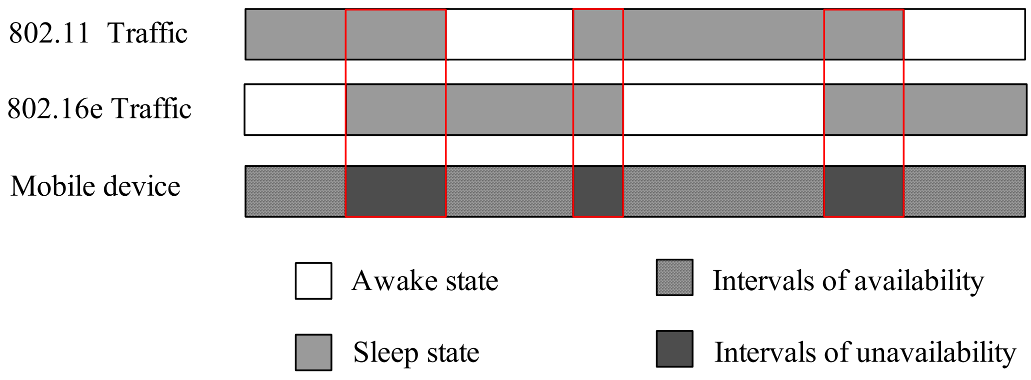

Figure 1-5 Example of power-saving state of MS having two wireless traffics

1.5 Organization

The remaining of this thesis is organized as follows. In chapter 2, we will introduce some related work about the power saving mechanisms in IEEE 802.11 and IEEE 802.16e. Then the revised power saving mechanism will be proposed in chapter 3. The simulation result will show in chapter 4. In the end, chapter 5 will be conclusion and future work.

Chapter 2 Related Work

Most studies in heterogeneous network (IEEE 802.11 and IEEE 802.16e) are related with the handoff between IEEE 802.11 and IEEE 802.16e, like [7] and [8]. Nobody study about the coexisting of IEEE 802.11 traffic and IEEE 802.16e traffic in heterogeneous network. In this chapter, we focus on other work about the power management in IEEE 802.11 and IEEE 802.16e.

2.1 Work in IEEE 802.11

For IEEE 802.11, a simple method to conserve more power is having a long listen interval. In this way, mobile station will stay more time in power save mode. The drawback is that when traffic load is heavy buffered packets in AP will exceed the queue size before mobile station wakeup. To solve this problem, many studies are proposed. In [9] and [10], they propose listen interval adaptation mechanisms in which the mobile station dynamically adapts the duration of listen interval according to the traffic situation. Another problem of power save mode in IEEE 802.11 will appear when the numbers of mobile stations in power save mode is more. Some mobile stations might have no chance to get the buffered packets in AP causing by too many mobile stations wakeup at the same beacon interval. In [11], the authors propose a method to arrange the wakeup schedule for sleeping mobile stations such that the number of wakeup mobile stations in each beacon interval is balanced.

2.2 Work in IEEE 802.16e

For power saving mechanism in IEEE 802.16e, [12] [13] [14] [15] analyze the binary-increasing sleep window of power saving classes of type I by proposing a mathematical model. In [16], the author also proposes mathematical models to calculate the power efficiency and packet access delay. Unlike [12] [13] [14] [15] which only considering power saving classes of type I, [16] propose two models for power saving classes of type I and type II. The result in [16] shows power saving classes of type I can get better performance in power saving, but have worse packet delay causing by binary-increasing sleep window.

In [17], the authors propose two scheduling algorithms for sleep mode operations in power saving classes of type II. The first algorithm is periodic on-off scheme for connection which distributes small packets to all OFDM frames group these small packets together without violating the QoS requirement. Figure 2-1 is an example of periodic on-off scheme.

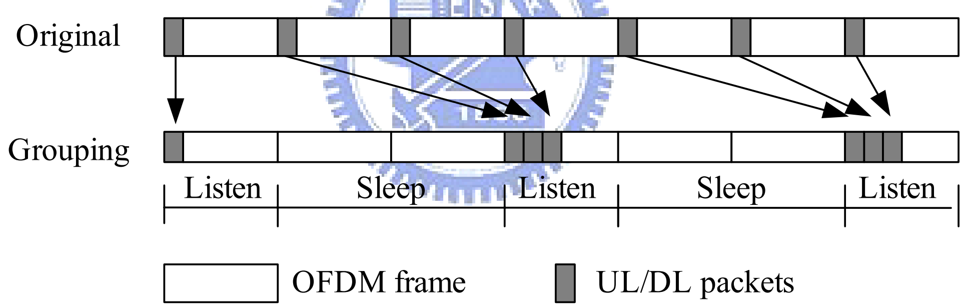

Figure 2-1 Periodic on-off scheme

The second algorithm is aperiodic on-off scheme. It merges the transmissions of different connections into fewer frames without violating the QoS requirements. It delays the transmission of connections and seeks if having transmission of other connection within the delay constrain. Figure 2-2 is an example of aperiodic on-off scheme. From (b), C2 will delay its transmissions and it finds C1 has transmissions within its delay constrain. From the view of mobile station, mobile station has fewer transmissions in (b). The reason is some transmissions of C2 transmit with C1.

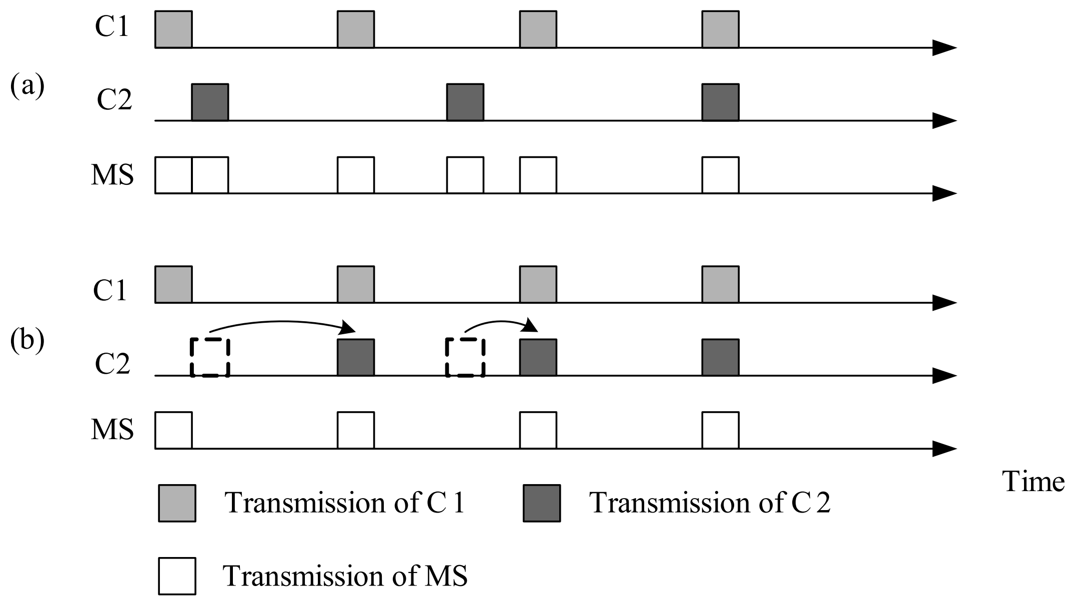

Figure 2-2 Aperiodic on-off scheme. (a) Original, (b) aperiodic on-off scheme.

Even if these two algorithms can reduce the times of transmission, there still are some drawbacks. First, they only consider the periodic fixed size traffic which be know before and ignore the variable size traffic like rtPS. The information of queue size of rtPS connection is obtained by polling or piggyback and is know in the run-time. Second, they don't consider the QoS requirements of power saving classes of type I. Third, the aperiodic on-off scheme is not optimal. In aperiodic on-off scheme, merging of transmission is done per connections. In order to solve the problems, the author of [18] proposes a new transmission merging mechanism.

In [18], there are three parts of this transmission merging mechanism. The first part handles periodic fixed size traffics, like UGS. It will calculate the next merging candidate set. Every frame within the set is optimal solution. The second part handles the variable size traffics, like rtPS, nrtPS and BE. It first calculates the size of next listening window according to the queue size. Then it calculates the maximum size of next sleep window according to the QoS requirement constrain and next listening window. Finally, from the next merging candidate set and maximum size of sleep window, the third part determines the actual listening window and sleep window.

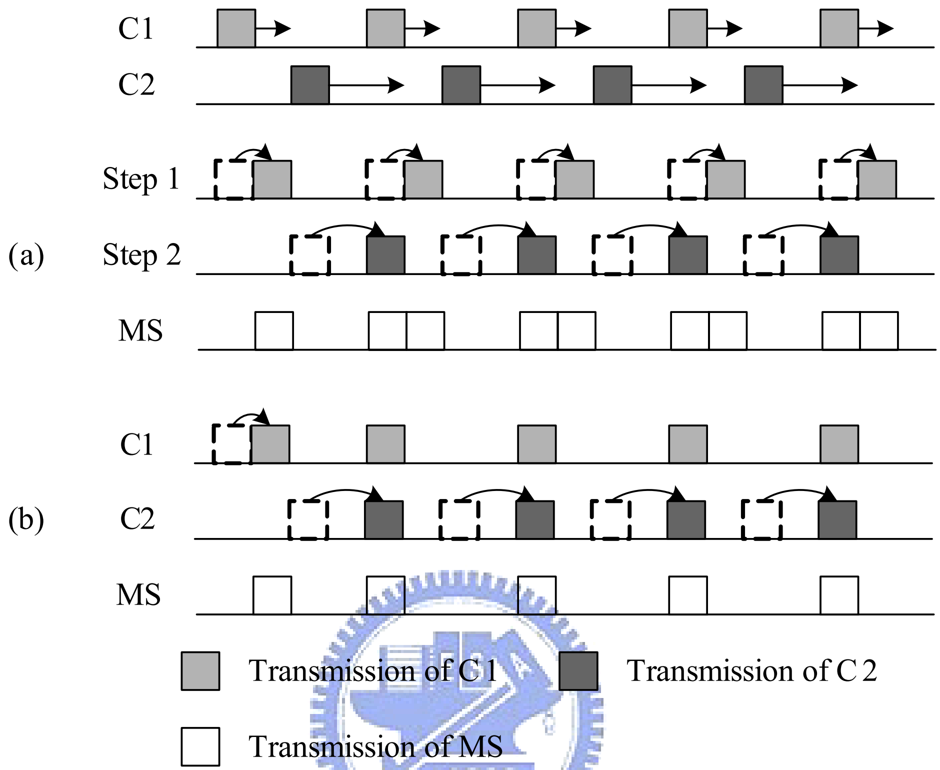

Figure 2-3 Merging methods in [17] and [18]. (a) [17] (b) [18]

The merging methods in [17] and [18] are shown in figure 2-3. Figure 2-3 is the worst case of aperiodic on-off scheme. From this figure, we can see the drawback of aperiodic on-off scheme. In aperiodic on-off scheme, it will choose the connection with small delay constrain first. In figure 2-3, the delay constrains of C1 and C2 are 1 and 2. First step, the aperiodic on-off scheme will choose C1 and can’t find any other transmissions within its delay constrain. In this situation, the aperiodic on-off scheme will delay the transmissions of C1 to reach maximum delay shown in figure 2-3 (a). Second step, it will choose C2 and can’t find any other transmissions within its delay constrain again. Then it does the same behavior like C1. Finally, we can see there is no transmission been merged. Unlike aperiodic on-off scheme in [17], the transmission merging mechanism in [18] will take all connections into consideration. From figure 2-3 (b), we can find that the mobile station only needs five transmissions. More detail about this mechanism will be described in next chapter.

Chapter 3 Power Saving Mechanism

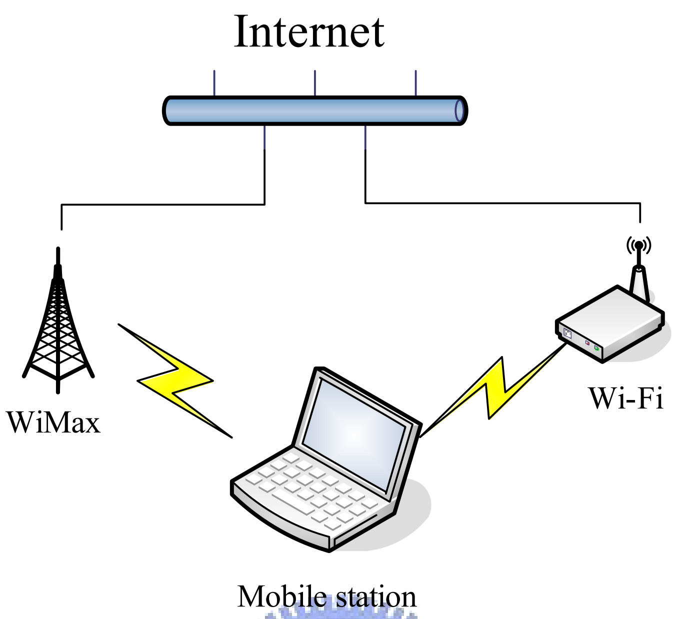

Figure 3-1 System environment

Before introducing the revised power saving mechanisms, let's recall our motivation again. We consider a heterogeneous network with Wi-Fi and WiMax coexisting like figure 3-1. In this environment, mobile station connects with Wi-Fi and WiMax at the same time and has wireless traffic for Wi-Fi and WiMax. In order to conserve power of battery, we want the sleep state of IEEE 802.11 and IEEE 802.16e can be synchronized. To do this, we propose different power saving mechanisms for IEEE 802.11 and IEEE 802.16e respectively in this chapter.

But we will mainly focus on IEEE 802.16e. The reason is that power management in IEEE 802.11 is more fixed than in IEEE 802.16e. In previous chapters, we have already introduced the power management and some related works in IEEE 802.11 and IEEE 802.16e. The awake/sleep state in IEEE 802.11 is more fixed except uplink traffic. Once mobile station decides the listen interval, the awake/sleep state will be fixed in downlink traffic. But power saving mechanism of IEEE 802.16e in [18] will make the awake/sleep state be flexible. In order to make the awake/sleep state of the traffics of IEEE 802.11 and IEEE 802.16e be synchronous, we will change the awake/sleep window of IEEE 802.16e to match IEEE 802.11.

3.1 Power Saving Mechanism for IEEE 802.16e

Since we mainly focus on power saving mechanism of IEEE 802.16e, we introduce power saving mechanism first. Our power saving mechanism for IEEE 802.16e is base on the transmission merging mechanism in [18]. The transmission merging mechanism in [18] will compute next merging candidate set for UGS traffics and maximum sleep window for rtPS, nrtPS and BE traffics. Then in order to get more time in sleep state, transmission merging mechanism will choose farthest frame in next merging candidate set and maximum sleep window. But our goal is to make the awake/sleep state of IEEE 802.11 and IEEE 802.16e be synchronous. Our power saving mechanism will choose appropriate next merging frame and next sleep window to match the awake/sleep state of IEEE 802.11.

Then we will introduce how to find next merging candidate set and maximum size of next sleep window. Table 3-1 shows some parameters of IEEE 802.16e traffic.

(a) Next merging candidate set of UGS traffics

UGS traffic has a special QoS requirement, grand interval. Grant interval means base station will schedule UGS traffic periodically. So we can know UGS traffic will be transmitted at which frame from grant interval.

The algorithm to find next merging candidate set of UGS traffics is showed in figure 3-2.

Table 3-1 Parameters of IEEE 802.16e service flow

Notation	Meaning	Service flow type	Unit
gb_i	Grant bandwidth of i_{th} connection	UGS	Bytes
gi_i	Grand interval of i_{th} connection	UGS	Frames
$r_{min,i}$	Minimum reserved rate of i_{th} connection	rtPS, nrtPS	Bytes/frame
$r_{max,i}$	Maximum reserved rate of i_{th} connection	rtPS, nrtPS, BE	Bytes/frame
d_i	Maximum latency	UGS, rtPS	Frames
r_i	Traffic generating rate of i_{th} connection	ALL	Bytes/frame

Algorithm 1

Step 1. Let F be the minimum F_i between all UGS connections.
$F = min\ (Fi|0<i\leq m)$.

Step 2. Let Y be the maximum Y_i between the UGS connections where their Y_i is less than F. $Y = max(Y_i|Y_i\leq F)$.

Step 3. Update Y_i and F_i between all UGS connection where their Y_i is less than Y and their F_i is bigger than F.
($Y_i = Y_i + gi_i$, $F_i = Y_i + d_i$)

Figure 3-2 Algorithm for finding next merging candidate set of UGS traffics

In algorithm 1 showed in figure 3-2, m is total number of UGS connections. Y_i is the next transmission frame of i_{th} UGS connection, and F_i is the farthest transmission frame of i_{th} UGS connection. d_i is maximum latency of i_{th} UGS connection , and gi_i is the grant interval of i_{th} UGS connection. Y is nearest next merging frame, and F is farthest next merging frame. So $[Y, F]$ is next merging candidate set. Step 1 is finding upper bound of next merging candidate set, and Step 2 is find lower bound of next merging candidate set. Step 3 is updating some values for applying this algorithm again at next time. Figure 3-3 is an example of this algorithm. In figure 3-3, there are three UGS connections, C1, C2 and C3. And we apply algorithm 1 three times and the results are figure 3-3 (a), (b), and (c).

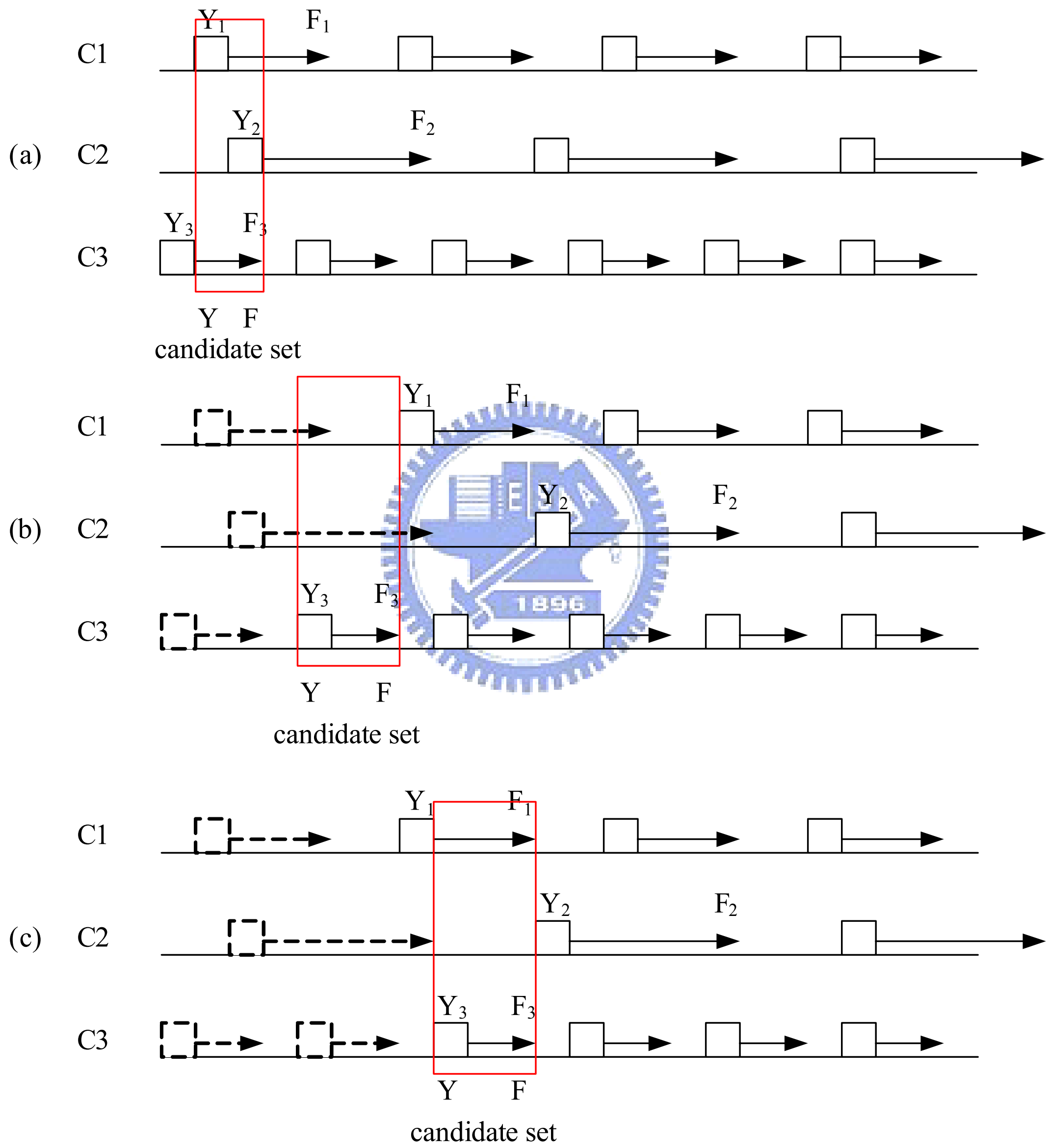

Figure 3-3 Example of algorithm 1

(b) Maximum size of next sleep window

Other service flows, rtPS, nrtPS, and BE doesn't have grant interval parameter.

Base station will schedule these service flows every frame if their queue is not empty. For uplink traffic, these connections will tell base station their queue size by piggyback. We know when mobile station enter sleep mode, it will only transmit/receive packets in listening windows. After listening window, mobile station will enter sleep state during sleep window. The size of listen/sleep window must be set appropriately to make the satisfying of QoS requirements. We will face two constraints, delay constraint and bandwidth constraint, when determine listening/sleep window.

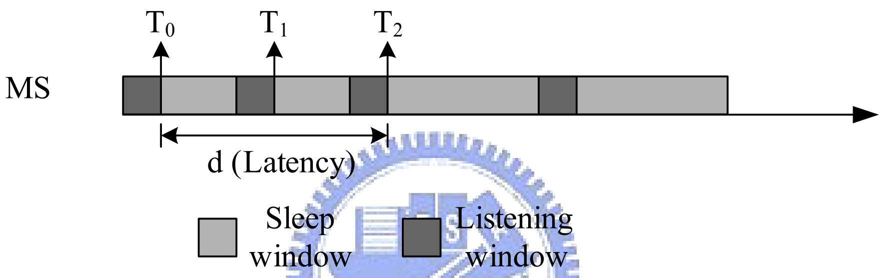

Figure 3-4 Example of listening/sleep window

The delay constraint means packets must be transmitted before maximum latency. When mobile station enter sleep mode, packets coming at sleep window will be transmitted during listen window. An example of listening/sleep window is shown is figure 3-4. Packets coming between first sleep window and second listening window will be queued and transmit at third listening window. They can’t be transmitted at second listening window because base station must know the queue size before scheduling these packets. And base station will know the queue size by piggyback after second listening window. Then base station will schedule these packets at next listening windows. In other words, packets transmit/receive at current listening window is coming during previous listening and sleep windows. The worst case is a packet might comes at T_0 which mobile station just finish listening window, and this packet will be transmitted until T_2. The latency of this packet will be d. We must make sure d will not greater than maximum latency of this packet. We can formulate delay constraint as follow:

$$S_t + W_t + S_{t+1} + W_{t+1} \leq d_{\min} \quad (1)$$

S means sleep window, and S_t means t_{th} sleep window. W means listening window, and W_t means t_{th} listening window. d_{min} means minimum value of all maximum latency. Because we merge all packets from different connections, we choose minimum value of all maximum latency of all connections to ensure every packet will satisfy its QoS requirement.

The bandwidth constraint means listening window must long enough to schedule all packets. We know packets coming during previous listening/sleep window will be scheduled at this listening window. We can formulated bandwidth constraint as follow:

$$W_{t+1} = \left\lceil \frac{\sum r_i (S_t + W_t)}{C - \sum r_{UGS} - \sum r_{non-PS}} \right\rceil \quad (2)$$

Denominator of (2) is summation of traffic generating rate of all connection during previous listening/sleep window. Numerator of (2) is residual bandwidth. C is bandwidth of base station, r_{UGS} is grant rate of UGS connections, and r_{non-PS} is maximum rate of connections belongs to other mobile station.

From bandwidth constraint, we can compute next listening window. How long the next sleep window does mobile station can sleep? We can use (1) to get the maximum size of next sleep window. There is one more thing we need to care about. The value of next sleep window will affect the value of the next two listening window according to (2). From (2), we know a longer sleep window (ex: S_{t+1}) will get a longer next listening window (ex: W_{t+2}). From (1), we know summation of two pair of listening/sleep windows must less than d_{min}. It is possible that summation of S_{t+1}, W_{t+1} and W_{t+2} will greater than d_{min}. We need to consider this situation, and get the following formula:

$$\begin{cases} W_{t+1} = \left\lceil \dfrac{\sum r_i (S_t + W_t)}{C - \sum r_{UGS} - \sum r_{non-PS}} \right\rceil \\ S_t + W_t + S_{t+1} + W_{t+1} \le d_{\min} \\ S_{t+1} + W_{t+1} + W_{t+2} \le d_{\min} \end{cases} \tag{3}$$

Using (3), we can get the maximum size of next sleep window.

(c) Our power saving mechanism

Our power saving mechanism is to adjust the awake/sleep state of IEEE 802.16e traffic to match the awake/sleep state of IEEE 802.11. We know downlink traffic of IEEE 802.11 will awake periodically. If base station knows the listen interval of IEEE 802.11 traffic, base station can adjust the listening window to match the awake state of IEEE 802.11 traffic. So we add one more parameter when IEEE 802.16e traffics enter sleep mode. The parameter is *BI* which the value of BI is listen interval of IEEE 802.11 traffic and the unit of *BI* is beacons. And base station will keep another parameter, bi_{next} which means the frame of next listen interval. We use the reserved bits in MOB_SLP-REQ to tell base station the value of *BI* and the initial value of bi_{next}.

After knowing the value of bi_{next}, we can introduce out power saving mechanism to determine the size of next sleep window. We know the transmission merging mechanism in [18] having three parts. The previous two parts compute the next merging candidate set and maximum size of next sleep window. The third part is determining the actual merging frame and next sleep window. There are three cases between next merging candidate set and maximum size of next sleep window which is showed in figure 3-5.

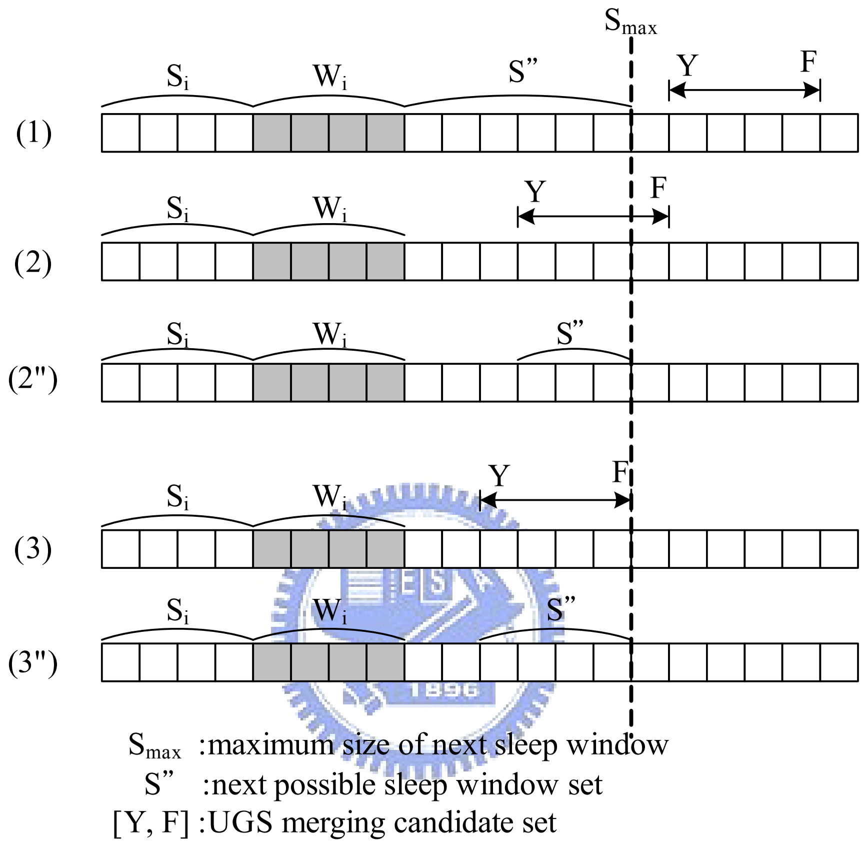

Figure 3-5 Three cases between next merging candidate set and maximum size of next sleep window

First case is that nearest frame of next merging candidate set Y is greater than S_{max}. In this situation, the value of next possible sleep window set S'' is $[0, S_{max}]$. Second case is that nearest frame of next merging candidate set Y is smaller than S_{max}, but farthest frame of next merging candidate set F is greater than S_{max}. In this situation, the value of next possible sleep window set S'' is $[Y, S_{max}]$. Third case is that farthest frame of next merging candidate set F is smaller than S_{max}. In this situation, the value of next possible sleep window set S'' is $[Y, F]$. After knowing the value of S”, we will see if bi_{next} is appear between *S"* or not to determine the actual size of next sleep window. If yes, the actual size of next sleep window is bi_{next}, otherwise the actual size of next sleep window will be the upper bound of S". The detail algorithm is showed in figure 3-6.

Algorithm 2

Step 1. Using algorithm 1 to compute next merge candidate set,*[Y,F]*.

Step 2. Using (3) to compute S_{max}.

Step 3. If $Y>S_{max}$, if next beacon frame bi_{next} appears between *S"*, the actual size of next sleep window is bi_{next}, else S_{max}. (case 1)

Step 4. If $Y<=S_{max}$ and $F>S_{max}$, if next beacon frame bi_{next} appears between *S"*, the actual size of next sleep window is bi_{next}, else S_{max}. (case 2)

Step 5. If $Y<=S_{max}$ and $F<=S_{max}$, if next beacon frame bi_{next} appears between *S"*, the actual size of next sleep window is bi_{next}, else *F*. (case 3)

Figure 3-6 Detail algorithm of determining the actual size of next sleep window

3.2 Power Saving Mechanism for IEEE 802.11

In the beginning of this chapter, we have already said our power saving mechanism is focus on IEEE 802.16e. Therefore our power saving mechanism for IEEE 802.11 only defines the timing to transmit uplink traffic of IEEE 802.11. The defining is as following:

Uplink traffic: Put the packets in queue until the traffic of IEEE 802.16e is awake state.

Downlink: According to traffic arriving rate to determine a proper listen interval.

Chapter 4 Simulation Results

In this chapter, we will show the performance of our power saving mechanism via simulation. We use the ns-2 simulator [19] and apply NIST WiMax module [20] into NS-2 to simulate our power saving mechanism. Some parameters of IEEE 802.11 and IEEE 802.16e are showed in table 4-1.

Table 4-1 Some parameters of IEEE 802.11 and IEEE 802.16e

IEEE 802.11		IEEE 802.16e	
Parameter	Value	Parameter	Value
Beacon size	0.1ms	Frame duration	0.005ms
Bandwidth	11Mbps	Bandwidth	8Mbps
Simulation time	10s	Simulation time	10s

We separate our simulation into three scenarios according to different traffic type of IEEE 802.11. First scenario, we only consider downlink traffics of IEEE 802.11. Second scenario, we consider uplink traffics of IEEE 802.11. Third scenario, we consider both uplink and downlink traffics of IEEE 802.11. In each result, we compute the overlapping time of sleep state of IEEE 802.11 and IEEE 802.16e. The overlapping time of sleep state means the summation time of sleep state of mobile device, like figure 1-5. And the improvement of overlapping time of sleep state means how many percentage of time increasing comparing with another method.

4.1 Scenario One

In the first scenario, the traffic of IEEE 802.11 is downlink traffic with different service rate. The traffics of IEEE 802.16e are three rtPS connections. The detail parameters of IEEE 802.16e connections are showed in table 4-2.

Table 4-2 Parameters of IEEE 802.16e connections in scenario one

Flow id	Max rate(Kbps)	Min rate(Kbps)	Max latency(frames)
1	400	200	d_1
2	450	250	d_2
3	550	300	d_3

The values of maximum latency in table 4-2 are not defined because we will observe the effect of different latency in the overlapping time of sleep state between IEEE 802.11 and 802.16e. We compare our power saving mechanism with transmission merging mechanism in [18]. And the improvement of overlapping time of sleep state is showed in table 4-3.

Table 4-3 Improvement of overlapping time of sleep state (IEEE 802.11 with 0.1M CBR)

%	Listen interval (beacons)								
d_{min}	2	3	4	5	6	7	8	9	10
6	-0.025	3.608	0.009	0.926	2.488	-0.522	0.203	1.413	-0.461
7	0.322	-0.009	0.357	-0.163	0.464	1.663	0.212	-0.152	-0.174
8	3.151	0.852	3.122	1.180	2.201	0.482	1.651	-0.137	1.236
9	-1.146	1.450	2.047	1.051	-0.083	0.251	0.297	1.461	-0.260
10	2.948	2.985	2.921	2.444	2.059	1.803	1.544	1.417	1.156
11	0.084	-0.321	0.102	0.905	0.916	0.426	0.150	-0.482	-0.356
12	-0.815	0.891	1.860	0.864	1.053	1.062	0.163	0.744	0.853
13	-0.170	1.717	-0.132	1.919	-0.036	1.235	-0.094	0.609	0.041
14	2.712	-0.276	2.547	-0.087	0.784	1.962	-0.151	0.732	-0.101

15	3.278	2.993	1.699	2.604	2.855	0.350	1.201	2.067	0.347

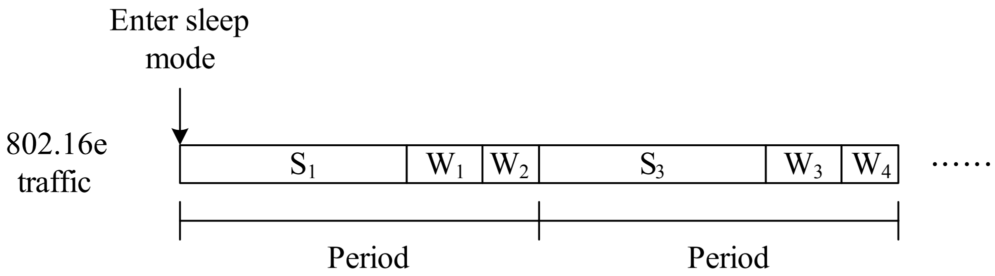

Figure 4-1 Behavior of listening/sleep window in transmission merging mechanism

From table 4-3, we can find two obvious results. First, in some cases the values of improvement are negative. It means using our power saving mechanism can't increase the overlapping time of sleep state. Before explain this problem, we need to know the behavior of listening/sleep window while using transmission merging mechanism in [18]. An example is showed in figure 4-1. From figure 4-1, we can find that the behaviors of listening/sleep window are periodic. In transmission merging mechanism, if there is no UGS traffic, it will only compute formula (3) in chapter 3 to obtain the value of maximum size of next sleep window, S_{max}. Then it will set S_{max} be next sleep window. When we have a long next sleep window, it will make the next two sleep window be zero to satisfy formula (1) in chapter 3. The value of period will equal to d_{min}. In this situation, the awake/sleep state of IEEE 802.11 and 802.16e traffics are both period. Therefore the awake/sleep state of IEEE 802.11 and 802.16e traffics will overlap periodically even if doing nothing. But when applying our power saving mechanism, it will destroy the period of IEEE 802.16e. So in some cases the summation of overlapping time which using our power saving mechanism might less than transmission merging mechanism.

Then the second result is the improvements are not regular even if under the

Table 4-4 Average length of sleep window (IEEE 802.11 with 0.1M CBR)

		Minimum latency (d_{min})									
	Listen interval	6	7	8	9	10	11	12	13	14	15
Ours	2	3.72	4.68	6.00	6.02	8.00	8.02	4.59	9.94	10.51	10.69
	3	4.00	4.67	5.51	6.58	8.00	8.01	5.43	9.21	9.21	12.00
	4	3.99	4.68	6.00	6.89	8.00	8.02	5.09	9.95	10.51	10.53
	5	3.89	4.99	5.70	6.97	8.00	8.96	4.83	9.64	10.94	11.44
	6	4.00	4.99	6.00	6.59	8.00	8.92	5.20	9.14	10.47	12.00
	7	3.99	5.00	5.79	6.76	8.00	8.78	5.05	9.82	11.00	11.11
	8	3.93	4.96	6.00	6.90	8.00	8.68	4.91	9.40	10.44	11.65
	9	4.00	4.93	5.84	7.00	8.00	8.62	5.13	9.93	10.90	12.00
	10	3.99	4.91	6.00	6.98	8.00	8.96	5.05	9.60	10.44	11.40
Original	N/A	4	5	6	7	8	9	5	10	11	12

same listen interval or same value of d_{min}. The main reason is our power saving mechanism makes the behavior of awake/sleep state of IEEE 802.16e be non-period. Even through, in most case, our power saving mechanism actually increases the overlapping time of sleep state.

Table 4-4 are the results of average length of sleep window. Original in table 4-4 means transmission merging mechanism. From table 4-4, we can find the average length of sleep window in our method is slightly small than transmission merging mechanism. Because in our method, we will choose small next sleep window to make the awake state of IEEE 802.11 and IEEE 802.16e synchronously. And in table 4-4, we can find when minimum latency is twelve the average length of sleep window is unusually small. This is because the behavior of listening/sleep window is this case is not like figure 4-1. It doesn't have zero length of sleep window. It has a long sleep window and a short sleep window interleaved.

Then we increase the traffic load of IEEE 802.11 to 0.3Mbps and 0.5Mbps. And the results are showed in table 4-5.

Table 4-5 Improvement of overlapping time of sleep state (IEEE 802.11 with 0.3M and 0.5M CBR separately)

0.3Mbps CBR									
%	Listen interval (beacons)								
d_{min}	2	3	4	5	6	7	8	9	10
6	1.590	4.542	-2.149	0.400	2.615	-0.845	-0.347	1.030	-0.066
8	7.214	-0.144	3.423	-0.787	0.879	0.861	1.735	-0.144	0.845
10	6.719	4.531	3.288	2.590	1.342	0.291	1.346	1.490	1.212
12	1.499	2.242	1.180	-0.124	1.057	0.014	-0.282	0.137	1.043
14	6.510	-0.298	1.529	-1.528	-0.559	2.082	-1.560	-0.450	-0.375
0.5Mbps CBR									
6	-0.930	3.636	-1.050	-0.635	2.678	-1.040	0.379	1.684	-0.306
8	7.759	-1.686	3.010	0.054	1.706	0.080	1.820	-0.015	1.316
10	7.190	4.811	0.817	2.649	2.291	1.892	0.573	1.243	1.110
12	0.475	2.395	0.304	0.100	1.167	0.889	-0.374	0.173	0.393
14	5.639	-1.921	0.218	-3.105	-0.146	2.063	-0.546	0.487	-0.647

Like the result in table 4-3, in some cases, our power saving mechanism can't get better performance and the ratio of bad case increases. But in some cases, the improvement of overlapping time of sleep state is increasing compare with table 4-3. The main reason is that awake state of IEEE 802.11 will become more longer while traffic load increases. And this makes the summation of overlapping time of sleep state of mobile device decrease. The percentage of improvement of our power saving mechanism becomes bigger naturally.

From table 4-2 and 4-3, we can find one more thing. The percentage of improvement with small listen interval is much bigger than long listen interval. Before explaining the reason, we need to know one more important thing. From chapter 3, we know our power saving mechanism in IEEE 802.16e is choose a proper next sleep window to make the next awake state of IEEE 802.11 and IEEE 802.16e to be synchronous. If IEEE 802.11 traffic has a small listen interval, IEEE 802.16e has more chances to adjust its next awake window to synchronize with IEEE 802.11 traffic. And the summation of overlapping time of sleep state will be big with high probability.

Then we will add UGS connections into IEEE 802.16e traffic. The parameters of UGS connections are showed in table 4-6. The results of simulation are showed in table 4-6.

Table 4-6 Parameters of UGS connections

Flow id	Grant period(frames)	Min rate(Kbps)	Max latency(frames)
4	14	64	5
5	9	64	4
6	5	64	2

Table 4-7 Improvement of overlapping time of sleep state (IEEE 802.11 with 0.1M CBR and IEEE 802.16e with UGS connections)

%	Listen interval (beacons)								
d_{min}	2	3	4	5	6	7	8	9	10
6	-0.450	0.252	0.840	0.458	0.164	-0.298	-0.042	0.340	-0.109
8	-0.516	0.550	0.530	0.356	-0.107	-0.034	-0.125	0.000	0.066
10	0.000	0.064	0.095	-0.144	-0.480	-0.699	-0.511	0.000	-0.256
12	2.058	1.160	1.203	0.626	0.095	0.004	0.000	0.000	0.128
14	2.058	1.160	1.203	0.626	0.095	0.004	0.000	0.000	0.128

Table 4-8 Average length of sleep window (IEEE 802.11 with 0.1M CBR and IEEE 802.16e with UGS connections)

		Minimum latency (d_{min})				
	Listen interval	6	8	10	12	14
Ours	2	2.23	2.69	3.60	3.99	3.99
	3	2.12	2.68	3.63	3.99	3.99
	4	2.10	2.70	3.74	3.99	3.99
	5	2.06	2.71	3.80	3.99	3.99
	6	2.07	2.70	3.79	3.99	3.99
	7	2.11	2.71	3.86	3.99	3.99
	8	2.06	2.70	3.87	3.99	3.99
	9	1.99	2.71	3.86	3.99	3.99
	10	2.04	2.71	3.89	3.99	3.99

Original	N/A	2.01	2.72	3.99	3.99	3.99

Comparing with table 4-3 and 4-7, we can find the improvement is decreasing. The main reason is the addition of UGS connections makes IEEE 802.16e traffic have more awake states. So these awake states will reduce the amount of sleep states and decrease the performance of our power saving mechanism.

Table 4-8 are the results of average length of sleep window. Comparing with table 4-4, we can find when IEEE 802.16e has UGS connections the length of sleep window will decrease. The main reason is the one grand period among UGS connections is small. From table 4-6, we can find there is a UGS connection with grand period is five. It means every five frames, the mobile station must wake up and receive/transmit UGS data.

4.2 Scenario Two

In previous section, we only simulate the downlink traffic of IEEE 802.11. Now in this section, we will see what will happen if the traffic type of IEEE 802.11 become uplink. In this scenario, we change the IEEE 802.11 traffic to be uplink traffic with different rate and the traffics of IEEE 802.16e are the same as table 4-2. We also simulate another two mechanisms for uplink traffic of IEEE 802.11. First is mobile station keep the sleep state until the queue size is 90% full. Second is transmitting the packet whenever coming, otherwise mobile station stays in sleep state. Figure 4-2 and 4-3 are the result of our simulation.

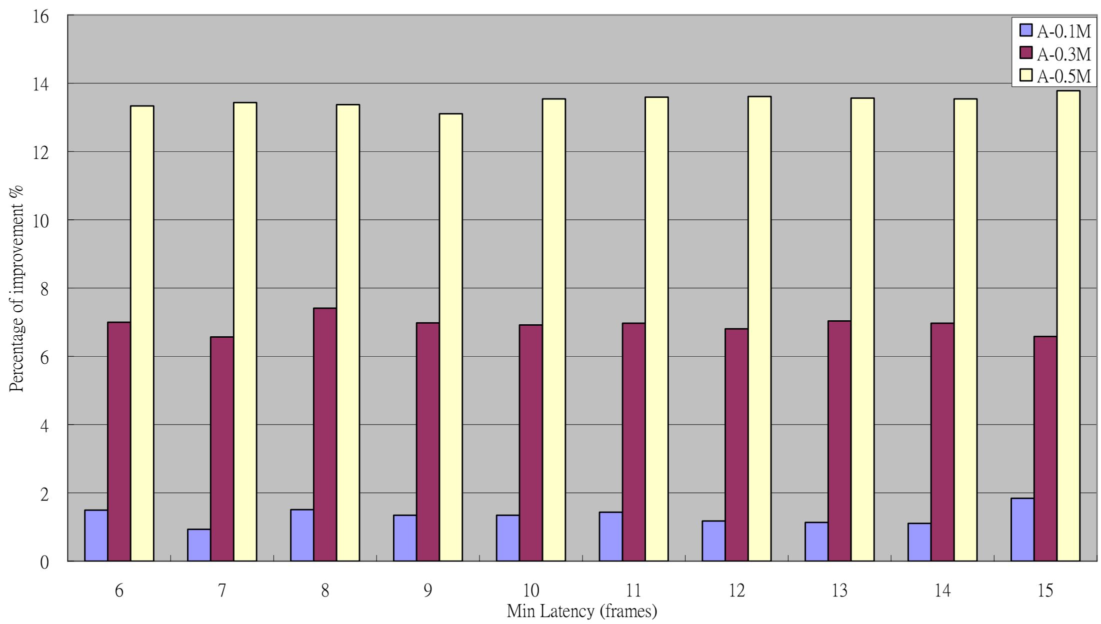

Figure 4-2 Improvement of overlapping time of sleep state comparing with queue constraint method

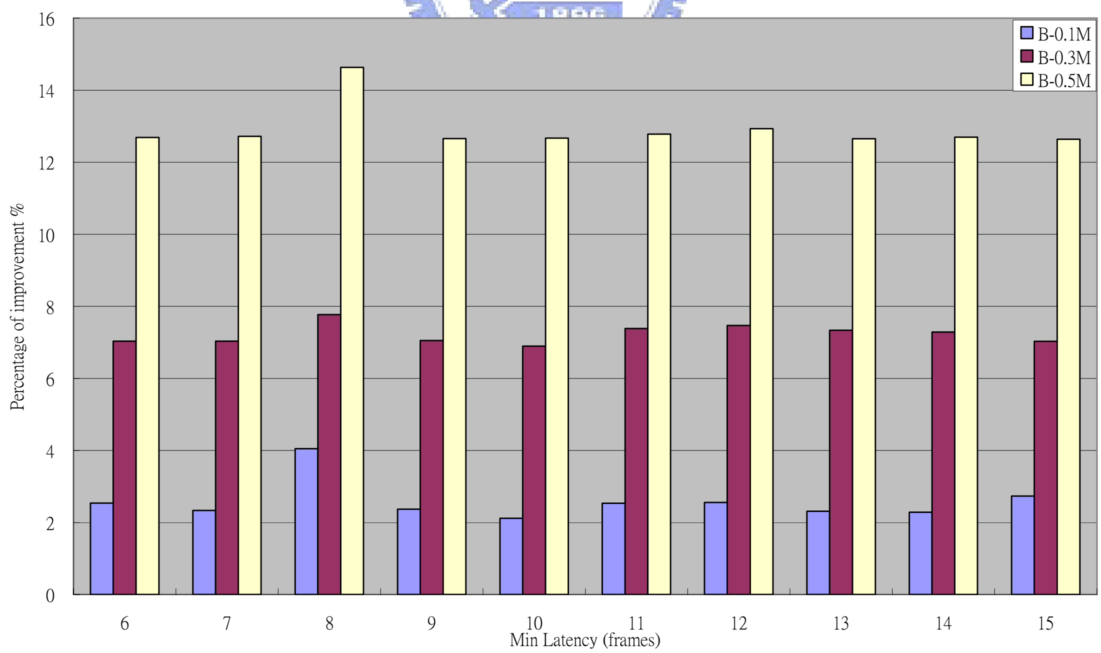

Figure 4-3 Improvement of overlapping time of sleep state comparing with immediately transmitting method

From figure 4-2 and 4-3, we can see our power saving mechanism has better performance in uplink. The main reason is because IEEE 802.11 doesn't define any power management for uplink traffic. The other two methods do not consider the behavior of IEEE 802.16e. And when the traffic loads of uplink increasing, the improvement also increases.

4.3 Scenario Three

In the previous scenarios, we discuss the effects of uplink and downlink traffics separately. In this scenario, we will consider uplink and downlink traffics of IEEE 802.11 at the same time. In this scenario, we use original power management in IEEE 802.11 which sets listen interval for downlink traffic and transmits uplink traffic immediately to compare with our power saving mechanism. The traffics of IEEE 802.16e are the same as table 4-2 and the result is showed in table 4-9.

Table 4-9 Improvement of overlapping time of sleep state (IEEE 802.11 with 0.1M uplink and 0.1M downlink)

%	Listen interval (beacons)				
d_{min}	2	4	6	8	10
6	2.44	2.28	4.97	2.55	1.85
8	6.81	6.77	5.74	5.31	4.74
10	5.61	5.56	4.58	4.19	3.68
12	1.37	4.56	4.25	3.26	3.55
14	5.42	5.36	3.99	3.21	3.06

From table 4-9, we can see no matter the value of d_{min} and listen interval is, our power saving mechanism can get much overlapping time of sleep state compare with original power management in IEEE 802.11 and IEEE 802.16e. The main reason is the consideration of transmitted time of uplink traffic in IEEE 802.11. In original power management in IEEE 802.11, mobile station can transmit uplink traffic whenever it has uplink traffic data. But this way will make mobile station stay awake frequently. In order to see this importance, we only use our power saving mechanism in IEEE 802.16e and do nothing for IEEE 802.11. The results are showed in table 4-10. From table 4-10, the improvements are slight and in some cases, only applying our power saving mechanism in IEEE 802.16e can't get any benefits. Comparing table 4-10 with 4-9, we can see the improvements in 4-9 are higher than 4-10. Hence we can know the time of transmitting uplink traffic of IEEE 802.11 is important.

Table 4-10 Improvement of overlapping time of sleep state without changing uplink traffic in IEEE 802.11(IEEE 802.11 with 0.1M uplink and 0.1M downlink)

%	Listen interval (beacons)				
d_{min}	2	4	6	8	10
6	0.02	-0.37	2.22	-0.04	-0.66
8	6.32	5.88	5.06	4.33	3.97
10	2.89	2.49	1.76	1.14	0.94
12	-0.92	1.53	0.96	0.00	0.35
14	2.80	2.33	1.23	0.18	-0.28

Normally, the downlink loads is higher than uplink loads. So we increase the downlink loads to 0.5Mbps and keep the uplink loads the same. The results are showed in table 4-11.

Table 4-11 Improvement of overlapping time of sleep state (IEEE 802.11 with 0.1M uplink and 0.5M downlink)

%	Listen interval (beacons)				
d_{min}	2	4	6	8	10
6	1.68	0.77	4.96	2.83	1.87
8	11.62	6.86	4.82	5.55	4.71
10	9.85	3.24	4.90	2.68	3.79
12	3.11	3.09	4.27	2.76	3.20
14	8.22	3.23	3.53	2.88	2.73

Even if we increase the downlink loads, our power saving mechanism still get better performance.

Chapter 5 Conclusion and Future Work

Wireless technology is the current trend of Internet. Wi-Fi is already popular and WiMax is coming soon. In the future, Wi-Fi and WiMax will be basic equipments in mobile devices and users can use Wi-Fi or WiMax to surf the Internet. People can choose one kind of method to connection with Internet. For wireless heterogeneous networks which combine with Wi-Fi and WiMax, we can use these two technologies at the same time due to the difference of radio frequency. For a mobile user with power constraint, how long can he stay in before running out the power of battery?

In fact, the standard of IEEE 802.11 and 802.16e both propose their own power management. But under such wireless heterogeneous networks, these power managements are not suitable. We focus on this problem and propose a power saving mechanism for both IEEE 802.11 and IEEE 802.16e. Through the results of simulation, we can find our power saving mechanism work and can improve the amount sleep state.

In the future work, we can apply the error and energy model in NS2 to see the effect. And in the simulation, we don't consider which traffic should belong to IEEE 802.11 or IEEE 802.16e. In fact, the traffic load will change the behaviors of awake/sleep state of IEEE 802.11 and IEEE 802.16e traffics. We can observe the distribution of traffics and find a better way to allocate these traffics.

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