國立交通大學

電機學院 電信學程

碩士論文

在無線隨意網上提供語音/數據服務之高節能效率媒體存取層協定

Energy-efficient MAC protocol for Voice/Data over Ad Hoc Networks

研　究　生：張建忠

指導教授：李程輝　教授

中華民國九十八年一月

在無線隨意網上提供語音/數據服務之高節能效率媒體存取層協定

Energy-efficient MAC protocol for Voice/Data over Ad Hoc Networks

研究生：張建忠　　Student：Chien-Chung Chang

指導教授：李程輝 教授　　Advisor：Tsern-Huei Lee

國立交通大學
電機學院　電信學程
碩士論文

A Thesis
Submitted to College of Electrical and Computer Engineering
National Chiao Tung University
in partial Fulfillment of the Requirements
for the Degree of

Master of Science
in

Communication Engineering

January 2009

Hsinchu, Taiwan, Republic of China

中華民國九十八年一月

在無線隨意網上提供語音/數據服務之高節能效率媒體存取層協定

學生：張建忠　　　　　　　　　　　　　指導教授：李程輝 教授

國立交通大學 電機學院 電信學程碩士班

摘要

為了延長使用電池供電無線網路設備之運轉時間，IEEE 802.11訂定了標準的同步式電源管理機制。由於工作站間彼此的時間必需同步化，因此在IEEE 802.11標準中有針對IBSS(Independent Basic Service Set)規定一套分散式同步電源管理機制TSF(Time Synchronous Function)，以達到不需外加同步設備即可達到同步的目的。

在IEEE 802.11電源管理機制中，時間是被切割成一段段的Beacon Interval，在每個Beacon Interval的起始段，每個工作站都必須醒來一段固定時間稱為ATIM Window，在這段時間裡如果工作站沒有資料要傳送或接收，將會在Data transmission Window時進入睡眠狀態，從許多研究顯示ATIM Window大小對MAC層省電效率及整體網路的效率有相當大的影響。

本論文設計一可以提供語音/數據之高節能效率媒體存取協定並提供服務品質保證。我們將使用頻寬保留機制在語音傳送上，一但工作站在ATIM Window中成功完成ATIM 訊息交握，工作站將不必要在ATIM Window中競爭發送ATIM 訊息，即可在Data transmission Window中傳送語音封包。本論文也提出可隨負載流量動態調整ATIM Window 大小的方法，並且改善頻道使用率。本論文也同時讓工作站僅需要在Data transmission Window中傳送資料時醒來，以減少工作站醒來時間及切換次數。

Energy-efficient MAC protocol for Voice/Data over Ad Hoc Networks

student：Chien-Chung Chang　　Advisors：Dr. Tsern-Huei Lee

Degree Program of Electrical and Computer Engineering
National Chiao Tung University

Abstract

To prolong the network operating time of battery-powered wireless LAN devices, this work proposes a synchronized power management scheme specified in IEEE 802.11 standard. The proposed synchronous protocol requires precise time synchronization among all participating nodes within the Independent Basic Service Set (IBSS). Therefore, Time Synchronization Function (TSF) is defined to enable the protocol to operate without external timing sources. In the proposed 802.11 power management scheme, time is divided into so-called beacon intervals. At the start of each beacon interval, each node must stay awake for a fixed time-period called an ATIM window (Ad-Hoc Traffic Indication Map window). Nodes that have no data to send or receive during the ATIM window enter the doze state in the data transmission window. Many studies indicate that ATIM window size significantly affects power saving and throughput achieved by the nodes. This thesis introduces an energy-efficient t MAC protocol to support CBR Voice and Data. Overall Quality of service (QOS) is guaranteed. A bandwidth reservation scheme can be used for CBR Voice transmission. Once stations finish the ATIM message exchange in ATIM window, stations transmit CBR Voice packets in the Data transmission window without further ATIM contention. The proposed protocol improves bandwidth utilization to dynamically adjust ATIM window length to the traffic load. Stations are also allowed to stay awake for only a fraction of the Data window which reduces switch-over time in the Data transmission window.

Acknowledgement

I am deeply grateful to my academic advisor, Professor Tsern-Huei Lee, for invaluable guidance and constant encouragement. The research could not be completed without his valuable assistance.

Professor Jui-Teng, Wang of Graduate Institute of Communication Engineering, National Chi Nan University, and Professor Yaw-Wen, Kuo of Graduate Institute of Communication Engineering, National Chi Nan University are appreciated for their valuable opinions, which have substantially improved this thesis.

I am also grateful to the PhD candidates, Jing-Rong Hsieh, and Yu-Wen Huang in the Network and Telecommunication Laboratory (NTL), Department of Communication Engineering, National Chiao Tung University, for their valuable opinions.

I appreciate the Chief of EMC, Network operation &Maintenance Dept. in Northern Taiwan Business Group of Chunghwa Telecom Co., Ltd, Pin-Chih Huang, Chiu-Lun Lin, who has been very supportive during my masters' studies. I also would like to thank Hao-Wen Sun, Chien-Tai Tsai, Chi-Lu Kuo, Deng-Tai Hu and other colleagues for their valuable help.

Finally, I am deeply grateful to my wife and my daughter and son for their continuing encouragement, understanding and patience in our daily life. I thank my mother for raising me up with her great maternal love.

Special sincere thanks to my father in heaven.

Contents

List of Tables

Lists of Figures

Chapter 1

Introduction

Rapid development of wireless communication technologies makes it possible to have information accessible anywhere, at any time, and at any device. Among these wireless technologies, IEEE 802.11 [1] [2] plays an important role. The IEEE 802.11 MAC consists of two components: PCF (Point Coordination Function) and DCF (Distributed Coordination Function). PCF is a centralized MAC protocol that supports collision free and time bounded services, in which an access point uses PCF to control all transmissions. DCF is a random access scheme, which based on the carrier sense multiple access with collision avoidance (CSMA/CA) and thus works efficiently even without an access point. There are two possible topologies for a single-hop network. The first one is the star topology (see Figure 1.1), where the base station is in the center of the network and the other nodes are in the one-hop neighborhood of the base station. In this topology all traffic flows through the base station. The second topology is the fully connected single-hop topology (see Figure 1.2), where all the nodes are in the single-hop neighborhood of each other.

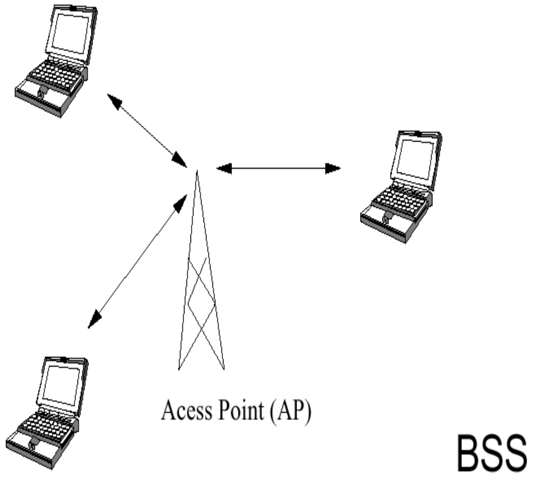


Figure 1.1: BSS

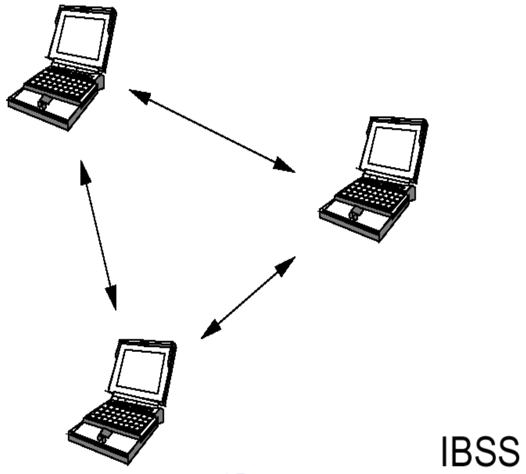


Figure 1.2: IBSS

Ad hoc networks are wireless networks where all nodes cooperatively maintain network connectivity. This type of network is well suited to fulfill the tactical communication requirements of a small to medium size military group (*i.e.*, a squad) or a law enforcement group (*i.e.*, police officers pursuing a criminal or airport security personnel searching a group of passengers), where the members of the network may want to communicate simultaneously with each other.

Wireless hosts are often powered by batteries and battery life is not expected to increase significantly in the coming years. Therefore, power is arguably the scarcest resource for mobile devices, and power saving has always been a major design issue for the developers of mobile devices, wireless communication protocols and mobile computing systems. Since users normally do not accept frequent recharging or changing of batteries, neither is it desirable for users to carry a heavy battery pack, a lot of limitations are imposed on the operations of a mobile device by power. To increase battery lifetime, it is important to design techniques for reducing energy consumption by wireless hosts.

Previous researches have investigated energy conserving mechanisms at various layers of the protocol stack, including work on Physical layer (Tuning transmission energy for higher channel utilization. Power control [3][4][5] reduces the power level of a transmission to achieve reduced power consumption while maintaining the transmission success rate and network connectivity), medium access control (MAC) layer (power mode management)and Network layer(Routing in an ad hoc network with energy-saving in mind). Since nodes in an ad hoc network communicate via radio, and the radio channel is shared by all nodes, it becomes necessary to control access to this shared media. Several authors have developed channel access protocols to maximize throughput and minimize transmission delays. From previous three solutions, we focus on MAC protocol to reduce the power consumption at each node.

Several experimental results show that energy in ad hoc networks is not always consumed by actual communication. This means that wireless network interfaces in the idle state waste a significant amount of energy. Energy dissipation in the idle state cannot be ignored because network interfaces often stay in the idle state for a long time. Thus to conserve this energy, it is generally desirable to turn the radio off when they are not in use. Much recent research proposed to reduce energy consumption in dense ad hoc networks by turning off devices that are not necessary for global connectivity. In addition, some MAC protocols have also been proposed to conserve energy based on IEEE 802.11 PSM.

As noted above, in ad hoc networks, the wireless network interface consumes energy except in the off state. In the awake state, the energy consumption in Lucent IEEE 802.11 WaveLAN card [6] consumes 1.65W, 1.4W and 1.15W in transmit, receive and idle modes respectively. In the doze state, WaveLAN card consumes 0.045W. Clearly, the energy consumed in the idle mode is almost the same with transmit mode. The idle power consumption is significant, as hosts must maintain their network interfaces in idle mode in order to cooperate in maintaining the ad hoc routing fabric. The hosts have to monitor the channel and consume power even through the packets are not directed to them, thereby unnecessarily consuming a large amount of energy.

1.1 Motivation

Having summarized the unique characteristics of Ad Hoc, we will focus on the Specific area of this dissertation – energy efficient for voice and data communications in Ad Hoc.

Many applications require a peer-to-peer single hop infrastructure less reliable radio network architecture that enables real-time communication. Voice and data communication is commonly used in many Ad Hoc scenarios that include groups of people with no available infrastructure support. Proposed protocol has been designed to be a very energy efficient, reliable protocol to support real-time broadcasting.

1.2 The Challenges of Power Saving Mode in 802.11Ad Hoc Networks

The relation among energy consumption, throughput and delays is a trade-off. Power Saving Mode in ad hoc networks has some inefficient problem. First, Fixed ATIM window size affects throughput and energy consumption. Secondly, serious contention and energy consumption occur in ATIM and Data transmission window. Thirdly, when real-time applications such as CBR Voice traffic are served, this scheme may cause intolerable delay and possibly packet loss.

1.3 Thesis Objective and Organization

In the thesis, we focus on the power management in fully-connected ad hoc networks. We assume that time is divided into beacon intervals which begin and end approximately at the same time at all nodes. We propose a power saving efficient MAC protocol that integrates voice and Data traffic with the QOS method and the ATIM window adjustment to achieve a better trade-off between power consumption, network throughput and delay.

The remainder of this thesis is organized as follows. Chapter 2 provides a review of

IEEE 802.11 PSM in DCF and related works. Chapter 3 presents our proposed protocol. In Chapter 4, we describe our simulation model and discuss simulation results. Finally, a conclusion to this thesis is presented in Chapter 5.

Chapter 2

Overview of IEEE 802.11 Power Saving Mode and Related Works

In this chapter, firstly, we will review the power management as defined in IEEE 802.11, and then discuss some drawbacks in the current standard in section 2.1. Much research has been done in power saving for mobile devices in the past. We will also show the inefficiency of the other power-saving mechanisms and will be presented in section 2.2.

2.1 Overview of IEEE 802.11 PSM

We briefly review the main operation of the power saving mode in an IEEE 802.11 ad hoc network. According to the IEEE 802.11 power saving mode, all nodes are connected synchronously by waking up periodically to listen beacon messages. This scheme requires the synchronization among the stations. Therefore, a TSF (time synchronization function) is defined in the standard. To save energy, stations go to the Power Saving (PS) mode when no incoming or outgoing traffic is present. In PS mode, the system is in a Doze state and its transceiver is shut down to save power. If a node acquires the medium, it will send an ATIM frame to the destination node based on the CSMA/CA access scheme. The ATIM frame is announced inside the ATIM window. If the destination node receives the ATIM frame, it will respond with an ATIM-ACK frame and stay active to receive data in the data window. After the ATIM window, the buffered data should be sent based on the CSMA/CA access scheme. If a node fails to send its ATIM frame in the current ATIM window, it should retransmit the ATIM frame in the next ATIM window. If a node does not send or receive any ATIM frame during the ATIM window, it will switch to PS mode to decrease power consumption until the next beacon interval begins. The IEEE 802.11's power management is shown in Figure 2.1-1.

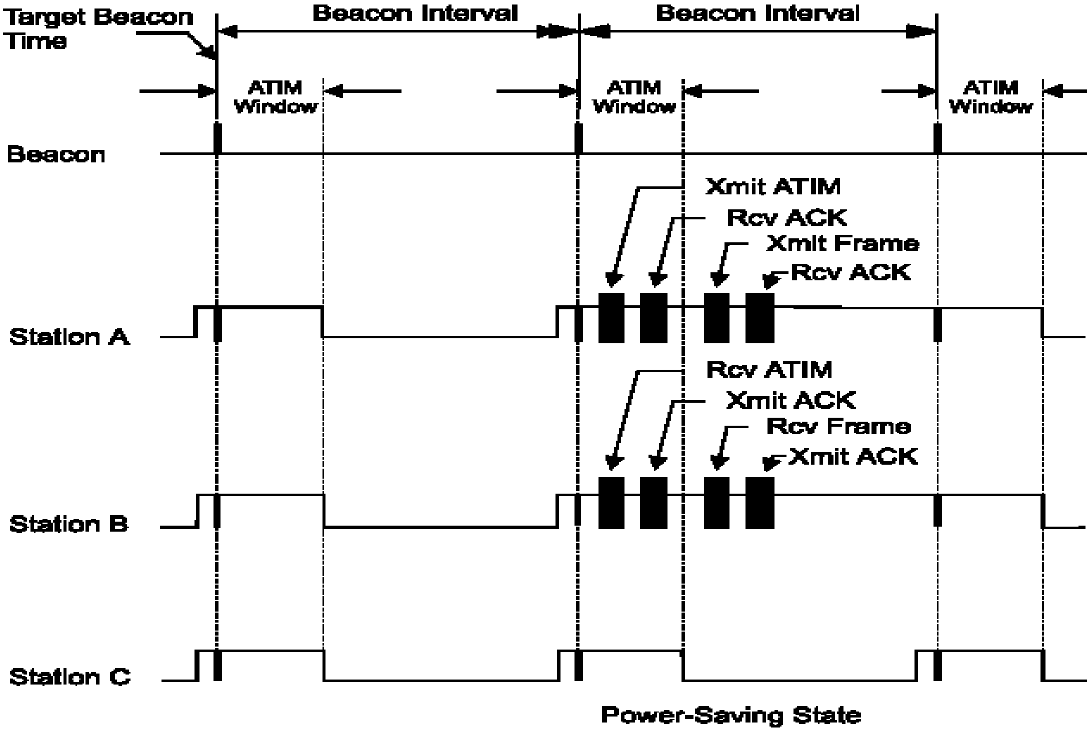


Figure 2.1: Power-saving mechanism in IEEE 802.11

Fig 2.1-1 shows an example. Initially, all nodes wake up at the beginning of the beacon interval. Since all nodes did not send or receive any ATIM frames in the ATIM window of the first beacon interval, all nodes will switch to sleep state in the Data transmission window. In the ATIM window of the next beacon interval, node A has a packet destined for node B. Therefore, nodes A sent ATIM frames to node B based on the CSMA/CA access scheme and successfully received the ATIM-ACK. After the ATIM window ends, nodes A tried to transmit buffered data to node B based on the CSMA/CA access scheme.

The performance of PSM is affected by the size of the ATIM window. When the ATIM window is too short with transmitting stations in the system, the contention in ATIM is high and only a few stations can send their ATIMs successfully. Then the channel utilization of data window of the same beacon interval is poor. If ATIM window is too long with transmitting stations in the system, many stations can enter the data transmission. This will cause not only higher contention in data window, but also the waste of energy for those who couldn’t get a chance to transfer data during the current beacon interval, since all stations who succeed in transferring their ATIMs are required to stay in Active Mode throughout the beacon interval. Both the ATIM window and the beacon interval are fixed length. It was shown in [7] that PSM performed well when the length of the ATIM window was approximately 1/4 of the beacon interval. Furthermore, the IEEE 802.11 PSM has two-contention transmissions (one for the ATIM frame and one for data packet). This will often cause a mismatch of the number stations in each contention period. For example, we may have many successful nodes in the ATIM window, but only a few nodes can transmit their data packet in the data transmission interval due to the high contention in the data window.

The power-saving mechanism suffers several problems with end-to-end delays and throughput. If a sender wants to immediately transmit packets to a receiver but has not transmitted an ATIM frame to the receiver, the packets cannot be sent at once. Therefore, PSM shall allow for longer larger delays as compared to the normal IEEE 802.11.

Furthermore, if the network traffic is heavy, then a sender in PSM cannot inform a receiver of its pending packets by the ATIM frames for an ATIM window, resulting in a declination of throughput. Ad hoc networks in PSM have large end-to-end delays and a degraded throughput. As will be seen from this thesis, we improve the energy efficiency in PSM without degrading throughput.

2.2 Related Works

In the section, we review several existing power management protocols for IEEE 802.11ad hoc networks as following.

2.2.1 Power-Saving Mechanism in Emerging Standards for Wireless LANs: The MAC Level Perspective

Woesner *et al.* [7] presented simulation results for the power saving mechanisms of two wireless LAN standards, IEEE 802.11 and HIPERLAN. It showed the different sizes of beacon intervals and ATIM windows in IEEE 802.11 had a significant impact on throughput and energy consumption. The authors indicate that the ATIM window size should take approximately 1/4 of the beacon interval. However, the effects of load variety is not put much focus on. We can see here that it affects this optimal ratio between the ATIM window and the beacon interval quite significantly.

2.2.2 A power-saving scheduling for IEEE 802.11 mobile ad hoc networks

M. T Liu *et al.* [8] proposed an energy efficiency MAC protocol for IEEE 802.11 networks by scheduling transmission after the ATIM window and adjusting the Beacon

Interval dynamically to adapt to the traffic loads. All stations are required to be able to hear from each other directly. Nodes that overhear ATIM frames will generate a contention-free schedule for data transmission in the rest of the beacon interval, rather than let those nodes that have succeeded to announce in the ATIM window to contend again for the data transmission. With all the information received at each station during the ATIM window, a deterministic scheduling can be generated. This not only eliminates extra contention in the data transmission but also increases the efficiency of power saving.

2.2.3 An energy efficient MAC protocol for IEEE 802.11 WLANs

In [9], Wu *et al.* proposed an energy efficiency MAC protocol for IEEE 802.11 networks by scheduling transmission after the ATIM window and adjusting the ATIM window dynamically to adapt to the traffic Loads. But they did not consider the energy consumption caused by overhearing among neighboring nodes. Nodes schedule those to-be-transmitted data frames after ATIM window. According to a buffered data frame’s duration, nodes determine the transmission order. Data transmission takes place to avoid unnecessary frame collision and backoff time. Besides, nodes adjust the ATIM window dynamically to adapt to the traffic loads.

Chapter 3

Power-Saving MAC Protocol

3.1 Overview

The proposed power-saving MAC is an energy-efficient dynamically-adjustable ATIM window protocol designed for real- and non-real time data broadcasting. Under the proposed protocol, data is transmitted according to a dynamically updated transmission schedule. Each node utilizes prioritized contention based on Enhanced Distributed Channel Access (EDCA) for periodical real-time (CBR Voice) and non-real time (Data) traffic. Each node with real-time (CBR Voice) traffic initializes access to medium is through contention, but once a node reserves transmission time, its reservation time in the subsequent Beacon Interval continues automatically as long as the node continues to broadcast a packet in each Beacon Interval. Thus, nodes need only contend for transmission time at the beginning of Real-time (CBR Voice) traffic bursts in the ATIM window.

Nodes transmitting Real-time (CBR Voice) traffic also require the Reservation Occupation Table maintenance scheme to ensure correct channel utilization. The CBR Voice nodes transmit Beacon messages which carry the Reservation Occupation Table to each network node at the beginning of the ATIM window. Beacon generator handover occurs during the CBR Voice transmission schedule by specifying the new Beacon generator ID.

Figure 2.1 indicates that the fixed lengths of the ATIM window and the beacon interval of IEEE 802.11 ad hoc power saving mode (PSM) often consume excess energy. The inefficiency of the fixed ATIM window size under different traffic loads requires dynamic adjustment of the ATIM window size.

Finally, in the power saving mode (PSM) of IEEE 802.11, nodes that successfully announce ATIM frames stay active during the entire beacon interval. After Data transmission, nodes need not remain active state. After a node finishes Data transmission, the proposed power-saving MAC protocol switches the node from an active state to a sleep state to minimize power consumption. The novel feature of the proposed MAC protocol is the decreased idle time in active state and the switchover times (active-to-sleep state or sleep-to-active state).

The following sub-sections describe these features in more detail.

3.2 Basic Operation

The proposed power-saving MAC protocol matches time-frame duration to the periodic rate of voice packets. Figure 3.1 presents the frame format. Each frame consists of two sub-frames: a ATIM sub-frame and a data transmission sub-frame. The ATIM sub-frame consists of a beacon generation window and a ATIM window. The data transmission sub-frame consists of a CBR Voice window and Data window.

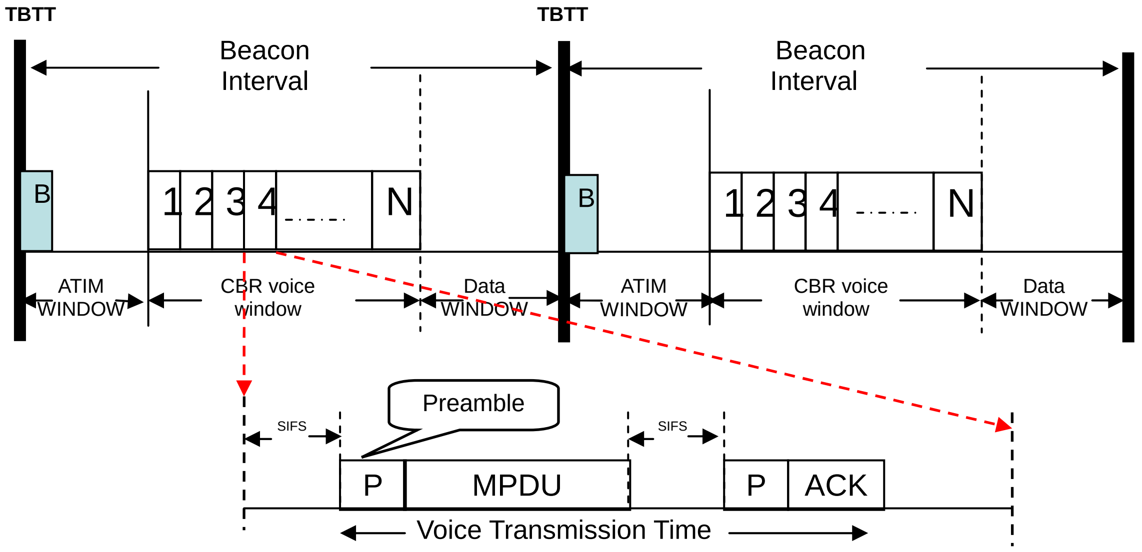


Figure 3.1: Representation of Proposed power-saving MAC frame format

3.2.1 Definition for new management frames in ATIM window

Because the ATIM and ATIM_ACK frame defined in the standard has MAC header, Frame Check Sequence (FCS) and an empty frame body, the standard was slightly modified to include that information in the ATIM and ATIM_ACK frame. A frame body of several octets was added to deliver that information can be easily done and will not affect other operations defined in the standard. Besides, the beacon frame carries the ROC (Reserved OCcupation Table) to indicate Reserved CBR Voice information. The following definitions and frame formats are used in the proposed protocol.

ROC (Reserved OCcupation Table)

- Indicates Reserved CBR Voice information including Source address, Destination address, and Transmission Order
- Beacon Frame carries ROC used by residential nodes

BGS (Beacon Generation Sequence)

- Nodes with reserved CBR Voice must send Beacon with ROC at TBTT in sequence
- The beacon transmission sequence with ROC
  - Every CBR Voice responder attached to Every CBR Voice sender to form the BGS.

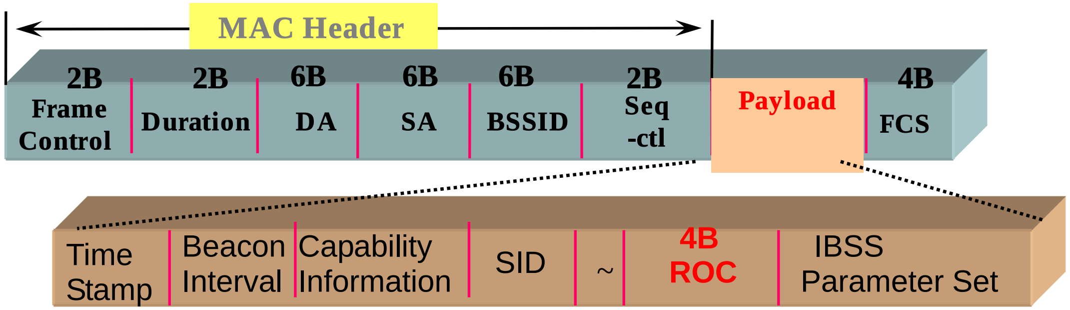
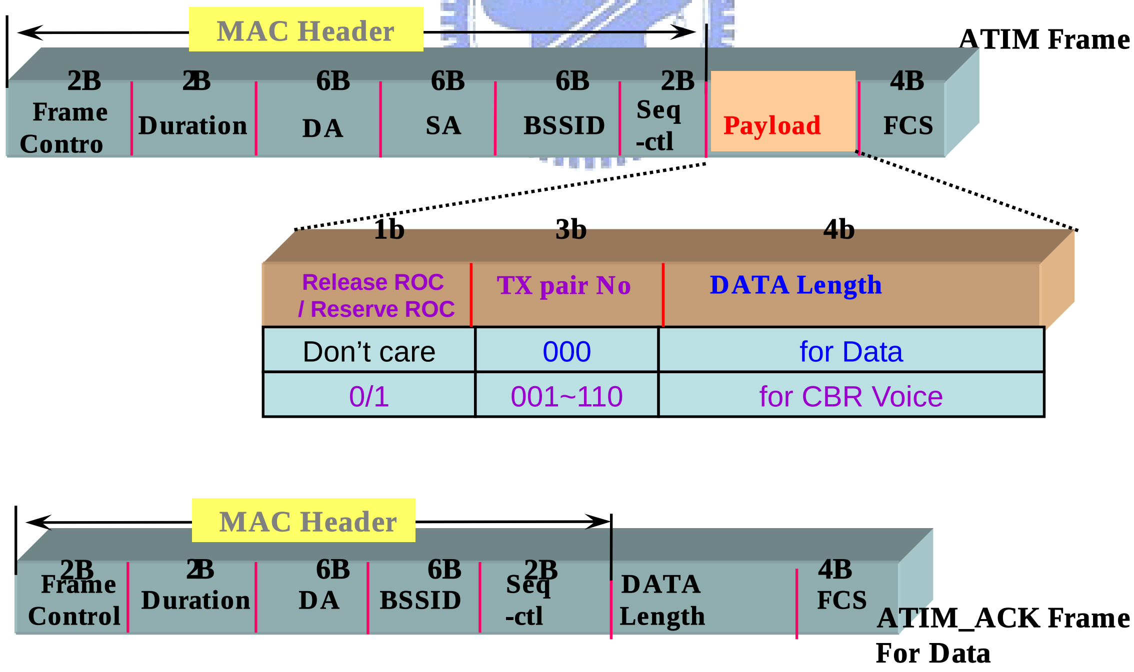


Figure 3.2: Beacon Frame with ROC



Release ROC / Reserve ROC	TX pair No	DATA Length
Don’t care	000	for Data
0/1	001~110	for CBR Voice

Figure 3.3: ATIM and ATIM_ACK Frame for Data

3.2.2 Beacon generation procedure

In the initial startup stage, nodes at TBTT that have no BGS within the Ad Hoc contend to transmit the beacon frame (Fig. 3.4). Each node calculates a random delay uniformly distributed within the range from 1/4 to 2**CWmin***SlotTime* (*CWmin* is the minimum contention window used in the backoff mechanism), then waits for the duration of the delay using the backoff mechanism. When the delay counter expires, the beacon is transmitted with a timestamp, which is a copy of the sender’s local TSF timer of the sender, with some adjustment. Nodes cancel the beacon transmission if a beacon arrives before their random delay counter expires. When a beacon is successfully received, stations set the TSF timer according to the timestamp of the beacon if the value of the timestamp is later than the TSF timer of the station itself in PSM of 802.11. Therefore, the TSF timer can only be adjusted forward. In the proposed protocol, Timers can be set both forward and backward to ensure that all nodes wake up simultaneously.

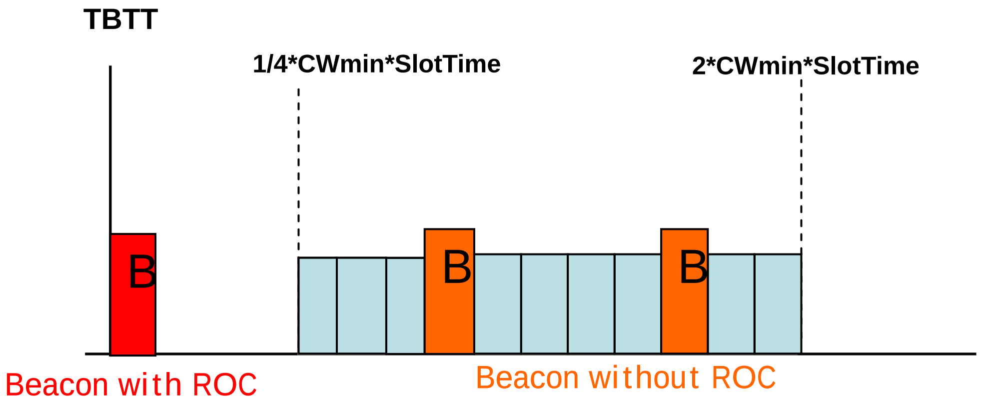


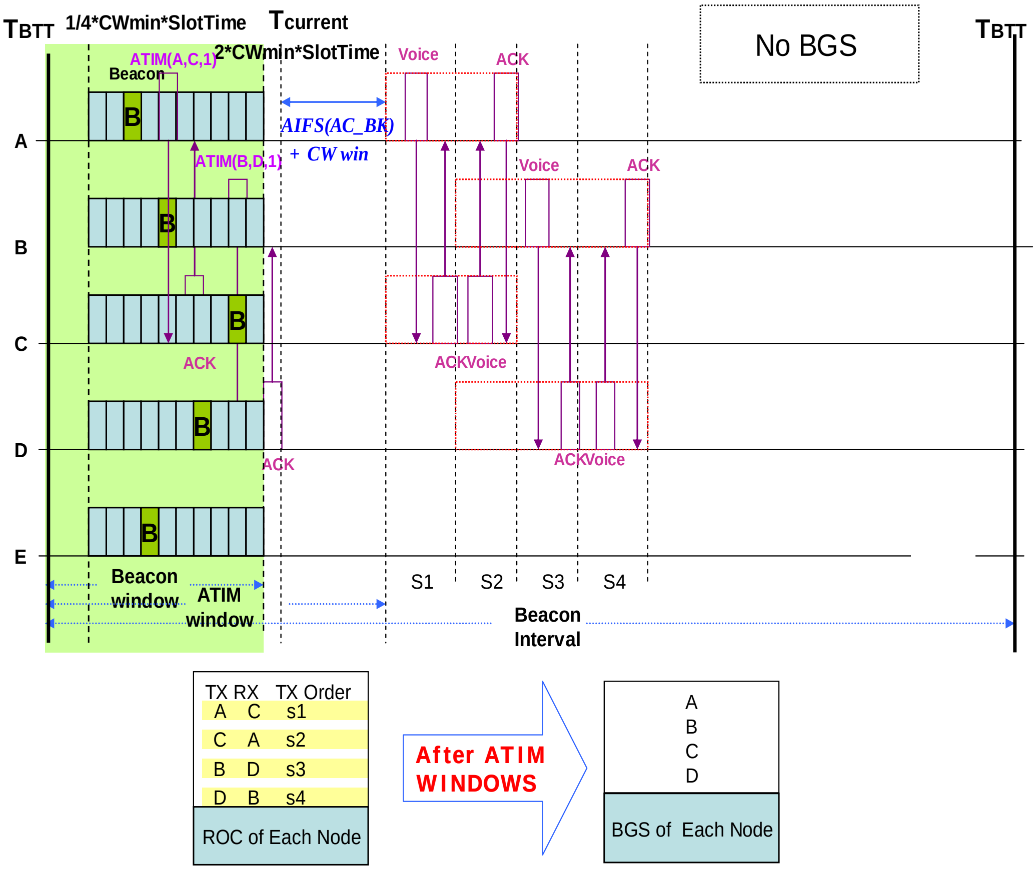
Figure 3.4: Beacon generation Window

As soon as nodes have BGS, those that have reserved bidirectional CBR Voice must send a Beacon with ROC at TBTT in turn. If the Beacon generator node fails, the remaining network nodes should be able to compensate for this situation and should be able to continue normal operation as quickly as possible. The BGS is a more natural and complete way of backing up the beacon generator and it provides a perfect beacon transmission order list of ROC after ATIM exchange. Every CBR Voice responder is attached to CBR Voice sender to form the BGS. Nodes that have reserved CBR Voice can listen for the beacon and become the beacon generator whenever the previous beacon generator fails. The first sender in the sequence is the first generator; the second sender is the second generator; and the senders append the responders. The backup nodes listen to the beacon, which is a part of normal network operation. If the second generator does not hear the beacon for a short interframe space (SIFS) time, then the first generator is assumed dead and the second generator modifies the ROC and transmits the beacon with ROC. If the beacon is not transmitted for two SIFS times, then the third generator understands that both generators are dead. It then modifies ROC and transmits the beacon. If after N SIFS times no beacon is transmitted, then the rest of the nodes understand that No CBR Voice is reserved, and each node calculates a random delay uniformly distributed within the range between 1/4 and 2*CWmin*SlotTime and the transmitted beacon. The Maintenance scheme of Reserved OCcupation Table can be summarized as follows:

- Initially, nodes send ATIM message piggyback Transmission Order (s1, s2) if No

Beacon Generation Sequence (Fig. 3.5).

- If reservation is successful, pair nodes continues to reserve the Transmission in future cycles (Fig. 3.6).
- Finally, nodes send ATIM message and release the piggyback ROC after the conversation is completed or if the partner dies (Fig. 3.7).
- If the pair Nodes suddenly shut down, the other nodes should know the pair nodes have died and modifies ROC.



TX	RX	TX Order
A	C	s1
C	A	s2
B	D	s3
D	B	s4

ROC of Each Node

Figure 3.5: Maintenance scheme of Reserved OCcupation Table (一)

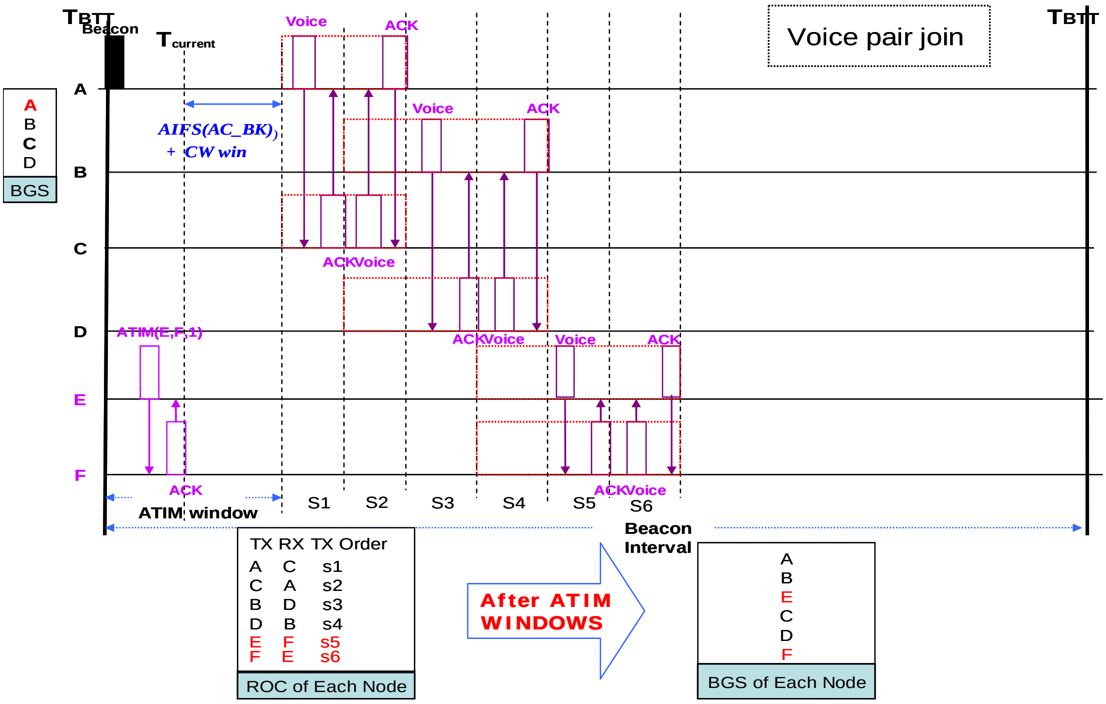


Figure 3.6: Maintenance scheme of Reserved OCcupation Table (二)

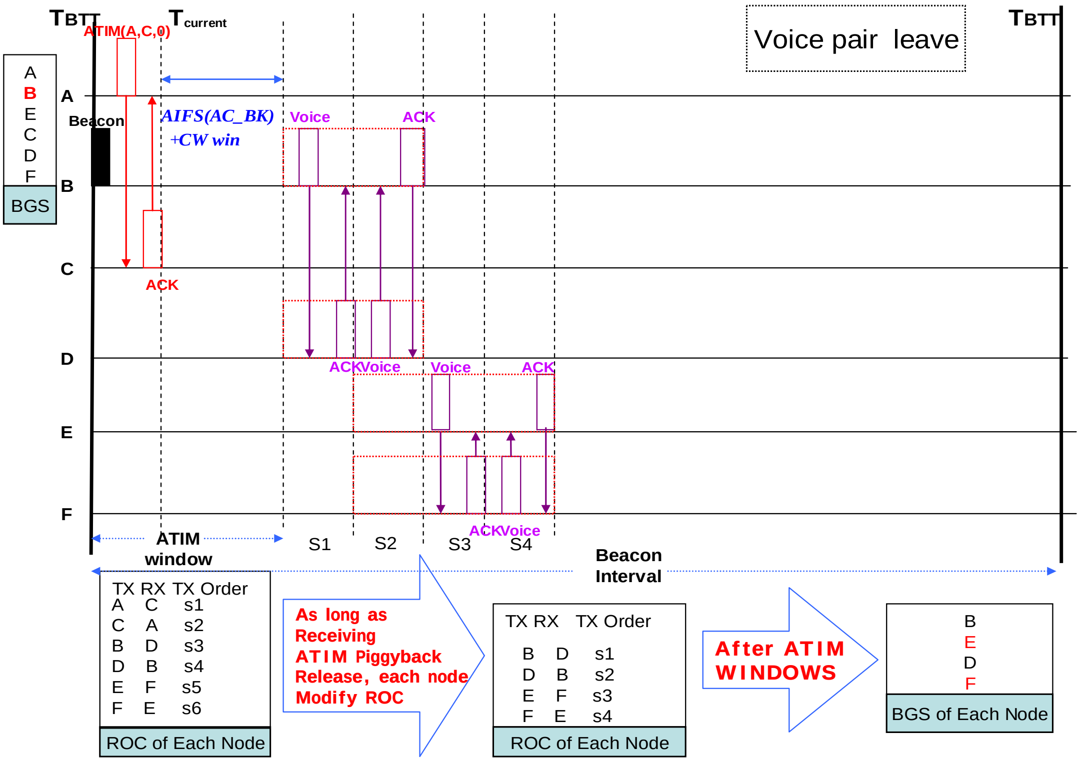


Figure 3.7: Maintenance scheme of Reserved OCcupation Table(三)

3.2.3 ATIM Information Exchange procedure

After the beacon transmission window, nodes enter the ATIM window. For ATIM information exchange, the system piggybacks the number of pending packets of ATIM announcement for Data. The information about the sender, receiver, and length of the pending data are contained in ATIM frame denoted ATIM (Sender ID, Receiver ID, Data Length). The transmission Release/Reservation status of ATIM announcement for CBR Voice is also piggybacked. The information about the sender, receiver, and Release/Reservation status of the CBR Voice traffic is contained in the ATIM frame denoted as ATIM (Sender ID, Receiver ID, TX status). According to IEEE 802.11 regulations, all nodes are fully connected and all PS mode nodes can wake up at almost the same TBTT. At the TBTT, each node wakes up for an ATIM window interval. If a node with buffering Data to a PS mode node, it sends an ATIM frame to the PS mode node within the ATIM window period. Upon receiving the ATIM frame, the PS mode node responds to an ATIM ACK to the sender of the ATIM frame and completes the reservation of the data frame transmissions. If a node with buffering CBR Voice to a PS mode node, it sends an ATIM frame to the PS mode node within the ATIM window period. Upon receiving the ATIM frame, the PS mode node responds with an ATIM ACK to the sender of the ATIM frame and joins the Reservation OCcupation Table (ROC). These pair nodes are not required to send further ATIM frames during the remaining conversation. The exception is if any nodes want to terminate the conversation or if their pair nodes do not respond to with an ATIM ACK to the sender during CBR voice transmission. Due to the broadcast nature of the wireless medium, each node can overhear the ATIM exchange information and get all node transmission tables (Data Length and CBR Voice Transmission Order) as Table 3.1 shows.

TX	RX	Data Length	TX Order
A	C	10B	s1
C	A	15B	s2
D	C	30B	
B	D	20B	s3
D	B		s4
E	B	25B	
C	E	40B	

Table 3.1:Transmission table during ATIM window

Each node employs prioritized contention-based Enhanced Distributed Channel Access (EDCA) as defined in the 802.11e [10]. Each transmission queue has a different interframe space (AIFS) and a different contention window limit. Each node that intends to transmit data calculates its priority according to the collected data profiles. The proposed protocol uses Data and voice traffic only. Nodes adjust the contention window size and AIFS time. The smaller its AIFS, the higher the priority a node can have. Similar protocols apply to the contention window size. Figure 3.8 illustrates the time diagram of EDCA [10]. The 802.11e suggests the use of different AIFS and different contention window limits according to different ACs. Table 3.2 shows the parameters for the maximum contention window (CW_{max}), the minimum contention window(CW_{min})

and AIFS for each AC.

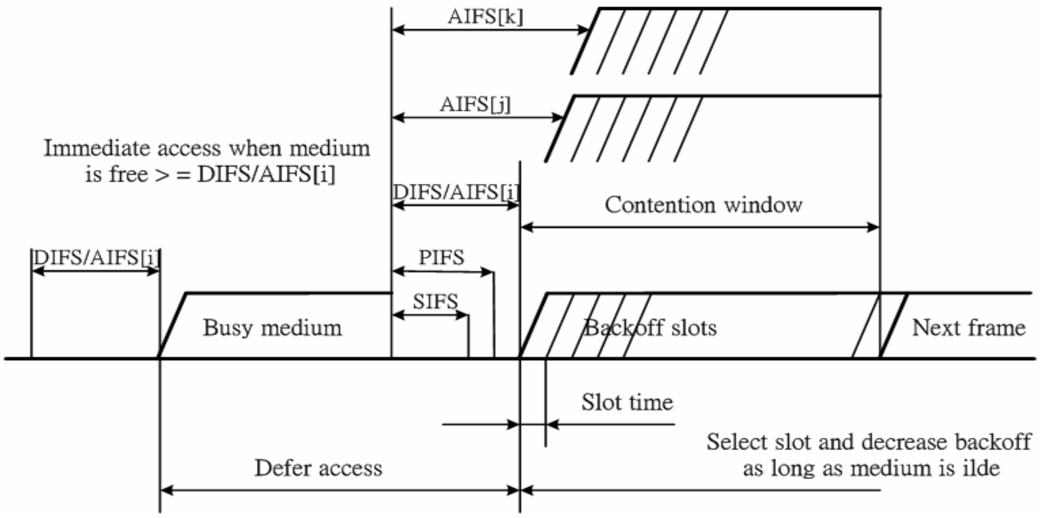


Figure 3.8: The timing diagram of 802.11e EDCA[10]

AC	CW_{min}	CW_{max}	A I
AC_BK	aCW_{min}	aCW_{max}	7
AC_BE	aCW_{min}	aCW_{max}	3
AC_VI	$(aCW_{min}+1)/2$	aCW_{min}	2
AC_VO	$(aCW_{min}+1)/2$	$(aCW_{min}+1)/2$	2

Table 3.2: The default EDCA parameters [10]

The value of AIFS is determined by the following equation (1)[10]:

$$AIFS = AIFSN \times aSlotTime + SIFS \qquad (1)$$

where the value of AIFS Number (AIFSN) is an integer greater than zero and is dependent on each AC.

3.2.4 Traffic-Load oriented ATIM window adjustment

To conserve the power used by PS mode nodes and to improve network throughput, the relationship between the lengths of the ATIM window and the corresponding beacon interval is discussed in [7] as mentioned above. The authors indicated that the ATIM window size should take approximately 1/4 of the beacon interval. The proposed scheme can dynamically adjust the ATIM window according to the channel idle time and the actual traffic load of the network. Each node senses how long the channel is continuously idle during the ATIM window. If nodes sense that the channel is idle longer than *AIFS (AC_BK) + CWmin*, the assumption is that no nodes have buffered frames to send. Besides, if ATIM collision occurs and Remaining Beacon Interval $\geqq$ $\mathrm{TMAX}_{\mathrm{MPDU}}$, nodes could stay awake until no further ATIM collision occurs or remaining Beacon Interval $\leqq$ $\mathrm{TMAX}_{\mathrm{MPDU}}$. Therefore, all nodes can close the ATIM window and enter the data transmission window according to transmission table. The following Fig. 3.9 is the traffic Load-oriented ATIM window adjustment algorithm.

```
In ATIM window
   Uses ATIM and ATIM_ACK with EDCA scheme to reduce collision and
   generate a contention-free transmission table

   Dynamically Adjust ATIM Window Size
{
  While(1)
     {
      R=0      R( Retransmit counter)
      IF ($Remaining\ BI <= T_{SIFS} + T_{FRAME\ Min}$)
      Then AW=(Tcurrent-TBTT) ,Break;
      ELSE Do
                {
                 CW=random [0, Min (CWmin*$2^R$ , CWmax) ].  SlotTime
                 R=R+1
                 }
                While( ATIM collision occur and $Remaining\ BI \geqq TMAX_{MPDU}$) IF
                (Tchannel idle $\geqq AIFS(AC\_BK)$ + CW)
                then    AW=(Tcurrent-TBTT)+ $AIFS(AC\_BK)$ +CW , Break;
     }
  Nodes immediately transmit CBR Voice and Data on schedule
}
```

Figure 3.9: Traffic-Load oriented ATIM window adjustment

3.2.5 Transmission Window operation

At the end of ATIM window, each PS mode node that successfully have finished ATIM exchange during an ATIM window wakes up to transmit its Voice/data packets and then enters a doze state according to its individual transmission order. Each node transmits CBR Voice according to the ROC and transmits data according to the Data transmission scheme.

To minimize the switchover penalty of data transmission, the heuristic algorithm developed by Prof .Tsern-Huei Lee *et al.* is used. The sub-optimum heuristic algorithm that minimizes the number of switchovers from the Doze state to the Awake state is determined based on graph theory. Details of the heuristic algorithm are shown below.

Heuristic Algorithm

Step 1. Set Schedule_List = $\varnothing$.

Step 2. Select a node *n* of graph **G** with minimum degree.

Step 3. Assume that *Neighbor*(*n*) = $\{n_1, n_2, \ldots, n_j\}$ and $deg(n_i) \le deg(n_{i-1})$ for all *i*, $2 \le i \le j$. Append the list of edges (n, n_1), (n, n_2), …, (n, n_j) to Schedule_List and then remove these edges from graph **G**.

Step 4. Remove a node if all edges incident on it are removed.

Step 5. Let **G** denote the resulting graph. Stop the algorithm if graph **G** becomes empty.

Step 6. While node n_j is removed, set n = n_{j-1} till n = n_1.

Step 7. If node n is removed, go to Step 2. Otherwise, go to Step 3.

The scenario in Fig 3.10 below is an example of bidirectional CBR Voice and data transmission operation.

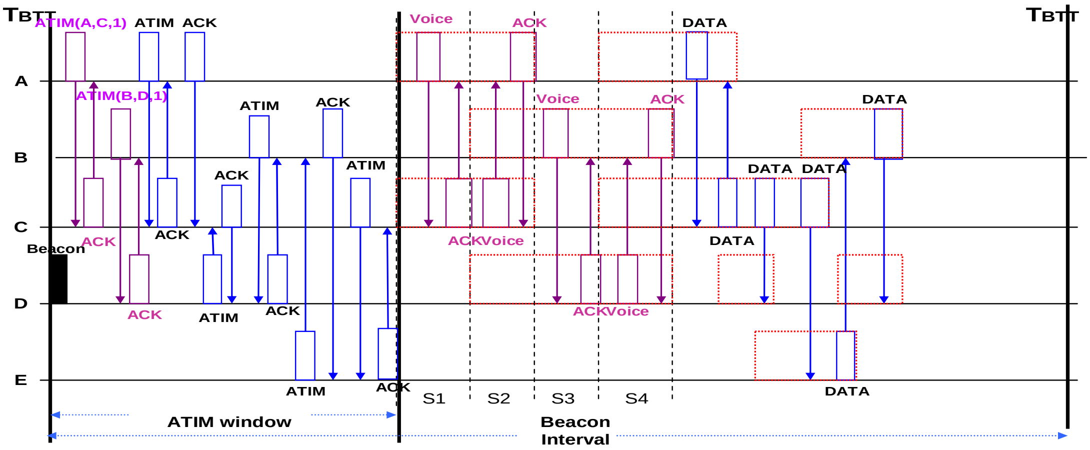
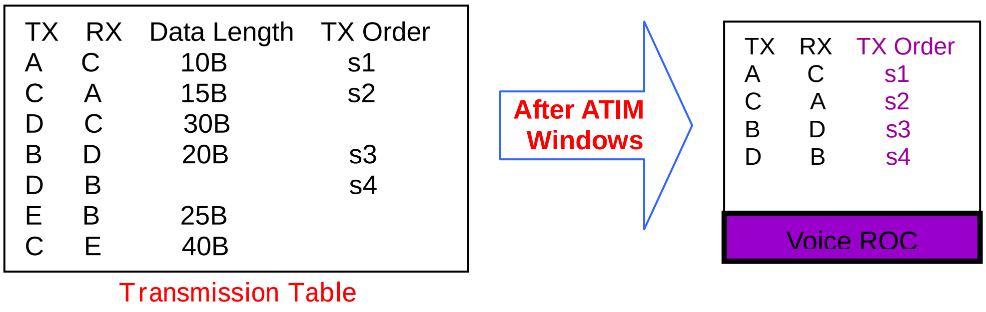


Figure 3.10: Example of our proposed protocol omitted the beacon generation procedure procedure

To simply the presentation, the beacon generation procedure in the previous section is omitted. Five PS mode nodes involved in the ATIM frame transmission are the following: A,B,C,D and E. During the ATIM window, ATIM frames are announced successfully as follows, i.e., ATIM(A, C, 1),ATIM(B, D, 1), ATIM(A, C, 10), ACK(C,A, 15) ,ATIM(D, C, 30),ATIM(B, D, 20), ATIM(E, B, 25),ATIM(C, E, 40). Therefore, at the end of the ATIM window, all network nodes should maintain the transmission table in Tables 3.3 and 3.4 if no transmission errors occur.



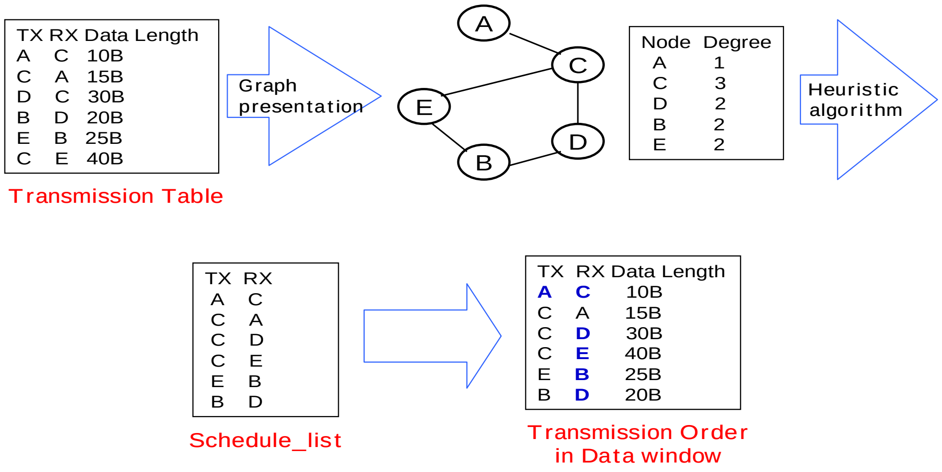
TX	RX	Data Length	TX Order
A	C	10B	s1
C	A	15B	s2
D	C	30B	
B	D	20B	s3
D	B		s4
E	B	25B	
C	E	40B	

Transmission Table

TX	RX	TX Order
A	C	s1
C	A	s2
B	D	s3
D	B	s4

Voice ROC

Table 3.3: Example of bidirectional CBR Voice Table



TX	RX	Data Length
A	C	10B
C	A	15B
D	C	30B
B	D	20B
E	B	25B
C	E	40B

Transmission Table

Node	Degree
A	1
C	3
D	2
B	2
E	2

TX	RX
A	C
C	A
C	D
C	E
E	B
B	D

Schedule_list

TX	RX	Data Length
A	**C**	10B
C	A	15B
C	**D**	30B
C	**E**	40B
E	**B**	25B
B	**D**	20B

Transmission Order in Data window

Table 3.4: Example of Data Transmission Table

After the ATIM window, firstly, nodes with bidirectional CBR Voice transmit voice packet according to ROC. The A and C wait a SIFS time, and A transmits a Voice packet according to ROC and C response ACK frame to A. At the same time, B and D wake up according to ROC. After a SIFS time, C transmits a Voice packet to A according to ROC. The A then sends a response to ACK frame to C. After completing the exchange of bidirectional CBR Voice traffic, A and C go into a doze state. Then B continues to transmit bidirectional CBR Voice to D according to ROC. The D follows the same rule as A and C. After completing the bidirectional CBR Voice transmission, the nodes transmit data based on Data transmission order. At the same time, A and C wake up at the CBR Voice transmission time of D to B and A transmit data frames to C follows the Data transmission order. Other nodes then follow the same rule as A and C. Finally, B and D wake up according to Data transmission order at the transmission time of E to B and transmit their data frames. After completing the Data transmission, B and D enter a doze state until the end of the beacon interval since there is no entry in their transmission table.

This chapter proposes a new protocol for improving throughput and power saving by dynamically adjusting ATIM window length. Nodes are also allowed to stay awake for only a fraction of the beacon interval following the ATIM window. Consequently, more stations can go into sleep mode in the middle of the beacon interval and stay in the sleep mode for a longer duration. Chapter 4 presents the results obtained by simulating the PSM scheme in IEEE 802.11, the proposed protocol, and power-saving mechanism proposed by the M. T Liu *et al.* [8] and the energy efficiency MAC protocol proposed by Wu *et al.* [9] in order to evaluate the performance of the proposed protocol.

Chapter 4

Simulation and Discussion

This chapter describes computer simulations to evaluate the energy conservation performance of the proposed protocol in the last section for an ad hoc wireless LAN consisting of ten to twenty hosts. The assumptions are that all hosts are fully-connected, and no transmission errors have occurred, implying that no packet is lost due to poor quality of the channel, and all protocol can avoid overhearing in data transmission window.

4.1 Simulation Model

For our simulation, C++ is used to implement a simulator The proposed MAC protocol is compared with the original IEEE 802.11 power-saving operation and the M. T Liu *et al.* [8] proposed power-saving mechanism, and the Wu *et al.* [9] proposed energy efficiency MAC protocol. Two traffic types are modeled.

- Only Pure Data
- Pure Data and CBR Voice (6pairs in 10 nodes)

Each simulation was performed 100 times. A 2Mbps channel rate is assumed. To investigate non-real time and real-time traffic over an ad hoc network, two traffic types are considered.

- Pure Data traffic: The arrival rate of data frames from each station is smaller than 10 kbits within 0.1sec. The frame size is 256 bits to 1024 bits long.

- Voice traffic: Voice traffic is usually considered constant bit rate (CBR) traffic. After referring to other voice traffic models [11] , the data rate of voice traffic is set to 64Kbps. The value of maximum tolerance is 20 ms. Voice traffic is assumed to have highest priority, and pure data traffic has the lowest priority. Voice belongs to real-time traffic and has the maximum tolerance delay time. According to the traffic models defined above, Table 4.1 summarizes the traffic parameters of the protocol.

Parameters	Value
Minimum Contention window	31
Maximum Contention window	1024
ATIM window size	5ms
Beacon Period (Voice Delay Bound)	20ms
DIFS	50 us
Beacon window size	0~1240us
SIFS	10us
Slot time	20us
Channel bit rate	2Mbps
Voice coding rate	64Kbps
AC_VO	AIFSN=2,CWmin=3
AC_BK	AIFSN=7,CWmin=15
Doze-to-awake time	800us

Packet Length	Value
Data Frame	256,512,768,1024bits
ATIM Frame	28Bytes
ATIM ACK	22Bytes
PHY Header	128bits
MAC Header	272bits

mode	Energy
Idle	1.15W
Receiving	1.4W
Transmitting	1.65W
Doze	0.045W

Table 4.1: Simulation Parameters

4.2 Performance Measurements

From many papers analysis on energy saving issues, some conditions are required be covered for each performance measurement:

1. Energy goodput: We used this energy goodput define in [12] to evaluate power efficiency.

   $$\text{Eergy goodput} = \frac{\text{TotalBitsTransmitted}}{\text{TotalEnergyConsumed}}$$

   The unit of energy goodput is bits/Joule, this metric measures the amount of data delivered per joule of energy. The higher the energy goodput is, the lower the energy it consumes.

2. Throughput: The throughput is defined the channel rates that can be used to transmit pure frame by all traffics types of stations. The contention cost is excluded from the throughput.

   $$\text{Throughput} = \frac{\text{Frame\_Length} * \text{theAmountofSuccessfulPackets}}{\text{TotalTime}}$$

3. Average Frame Delay: A period of the time from a frame arrives the system to it transmits completely.

4.3 Simulation Results

Figures 4.1 and 4.2 show the Energy goodput (*bits/joule*) for pure data and voice & pure data traffic, respectively. Figure 4.1 shows the Energy goodput for four power-saving protocols with data traffic. When the number of nodes increases, the proposed protocol always achieves better energy goodput than any other protocol because it minimizes switchover time in data transmission window. The protocol consumes less power than other protocols do.

Figure 4.2 illustrates the Energy goodput for power saving protocols with voice & pure data traffic. When the number of voice pairs increases, a node spends less time in doze state because of voice transmission. Because the proposed protocol provides a Voice reserved scheme to reduce contention among the nodes in ATIM window.

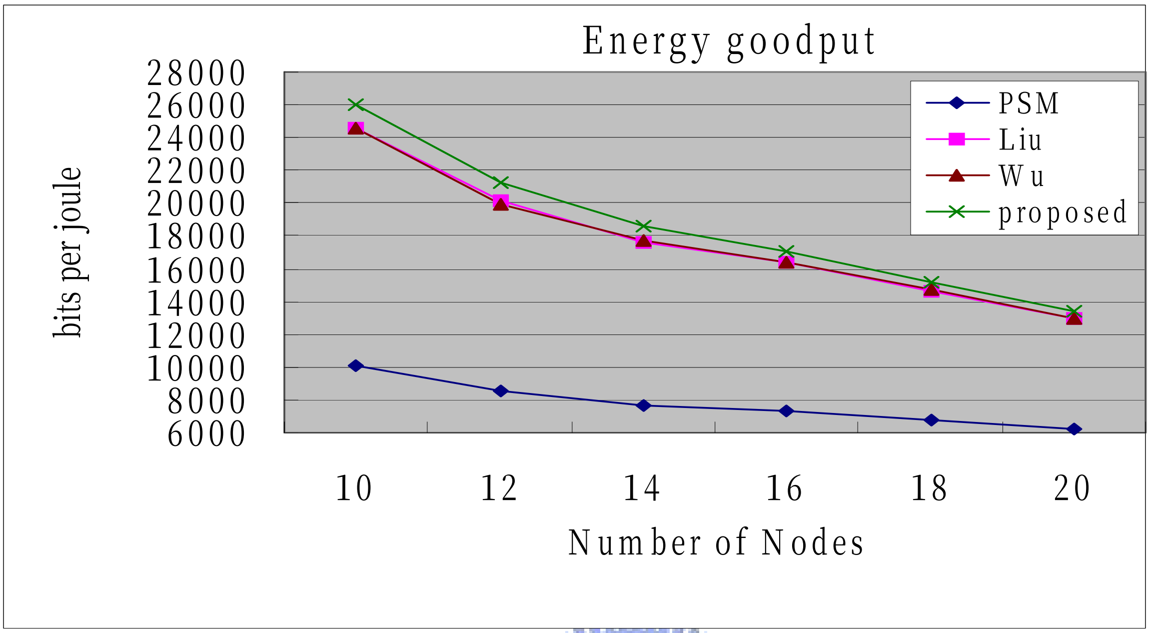


Figure 4.1: Number of Nodes v.s Energy goodput with pure data traffic

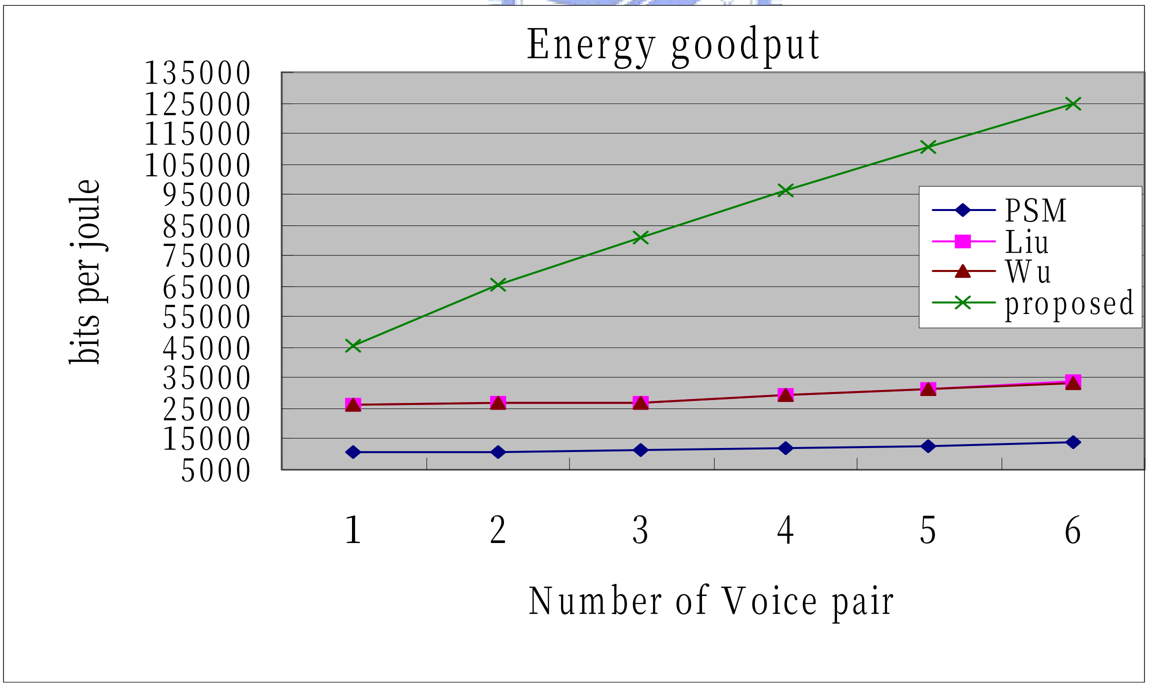


Figure. 4.2: Number of Voice pair v.s Energy goodput with pure data &Voice traffic

Figures 4.3 and 4.4 illustrate the average throughput (bits/sec/node) for pure data and voice & pure data traffic, respectively. Figure 4.3 shows the average throughput for four power saving protocols with data traffic. In the simulation results, PSM with ATIM window size of 5 *ms* may suffer severe throughput degradation . If the ATIM is too small in PSM, time is inadequate to announce ATIM. The Wu protocol and the proposed protocol can achieve higher throughput by choosing a suitable ATIM window with traffic load. Liu also used variable beacon interval to accommodate data announced in ATIM window.

Figure 4.4 illustrates the average throughput for four power saving protocols with voice & pure data traffic. When the number of voice pair increases, the proposed protocol has fine average throughput because it spends less time on contention. Voice traffic can again be reserved to reduce contention among the nodes in ATIM window. The other protocols have no such reserved scheme to avoid contention in ATIM window.

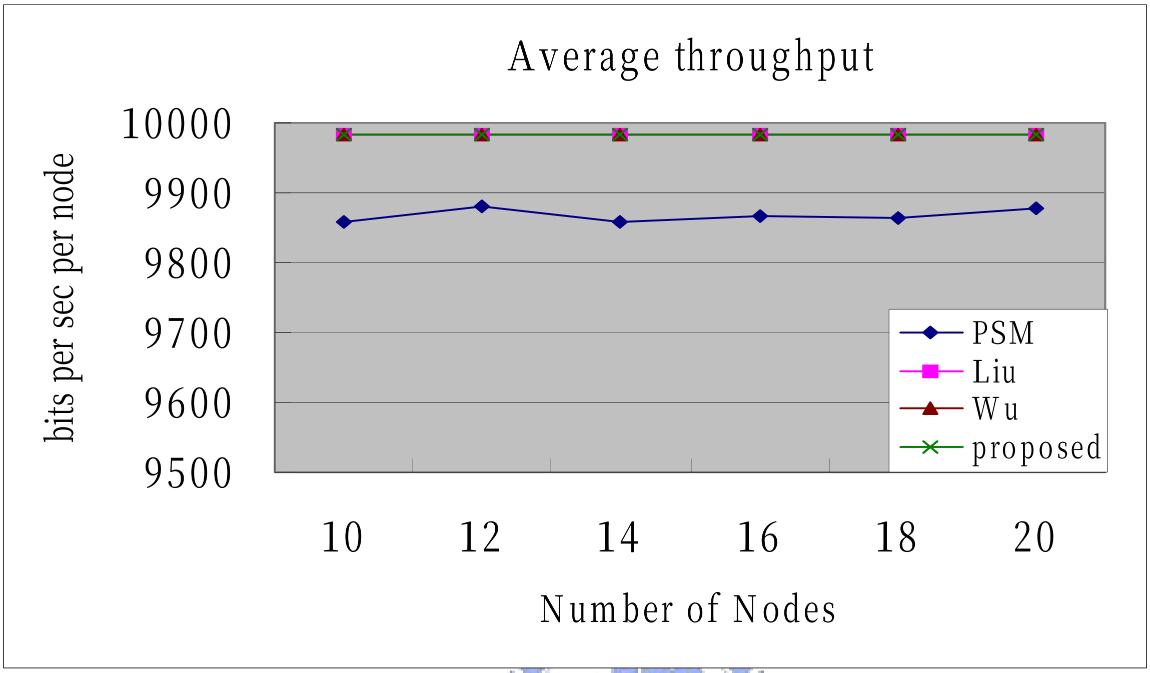


Figure 4.3: Number of Nodes v.s Average throughput with pure data traffic

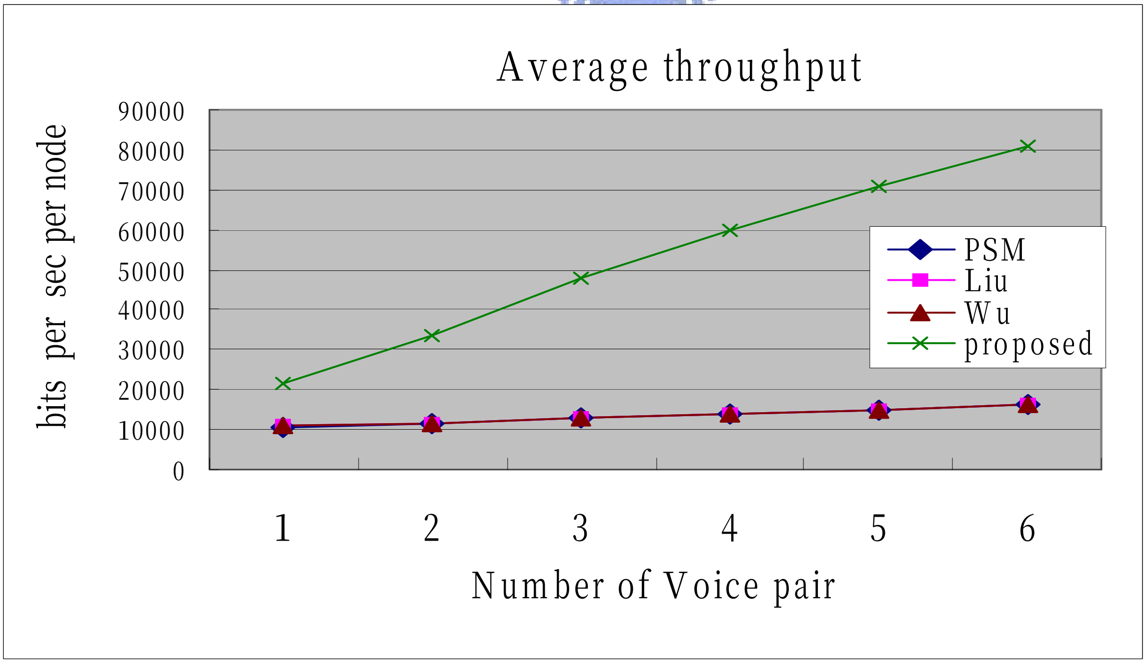


Figure 4.4: Number of Voice pair v.s Average throughput with pure data &Voice traffic

Figures 4.5 and 4.6 illustrate the average delay (msec per packet) for pure data and voice & pure data traffic, respectively. Figure 4.5 shows the average delay for four power saving protocols with data traffic. According to this figure, the PSM reveals a large average delay because it does not have sufficient time to announce the ATIM frame in the current ATIM window and contention in data transmission window. Nodes must retransmit ATIM frames in the next ATIM window, incurring a long average delay.

Figure 4.6 illustrates the average delay for four power saving protocols with voice & pure data traffic. When the number of voice pairs increases, the protocol has better average delay because real time frames have the higher priority than pure data frame and has a reserved scheme to transmit continuously. The other protocols have no such reserved scheme to transmit data continuously.

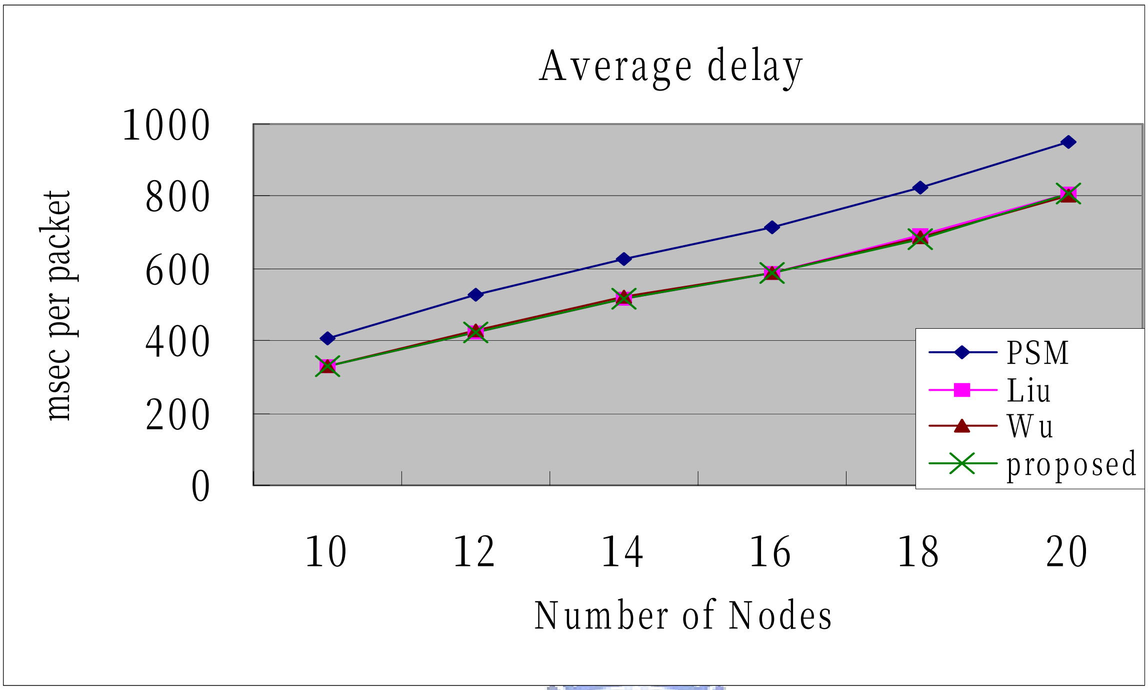


Figure 4.5: Number of Nodes v.s Average Delay with pure data traffic

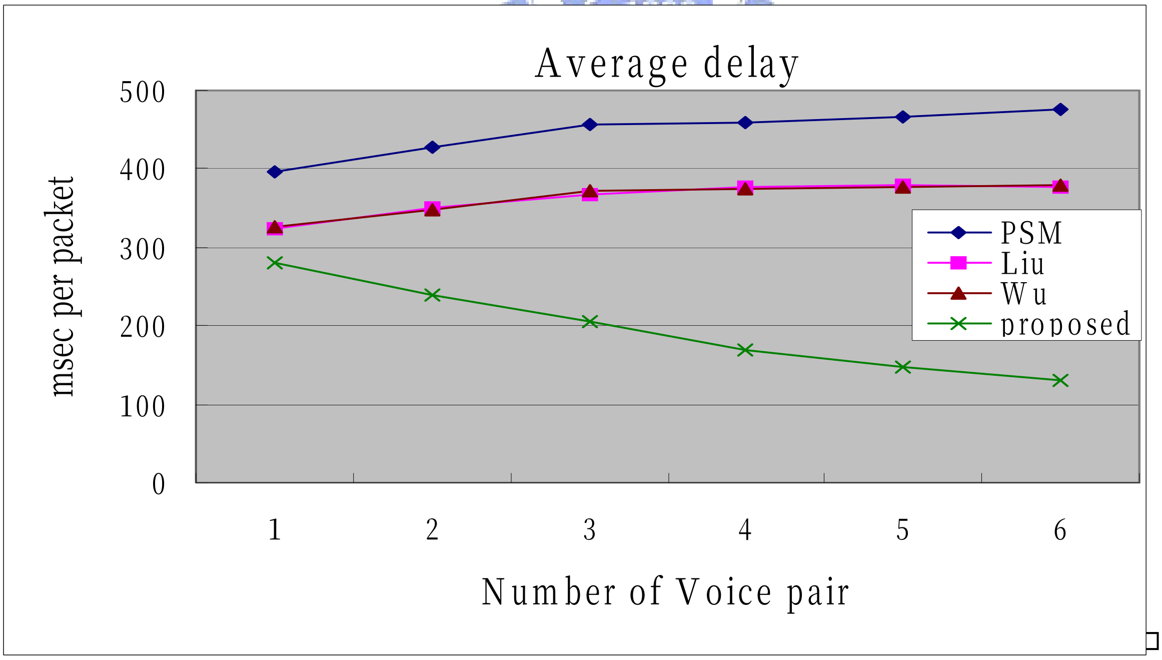


Figure 4.6: Number of Voice pair v.s Average Delay with pure data &Voice traffic

Chapter 5

Conclusion

This thesis presents an energy-efficient MAC protocol to support voice/Data traffics over ad hoc networks. The simulation results also demonstrate that the protocol performs much better than the other protocols with real-time and non-real time traffic.

Data transmission is assumed to be perfect and fully connected. Future studies should consider the transmission error and apply the proposed protocols in a multihop network.

Bibliography

[1] IEEE Std 802.11b, IEEE Standard for Wireless LAN Medium Access Control (MAC) and Physical Layer Specifications: Higher-Speed Physical Extension in the 5GHz Band, 1999.

[2] IEEE Std 802.11a, IEEE Standard for Wireless LAN Medium Access Control (MAC) and Physical Layer Specifications: Higher-Speed Physical Extension in the 2.4 GHz Band, 1999.

[3] J. Gomez, A. T. Campbellm, M. Naghshineh, and C. Bisdikian, 2001, "Conserving transmission power in wireless ad hoc networks," in Proc. Of *IEEE International Conference on Network Protocols*.

[4] Shih Liu Wu, Yu Chee Tseng Jang Ping Sheu "Intelligent medium access for Mobile ad hoc networks with busy tones and power control," *IEEE journal on Selected Areas in Communications*, pp. 1647-1657, Sep. 2001.

[5] E. S. Jung and N. H. Vaidya, "Mediun access control for ad hoc Networks: a Power control MAC protocol for ad hoc networks," in *Proc. ACM MOBICOM*, Sep. 2002, pp. 26-46.

[6] Feeney L.M., and Nilsson M., "Investigating the Energy Consumption of a Wireless Network Interface in an Ad Hoc Networking Environment", INFOCOM 2001.

[7] Hagen Woesner, Jean-PierreEbert, MortenSchlager, andAdam Wolisz, "Power-saving mechanisms in emerging standards for wireless lans : The mac level perspective", IEEE Personal Communications 1998

[8] Ming Liu, and M.T. Liu, " A Power-saving Scheduling for IEEE 802.11 Mobile Ad Hoc Network", ICCNMC 2003. 2003 International Conference on, 20-23 Oct. 2003 Pages:238 – 245

[9]Wu, S.L., Tseng, P.C.: An energy efficient mac protocol for IEEE 802.11 WLANS. In CNSR 2004. (2004) 137–145

[10] IEEE Draft Std 802.11e, Medium Access Control (MAC) Enhancements for

Quality of Service (QoS), D4.4, Jun. 2003

[11] S.-T. Sheu and T.-F. Sheu, DBASE: A Distributed Bandwidth Allocation/ Sharing/Extension Protocol for Multimedia over IEEE 802.11 Ad Hoc Wireless LAN," in Proc. of the IEEE INFOCOM'01., vol. 3, pp. 1558{1567,2001.

[12] Takeuchi S., Yamazaki K., Sezaki K., and Yasuda Y., ”An improved power saving mechanism for MAC protocol in ad hoc networks” , GLOBECOM '04. IEEE