國 立 交 通 大 學

資訊科學與工程研究所

碩 士 論 文

IEEE 802.11e 無線區域網路下針對 VoIP 話務之省電式媒體存取控制機制

A Power Saving MAC Mechanism for VoIP over IEEE 802.11e WLANs

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中 華 民 國 九 十 五 年 六 月

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碩 士 論 文

A Thesis

Submitted to Institute of Computer Science and Engineering

College of Computer Science

National Chiao Tung University

in Partial Fulfillment of the Requirements

for the Degree of

Master

in

Computer Science

June 2006

Hsinchu, Taiwan, Republic of China

中華民國九十五年六月

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摘 要

在近年來的網際網路應用中，網路電話因為具有許多優於傳統電話的特性：低通信成本、高頻寬以及易於創造新的服務，使得它已成為最吸引人的應用之一。然而，當網路電話被應用在無線區域網路的環境時，語音用戶的能源消耗成為了一個關鍵的議題。在本論文中，我們提出了一個在IEEE 802.11e無線區域網路下針對VoIP話務之省電式媒體存取控制機制(PSM-V)。PSM-V的基本概念是在EDCA機制中加入一段免競爭的期間給語音用戶使用。我們利用信標訊框去定期地發佈一個TDMA的存取排程表，使語音用戶能夠遵循。這個存取排程表可以讓語音用戶去避免封包的碰撞和減少語音用戶的閒置時間。模擬結果顯示，我們提出的PSM-V相較於U-APSD方法(包含在IEEE 802.11e標準內)[1]與U-APSD-M方法[2]，在以語音用戶的平均責任週期來評估其能源效率上，分別改善了51%與17%。模擬結果也顯

示，PSM-V相較於U-APSD與U-APSD-M，平均增加了63%與8%的總產量以及減少了34%與20%的平均封包延遲時間。總結來說，PSM-V在其系統容量內，能夠有效改善語音用戶的能源效率，並且能確保話務的產量與延遲效能不會被降低。

關鍵詞：增強型分散式通道存取、能源效率、無線區域網路、媒體存取控制層、省電、網路電話。

A Power Saving MAC Mechanism for VoIP over IEEE 802.11e WLANs

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Abstract

Among recent internet applications, Voice-over-IP (VoIP) is one of the appealing ones due to its advantages over traditional telephony, such as low communication cost, high bandwidth and easy creation of new services. However, when it is applied to wireless local area networks (WLANs), power consumption becomes a critical issue for voice stations (handsets) in the network. In this thesis, we propose a power saving MAC mechanism for VoIP applications (PSM-V) based on the IEEE 802.11e EDCA. The basic idea of PSM-V is adding a contention-free period for voice traffic in the EDCA mechanism. We utilize a beacon frame to periodically announce a TDMA access schedule for voice stations to follow. The access schedule can allow voice stations to avoid voice packet collisions and to reduce station idle time. Simulation results show that the proposed PSM-V improves the energy efficiency of voice stations over the U-APSD approach, which has been included in the IEEE 802.11e standard [1], and the U-APSD-M approach [2] by 51% and 17% in terms of average duty cycle, respectively. The simulation results also show that PSM-V improves the aggregate throughput of voice traffic over U-APSD and U-APSD-M on average by 63% and 8%, and it reduces the average delay of voice traffic over U-APSD and U-APSD-M on average by 34% and 20%. In summary, PSM-V can guarantee that while improving the energy efficiency of voice stations, the throughput and packet delay performance of the voice traffic will not be degraded under the system capacity.

Keywords: EDCA, energy efficiency, IEEE 802.11e, MAC layer, power saving, VoIP.

Acknowledgements

Many people have helped me with this thesis. I deeply appreciate my thesis advisor, Dr. Kuochen Wang, for his intensive advice and instruction. I would like to thank all the classmates in *Mobile Computing and Broadband Networking Laboratory* for their invaluable assistance and suggestions. The support by the NCTU EECS-MediaTek Research Center under Grant Q583 is also grateful acknowledged.

Finally, I thank my Father and Mother for their endless love and support.

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Chapter 1

Introduction

With the trend to minimize component size and the fast development of wireless technology, mobile devices are getting more and more popular in recent years. The increasing use of mobile devices leads to the development of new applications and the versatility of device functionalities. However, improvements on battery capacity are not fast enough to support these changes, which have generated significant research interests in energy efficient design techniques for mobile devices.

Among recent internet applications, VoIP is one of the appealing ones due to its advantages over traditional telephony, such as low communication cost, high bandwidth and easy creation of new services. However, when it is applied to wireless local area networks (WLANs), power consumption becomes a critical issue for voice stations (STAs) (handsets) in the network. We need to consider the VoIP over WLANs case, as there is a trend that new dual-mode handsets will be able to access 3G networks and WLANs complementarily.

A wireless STA can be in one of two different power modes: *active* mode and *sleep* mode. An STA in active mode is fully powered while in sleep mode an STA is not able to transmit or receive. The power consumed in active mode is high compared with that in sleep mode. Therefore, maximizing the time that a wireless STA stays in sleep mode during a voice call is the main goal of energy efficiency. Besides, the system capacity and the QoS of voice traffic are also two important goals while considering the energy efficiency issue. This type of research is classified as wireless network interface cards (WNICs) power states management.

Previous work [4] on voice traffic over WLANs has proposed a scheduling method to guarantee the transmission of voice packets by adapting the power save mode (PSM) of the

WLAN standard [5]. Although the authors claimed that the method is compatible with STAs that turn on the PSM, it did not consider the power consumption issue.

According to the analysis in [6], the authors concluded that the main reasons that greatly decrease the system capacity in VoIP over WLANs applications are the header overhead of voice packets and the inherent inefficiency in the IEEE 802.11 medium access control (MAC) protocol. The authors thus proposed a multiplex-multicast scheme which tries to reduce the packet header overhead. However, the scheme cannot allow PSM to be operated because all the downlink traffic are multiplexed into a single packet before reaching the access point (AP), and all the STAs thus need to be awake all the time, which obviously cannot save energy.

Several mechanisms have been proposed to improve the energy efficiency of the IEEE 802.11 MAC protocol. However, few of them focused on voice traffic over WLANs. [7] dynamically adjusts the ATIM window size in the PSM of IEEE 802.11 ad hoc mode. [8], [9] and [10] focused on the scheduling of transmissions under the PSM of single-hop ad hoc networks. LISP [11] is a method that minimizes the duty cycles of STAs on the route of a transmitted packet under the PSM of multi-hop ad hoc networks. [12] modified the MAC protocol to convert the idle period to the sleep period. [13] achieved power saving by combining consecutive frames into a single frame and gathering their headers.

Recent work that addressed the energy issue for voice traffic over WLANs focused on producing longer WNIC sleep time, i.e. to reduce the duty cycle of voice packet transmissions, by reducing numbers of control packets and contention access [1][2].

In this thesis, we propose a power saving MAC mechanism for VoIP applications (PSM-V) based on the IEEE 802.11e enhanced distributed channel access (EDCA) mechanism. The basic idea of PSM-V is to add a contention-free period for voice traffic in the EDCA mechanism. We utilize a beacon frame to periodically announce a TDMA access schedule for voice stations to follow. The access schedule can allow voice stations to avoid voice packet collisions and to reduce station idle time.

The rest of this thesis is organized as follows. In Chapter 2, we introduce two existing approaches from [1] and [2], and then compare them with our mechanism qualitatively. The proposed power saving MAC mechanism for VoIP applications are described in Chapter 3 in detail. Simulation results using ns-2 [14] are evaluated in Chapter 4. Finally, conclusions and future work are presented in Chapter 5.

Chapter 2

Related Work

2.1 PS-Poll Scheme (PS-Poll) [3]

Before describing two recent approaches of energy efficient voice traffic transmission over WLANs-U-APSD [1] and U-APSD-M [2], we introduce a legacy approach called the PS-Poll scheme, which utilizes PSM operations defined in the IEEE 802.11 standard. Note that U-APSD is an improvement of PS-Poll. First, a STA wakes up to contend the channel if it has uplink data to transmit. The AP then informs the STA of the buffered packet information by an acknowledgement frame. If the AP has buffered packets, the STA will solicit them by sending a PS-Poll packet to the AP, which again needs to contend the channel. After the transmission of the last acknowledgement for the downlink data packet, the STA can go to sleep mode to save energy. The timing diagram of the PS-Poll scheme is shown in Fig. 1(a). In Fig. 1(a), T_{act} and T_s mean the time periods of a STA that are in active mode and in sleep mode, respectively. These two periods form a T_{FI}. T_{FI} in the VoIP scenario means a voice traffic framing interval of the voice codec, i.e. the time interval between two successive voice packets. Besides, CW (contention window) in the figure means the contention access period of a packet transmission.

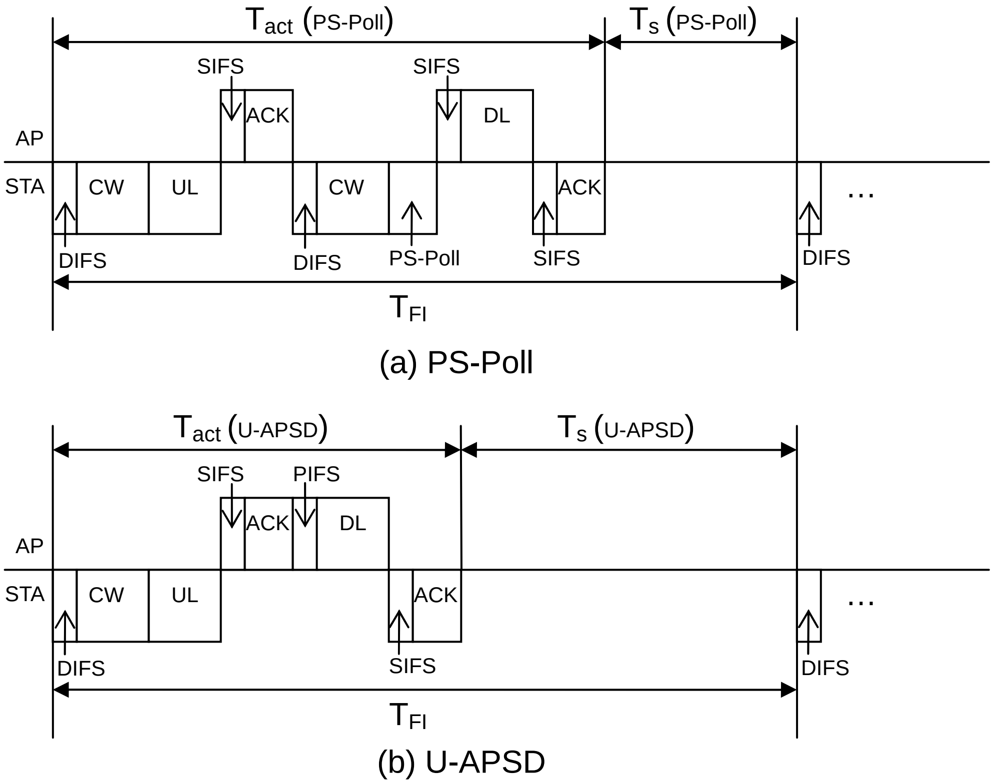

Fig. 1. The timing diagrams of (a) PS-Poll and (b) U-APSD.

2.2 Unscheduled Automatic Power Save Delivery (U-APSD) [1]

The first related work we introduce is from the IEEE 802.11e standard [1]. The method is called unscheduled automatic power save delivery (U-APSD) and was originally proposed in [3]. According to the timing diagram in Fig. 1(b), we can know that this method is an improvement over the PS-Poll scheme that simplifies the PS-Poll procedure. In this method, a buffered packet transmission from AP to STA is triggered by an uplink packet transmission. When the AP receives an uplink packet from a STA, it will automatically send buffered packets to the STA after sending an acknowledgement frame with a set of very high priority parameters. By the parameters, the AP need not contend for medium access. Therefore, this scheme has reduced the contention medium access period and the transmission of a PS-Poll frame. This means that the STA has more sleep time during a framing interval of voice traffic and less MAC overheads, which increases energy efficiency and voice capacity in WLANs.

2.3 Unscheduled Automatic Power Save Delivery-Multicast (U-APSD-M) [2]

U-APSD-M [2] utilizes the characteristic of a multicast packet transmission in WLANs which does not have an associated acknowledgement frame. The authors have applied this characteristic to the U-APSD scheme, called U-APSD-M. Due to the further reduction of control packets, this scheme can achieve better energy efficiency and higher voice capacity than U-APSD.

2.4 Comparison of Existing Approaches

In this section, we compare U-APSD and U-APSD-M with the proposed PSM-V in Table 1 qualitatively. The detailed procedure of PSM-V will be described in Chapter 3. In this comparison, all three approaches are for infrastructure WLANs. This means all the traffic to and from a STA must go through an AP, which is the case in the generic VoIP over WLANs system architecture. The detailed system architecture will be described in Chapter 3. U-APSD reduces some overheads introduced by the PS-Poll procedure to allow more sleep time and to increase system capacity. U-APSD-M further improves U-APSD by using multicast in WLANs. PSM-V, like the other two approaches, is based on the IEEE 802.11e EDCA mechanism, but it adds a contention free period for voice STAs in each beacon interval. In this period, by TDMA scheduling, PSM-V can guarantee voice traffic delivery by avoiding voice packet collisions, and increase voice STA sleep time and voice capacity. The voice stations in PSM-V require the least power consumption among the three approaches, which will be detailed in Chapter 4.

Table 1 Comparison of existing approaches

Approach	U-APSD [1]	U-APSD-M [2]	PSM-V
Wireless network architecture	Infrastructure	Infrastructure	Infrastructure
MAC layer	EDCA-based	EDCA-based	EDCA-based with contention free scheduling
Main idea	Reduce overheads introduced by the PS-Poll procedure during a voice traffic framing interval	Reduce acknowledgement frames by using multicast in WLANs to transmit voice packets	Form a contention free schedule in each beacon interval for voice traffic
Advantage	Increase voice STA sleep time and voice capacity	Increase voice STA sleep time and voice capacity	Guarantee voice traffic delivery by avoiding voice packet collisions, and increase voice STA sleep time and voice capacity
Power consumption	High	Medium	Low

Chapter 3
Design Approach

3.1 System Architecture

In the IEEE 802.11 standard, WLANs can be classified into two types of basic service sets (BSSs), i.e. *independent BSS* and *infrastructure BSS*. The main difference between these two is that STAs in an infrastructure BSS do not communicate with each other directly; i.e. all traffic to and from a STA must go through an AP, which is not necessary in an independent BSS.

Our work focuses on infrastructure BSSs, which is a generic VoIP over WLANs system architecture, as shown in Fig. 2. We assume that all voice sessions are between STAs in different BSSs, because VoIP users seldom call to persons who are in the same BSS. In a BSS, each voice session consists of two traffic streams: the uplink stream and the downlink stream. Therefore, bi-directional voice traffic will be transmitted when voice sessions are established. In Fig. 2, each voice STA runs a VoIP application and connects to the Internet via an AP. Routers route packets from the WLAN to the Internet. In this manner, voice STAs can communicate with their peer nodes located at the other end.

Our MAC layer protocol is based on the IEEE 802.11e EDCA mechanism. This mechanism categorizes the traffic into four access categories, each with a different access priority, by giving different set of contention parameters. So the AP can distinguish voice STAs from data STAs. The reasons that we did not realize our design on the IEEE 802.11e Hybrid Coordination Function (HCF) is as follows. Like the point coordination function (PCF) defined in the IEEE 802.11 standard, the HCF also defines a contention-free period in which STAs can have contention-free transmissions. However, this kind of contention-free transmission is solely initiated by the AP via polling; STAs in a WLAN only respond passively when the AP polls them. This kind of design is considered not efficient, and is complex to implement in commercial products. Moreover, we think that the EDCA mechanism is more flexible to adapt due to its distributed characteristic.

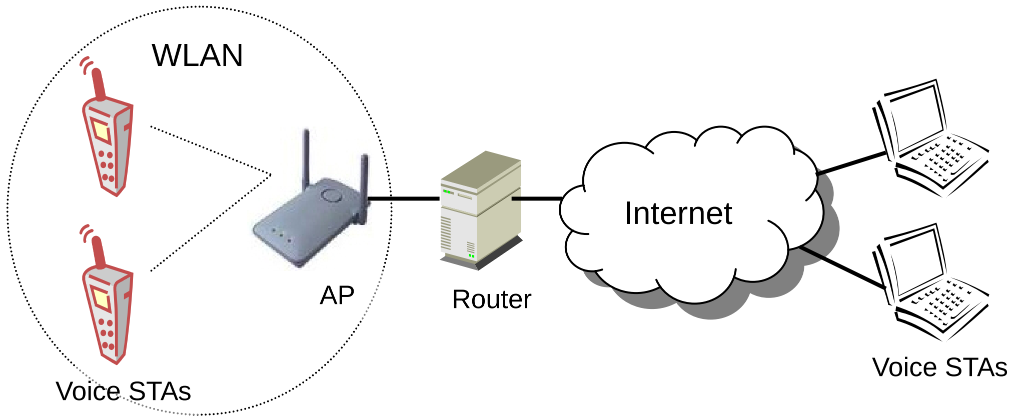

Fig. 2. Generic VoIP over WLANs system architecture.

3.2 Proposed PSM-V

We propose a power saving MAC mechanism for VoIP over IEEE 802.11e WLANs (PSM-V). The basic concept of the proposed PSM-V is adding a contention-free period for voice traffic in the EDCA mechanism. We utilize the beacon frame of the IEEE 802.11 MAC protocol. By sending the schedule information in each beacon frame, the AP can periodically broadcast a contention-free access schedule for voice STAs to follow. A TDMA access schedule can be formed to avoid voice packet collisions and to reduce STA idle time. Therefore, it is expected that PSM-V can save energy of the voice terminals efficiently, which will be verified in the simulation (Chapter 4). The scheme is illustrated in Fig. 3.

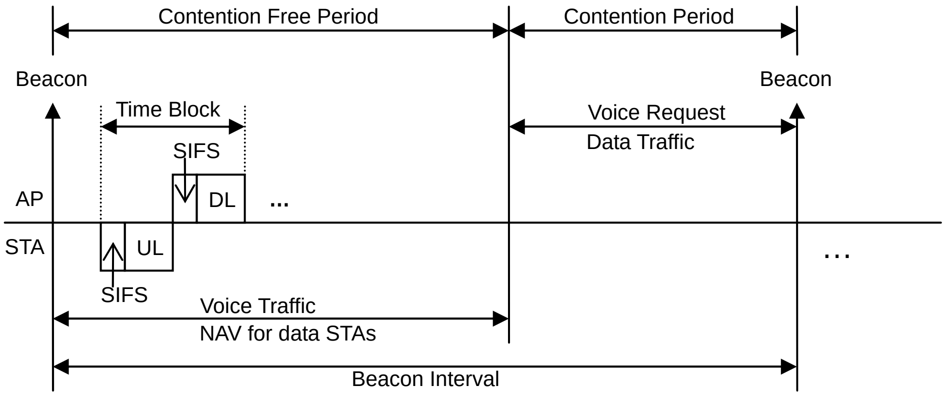

Fig. 3. Power saving mechanism in PSM-V.

As shown in Fig. 3, the AP periodically sends a beacon frame. Between two beacon frames, it forms a time period called a beacon interval (BI). We set the length of a BI to be the length of a framing interval of voice traffic. At the start of each BI, all the STAs awake and receive a beacon frame. In the beacon frame, the AP maintains an access schedule for voice STAs to follow in the following *contention free period* (CFP).

The CFP is achieved by setting the network allocation vectors (NAVs) of all data STAs. This means that only the voice STAs and the AP can access the medium during the CFP. The length of NAV is announced by a beacon frame, since the AP can know the length of each schedule. After receiving a beacon frame, each voice STA checks the schedule to see if it is scheduled at the following CFP and decides what to do next.

In Fig. 3, we can also see that there is a *contention period* (CP) after the CFP. In this period, those voice STAs that are not scheduled in the current CFP but want to transmit packets will contend with the uplink and downlink data traffic of data STAs based on the IEEE 802.11e EDCA mechanism. Here a voice STA sends an uplink *voice request* with the voice traffic priority to the AP, and the AP replies an acknowledgement frame to confirm this request. A voice request packet in our mechanism is defined as a packet that has the same format as a voice packet. It is used to ask the AP to schedule the sender of this request in the next CFP.

Before the CFP, the AP determines a schedule according to the voice requests received in the previous CP and the current packet queue status of the AP. In Fig. 3, the front part of the BI is a CFP for voice traffic. This is to guarantee the QoS of the real-time voice traffic. In the CFP, each STA that is included in the schedule will be allocated a time period called a *Time Block* (TB). In each TB, only the corresponding voice STA is allowed to transmit or receive packets, and the other voice STAs will be in sleep mode. Besides, each scheduled voice STA will be in sleep mode during the CP. From the above description, we can see that the length of a schedule, i.e. the CFP length, is calculated by summing up the length of all allocated TBs. Therefore, the start time of the CP can be known by all STAs.

By this time division multiple access (TDMA) scheduling method, PSM-V can avoid voice packet collisions and reduce STA idle time. All voice STAs need not go through the contention period during the voice transmissions except the voice request transmission mentioned earlier, so they can make their WNICs in sleep mode longer. Besides, in Fig. 3, the TB for voice traffic is formed by an uplink packet followed by a downlink packet without acknowledgement frames. This is because both the voice STA and the AP are aware of when to send packets and because the real-time voice traffic can tolerate packet loss. This kind of transmission can enhance the MAC efficiency and decrease the duty cycle of voice STAs. Therefore, we can see that the proposed PSM-V can decrease power consumption of the voice STAs and increase VoIP system capacity.

Based on the characteristics of VoIP applications, i.e. bi-directional and continuous voice traffic across voice packet framing intervals, in a TB, an uplink packet followed by a downlink packet are transmitted. A TB will be allocated to a voice STA in the current BI automatically when the STA has been allocated a TB in the previous BI. Using this scheme, the voice STAs do not need to send voice requests in each interval; thus it reduces the overhead and make more room for data traffic to be transmitted in the CP. However, if a scheduled voice STA does not involve in any traffic for a time period longer than two BIs, the AP will remove the STA from the schedule. We illustrate the PSM-V operation flow in Fig. 4.

The feasibility of applying PSM-V to the current WLANs system is described below. We can let PSM-V be an optional mode in the MAC protocol. The AP and STAs can decide whether to use this mode or not when establishing a connection of voice flow. Therefore, MAC software updates both in the AP and STAs are required for PSM-V.

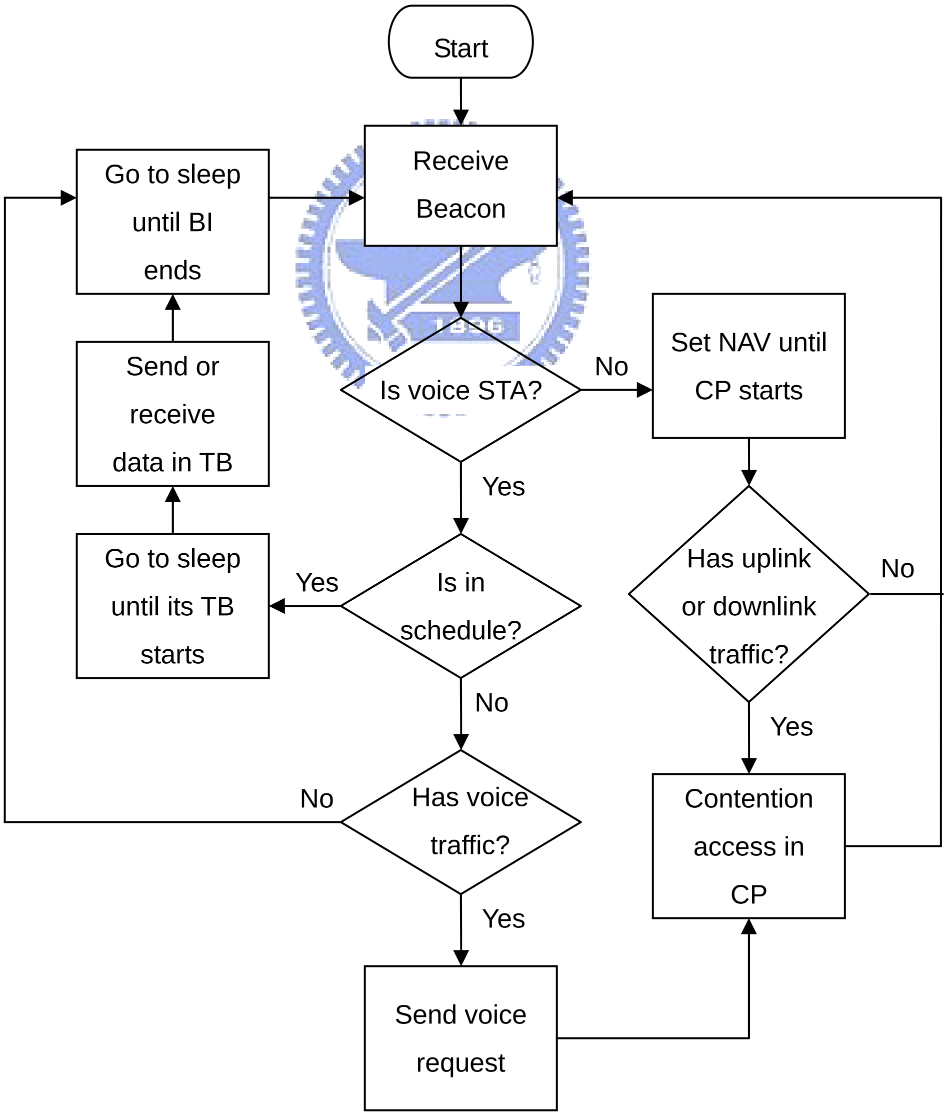

Fig. 4. PSM-V operation flow.

Chapter 4

Simulation and Discussion

4.1 Simulation Model

To evaluate the performance of our PSM-V approach, we have implemented PSM-V and the other two existing approaches, i.e. U-APSD and U-APSD-M, by modifying the source codes of ns-2. In the simulation, the BI length is set to 20 ms, which is equal to the voice traffic framing interval of the adopted voice codec, i.e. G.711. All voice STAs are under an AP, and are transmitting bi-directional constant bit rate traffic to their peer node outside the AP range. Other simulation parameters are listed in Table 2. AIFS, CW_{min} and CW_{max} are key parameters for EDCA to differentiate different traffic priorities. We set these values according to [3] for U-APSD and U-APSD-M. Voice traffic in PSM-V does not use these parameters except the voice request packet. Warmup time is defined as the amount of time that a STA requires to transit from sleep mode to active mode and the value is also from [3]. The length of a TB period is set to 0.905 ms; this value is calculated according to the link speed of WLANs and the size of a voice packet.

Table 2 Simulation parameters

Parameters	Value
Protocol	IEEE 802.11e
Link speed	6 Mbps data rate, 1 Mbps basic rate
SIFS / Slot time	10 μs / 20 μs
AIFS / CW_{min} / CW_{max} for voice	PIFS (30 μs) / 3 / 7 (uplink) PIFS / 0 / 0 (downlink)
Voice model	G.711 codec, bi-directional constant bit rate
Voice codec (G.711)	64 Kbps bit rate, 20 ms framing interval, 160 bytes payload size
Warmup time	1 ms
TB period	0.905 ms

4.2 Simulation Results and Discussion

Fig. 5 shows the average duty cycle (%) of voice STAs for the three approaches. Duty cycle is defined as the percentage of time that a STA is in active mode, having most of the transceiver ICs active, consuming a significant amount of power [3]. A STA is in active mode when it is transmitting, receiving, sensing, or warming-up. In sleep mode, a STA is in a low-power mode and requires a small amount of power to keep the reference oscillator and associated circuits running. In Fig. 5, PSM-V required the lowest duty cycle regardless of loading, while U-APSD had the highest duty cycle. This is because that PSM-V eliminates the contention access of voice STAs and decreases the number of frame exchanges in any given 20 ms BI. Besides, U-APSD-M still requires contention access for voice traffic, so its performance is between that of the other two methods. In PSM-V, once a voice STA is scheduled by the AP, the time period (i.e. a TB period) that the STA needs to be in active mode will be the same during each BI. This is why the average duty cycles of PSM-V are almost the same regardless of the number of voice STAs. PSM-V improves energy efficiency of voice STAs over U-APSD and U-APSD-M by 51% and 17% in terms of average duty cycle, respectively.

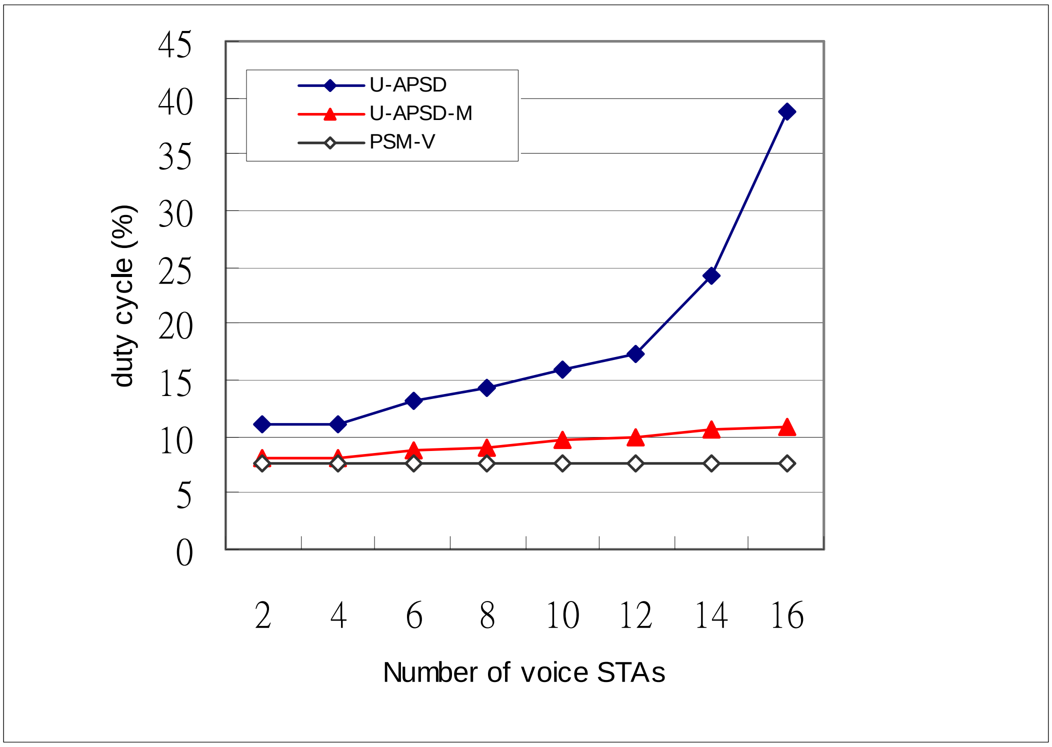

Fig. 5. Average duty cycle of voice STAs

Fig. 6 shows the aggregate throughput (Kbps) of the voice traffic for the three approaches. In the figure, the aggregate throughput of PSM-V grows stably with the increase of voice STAs. Unlike the other two methods, the throughput of each STA does not degrade when the number of voice STAs in the network increases. This is because that PSM-V guarantees every scheduled voice STA a time period, i.e. a TB, to send or receive packets in a contention free manner. However, the throughput of PSM-V will reach a limit when voice traffic approaches the system capacity. This is because the maximum length of the TDMA access schedule will not exceed the length of a BI. The aggregate throughput of PSM-V over that of U-APSD and U-APSD-M are 63% and 8% better, respectively.

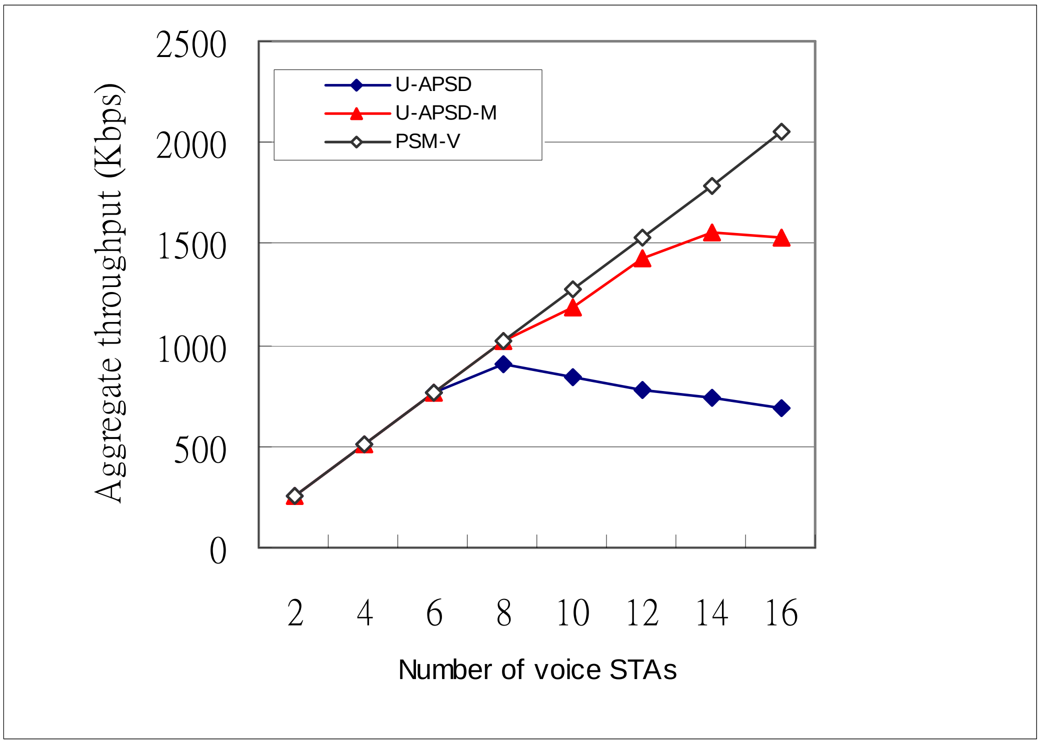

Fig. 6. Aggregate throughput of voice STAs

The average delay (ms) of voice packets is shown in Fig. 7. The delay value here includes the voice packet framing interval, propagation delay in the air, and the queuing delay caused by contention access. Due to our contention free access design, in Fig. 7 the average packet delay of the scheduled voice STAs is equal to the voice packet framing interval. This proves that the proposed PSM-V can eliminate contentions for voice STAs. The low delay is required for real-time traffic, like VoIP traffic. On the other hand, both U-APSD and U-APSD-M both require the contention access and the former further has the MAC overhead of acknowledgement frames. The average delay of PSM-V over that of U-APSD and U-APSD-M are 34% and 20% less, respectively.

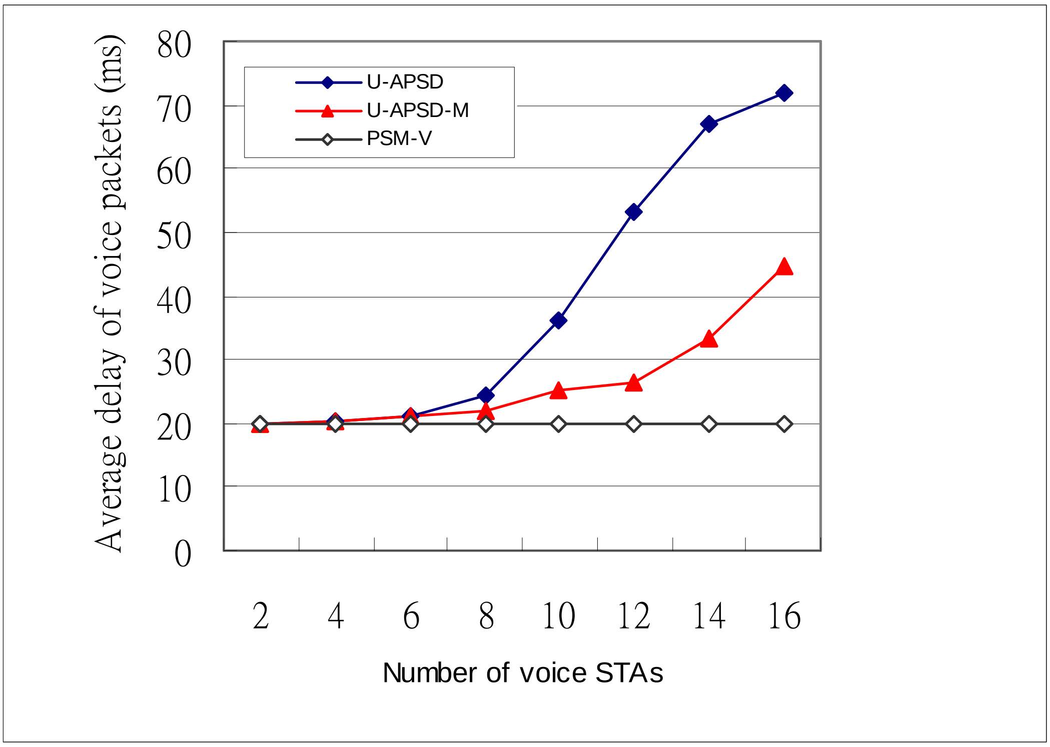

Fig. 7. Average delay of voice packets

Chapter 5

Conclusions and Future Work

5.1 Concluding Remarks

We have presented a power saving MAC mechanism for VoIP applications (PSM-V) based on the IEEE 802.11e EDCA mechanism. Energy efficiency of voice STAs is achieved by eliminating voice packet collisions from contention access and by reducing unnecessary voice STA idle time. In PSM-V, the basic idea is forming a contention-free period for voice traffic inside the BI of the EDCA mechanism. We used a beacon frame to carry scheduling information for voice STAs to follow in each BI. And a TDMA access schedule is formed for voice STAs to access the medium in a contention-free manner. Simulation results have shown that the proposed PSM-V improves the energy efficiency of voice stations over the U-APSD approach and the U-APSD-M approach by 51% and 17% in terms of average duty cycle, respectively. The simulation results have also shown that PSM-V improves the aggregate throughput of voice traffic over U-APSD and U-APSD-M on average by 63% and 8%, and it reduces the average delay of voice traffic over U-APSD and U-APSD-M on average by 34% and 20%. In summary, PSM-V can guarantee that while improving the energy efficiency of voice stations, the throughput and packet delay performance of the voice traffic will not be degraded under the system capacity.

5.2 Future Work

In PSM-V, the length of a BI is set according to the voice traffic framing interval. However, different voice codecs have different framing intervals. The variation of framing intervals can affect the system capacity of voice traffic and the performance of data traffic. Besides, the number of time blocks (TBs) in PSM-V should have a limit. This adjustable limit makes the performance between voice traffic and data traffic a trade-off. The future work is to take these issues into consideration in order to further investigate the performance of PSM-V.

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