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 話務之高能源效率媒體存取控制協定

A Power-Efficient MAC Protocol for VoIP Traffic over IEEE 802.11e WLANs

研究生：呂幸妤

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中華民國 九十五 年六月

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摘 要

在無線網路環境下對於 VoIP 攜帶式裝置，如何節省能源是一個重要的問題。在本論文中，我們提出了一個與 IEEE 802.11e 相容的高能源效率媒體存取控制協定(PEP)去改進原有的 ODP 機制。在 ODP 機制裡，當基地台收到連續兩個 QoS Null 訊框，就會將其對應的語音用戶站從輪詢表中移除。PEP 機制結合 HCF 中輪詢機制(HCCA)和競爭機制(EDCA)。基地台動態地維持輪詢表。我們假設在輪詢表中的所有語音用戶站皆是處於主動模式。當語音用戶站傳送 Null 訊框裡的貯列大小值為零，並且仍有剩下的 TXOP 時，其語音用戶站會被視為進入寂靜模式，此語音用戶站將會自輪詢表中被移除。此語音用戶站可在 EDCA 競爭週期裡尋求再加入到輪詢表中。為了增加預測語音用戶站進入寂靜模式的準確性，在 PEP 機制裡加入

了一個評估 TXOP 利用率的啟發式方法。模擬結果顯示關於能源消耗方面，在沒有犧牲網路產量的情況下，PEP 機制比 RRP 和 ODP 機制分別節省了 24.5%到 37.1%和 12.9%到 15.1%的能源。

關鍵詞： 混合協調機制，無線區域網路，媒體存取層協定，能源效率，網路電話。

A Power-Efficient MAC Protocol for VoIP Traffic over IEEE 802.11e WLANs

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Abstract

Power saving is a critical issue for VoIP over WLANs, especially when using handheld devices. In this thesis, we present an IEEE 802.11e compatible power-efficient MAC protocol to improve the on-demand polling (ODP) scheme. In the ODP scheme, if two consecutive QoS Null frames are received by a QoS AP (QAP), the corresponding QoS station (QSTA) will be removed from the polling list. The proposed *Power-Efficient Polling* (PEP) scheme uses both the polling-based (HCCA) and contention-based (EDCA) channel access over the hybrid coordination function (HCF) mechanism. A QAP maintains a polling list dynamically. All QSTAs in the polling list are assured active. When a QSTA sends a NULL frame with a queue size of zero and the allocated transmission opportunity (TXOP) is not used up, the QSTA will be regarded as entering the silence period. The QSTA will be removed from the polling list. The QSTA can join the polling list again during the contention-based period of EDCA. In order to increase the prediction accuracy of a QSTA entering the silence period, a heuristic method to evaluate the utilization of allocated TXOP is added to the PEP scheme. Simulation results show that the PEP scheme in terms of normalized power consumption outperforms the RR and ODP schemes from 24.5% to 37.1% and 12.9% to 15.1%, without sacrificing the throughput.

Keywords: HCF, IEEE 802.11e, MAC protocol, power efficient, VoIP.

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Chapter 1

Introduction

IEEE 802.11 wireless LANs (WLANs) provide broadband wireless access. The applications of WLANs to provide network connectivity to portable or mobile devices include best effort services such as FTP and email, and real time services such as voice or video services. In order to guarantee the quality of real time services, the WLAN has to support the QoS requirements of end users. In recent years, Voice over IP (VoIP) is gaining a lot of popularity and it allows users to make telephone calls using a computer network like the Internet. As many VoIP clients for mobile handheld devices, such as PDAs, are becoming available, VoIP over IEEE 802.11 WLANs will spread very rapidly. Because mobile handheld devices use batteries which have limited power capacity, minimizing power consumption is an important issue when considering VoIP over IEEE 802.11 WLANs.

1.1 Overview of IEEE 802.11

IEEE 802.11 is the most widely used standard for WLANs. It specifies two operation modes：(1) the infrastructure and (2) the ad hoc, which are shown in Fig. 1. In the infrastructure mode, when a station wants to communicate with others, it should communicate with an access point (AP) first. The AP plays the role as a gateway to the Internet. Each basic service set (BSS) includes one AP and some stations. In the ad hoc mode, the stations communicate in a peer-to-peer manner. IEEE 802.11 provides two functions in the MAC sublayer — PCF (Point Coordination Function) and DCF (Distributed Coordination Function). The PCF is a centralized mechanism, where a point coordinator (PC) sends a CF-Poll frame to each pollable station (STA) and allows it contention free to transmit frames. The DCF is based on the carrier sense multiple access with collision avoidance (CSMA/CA) mechanism and allows the station to contend to access the medium. In order to support quality of service (QoS), the task group E of the IEEE 802.11 standardizes the MAC protocol, donated IEEE 802.11e. IEEE 802.11e defines two MAC functions — *Enhanced Distributed Channel Access Function* (EDCAF) and *Hybrid Coordination Function* (HCF), which are extended from DCF and PCF, respectively. The HCF is suitable to the infrastructure network and real time services, which will be described in Chapter 2.

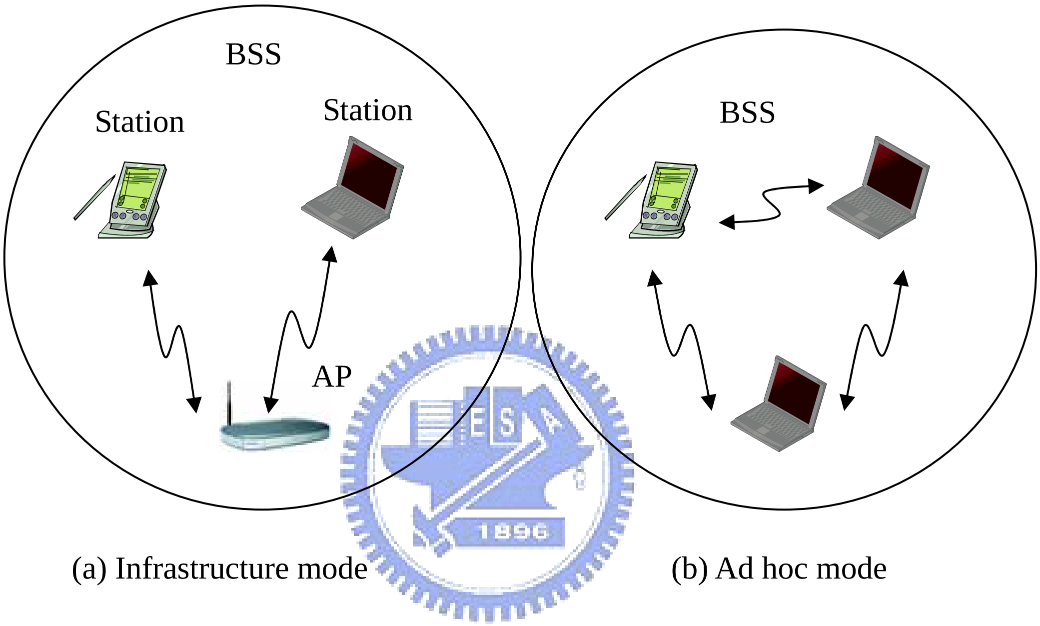


Fig. 1: Two operation modes of IEEE 802.11.

1.2 Power Saving Issues in IEEE 802.11 MAC

Solutions to the power saving issues in the IEEE 802.11 MAC can be classified into two categories: *Power Management* and *Power Control*.

1.2.1 Power Management

Power management techniques have been studied extensively in the context of CPU, memory and disk management in the past. Similar ideas have been used in the context of WLANs [1]. A wireless interface supports *sleep*, *active*, *power-off* and *power saving* modes. A power management policy in WLANs needs to decide when a device switches its state without degrading the performance of the device. An optimal power management scheme [2] using the Markov Decision Process (MDP) approach to model the power tuning process was compiled with the power saving mode (PS mode) deployed in IEEE 802.11 WLANs to reduce unnecessary power consumption. In [1], the authors presented a mathematical abstraction of time-out driven power management policies together with different wakeup mechanisms in WLANs to characterize the energy-performance trade-offs. In [3], it set up multiple queues in an AP buffer and used the AP to schedule the transmission sequence of buffered packets to improve energy efficiency without degrading the response time of the system.

1.2.2 Power Control

Since power control is not our focus, only a brief introduction is given. A power control policy is to vary the transmit power level to reduce power consumption. In [4], the proposed power control MAC (PCM) can improve the energy saving of a basic scheme without degrading network throughput. This is because the basic scheme uses different power levels for RTS-CTS and DATA-ACK, which degrades network throughput and results in higher power consumption. In [5], the authors presented a solution, called MINPOW, to provide a globally optimal routing solution with respect to total power consumed.

1.3 Thesis Objective and Organization

In this thesis, we assume that all stations are operated in HCF mode for all voice transmissions. We focus on power management in the infrastructure network. We propose a power-efficient MAC protocol (PEP) that an AP maintains its polling list dynamically to achieve power saving without sacrificing the throughput. This thesis is organized as follows. In Chapter 2, the HCF mechanism and Brady speech model are overviewed. Two existing polling approaches, the round-robin polling scheme and on-demand polling scheme, are briefly reviewed and compared in Chapter 3. In Chapter 4, the design approach of our proposed power saving scheme is described. In Chapter 5, we compare our scheme with other existing schemes and show the results of our scheme. Finally, we conclude this thesis and describe the future work in Chapter 6.

Chapter 2

Preliminary

Our proposed scheme is based on the IEEE 802.11e HCF and for VoIP traffic. Therefore, in this chapter, the HCF mechanism and two speech models are reviewed.

2.1 802.11e HCF Mechanism

The HCF provides stations with prioritized (EDCA) and parameterized (HCCA) QoS support access to the wireless medium and it combines both contention-based channel access (EDCA) and contention-free channel access (HCCA) [6]. All frames transmit during the contention period (CP) or contention-free period (CAP).

2.1.1 EDCA [6][7]

In the CP, the contention channel access depends on the EDCA mechanism which is based on the CSMA/CA algorithm. The traffic is mapped to four access categories (AC), as shown in Table 1, in order to meet different QoS requirements. Each AC associated with a prioritized queue. When the traffic requires lower transmission delay, the AC which has a higher priority can be used. ACs use different Arbitration Inter-Frame-Space (AIFS) and contention window sizes to contend for channel access. The value of AIFS is determined by the following equation:

$$AIFS = AIFSN \times aSlotTime + SIFS$$

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

It can be expected that the smaller AIFS a station has, the higher priority the station can have. Fig. 2 illustrates the IFS relationships diagram of EDCA.

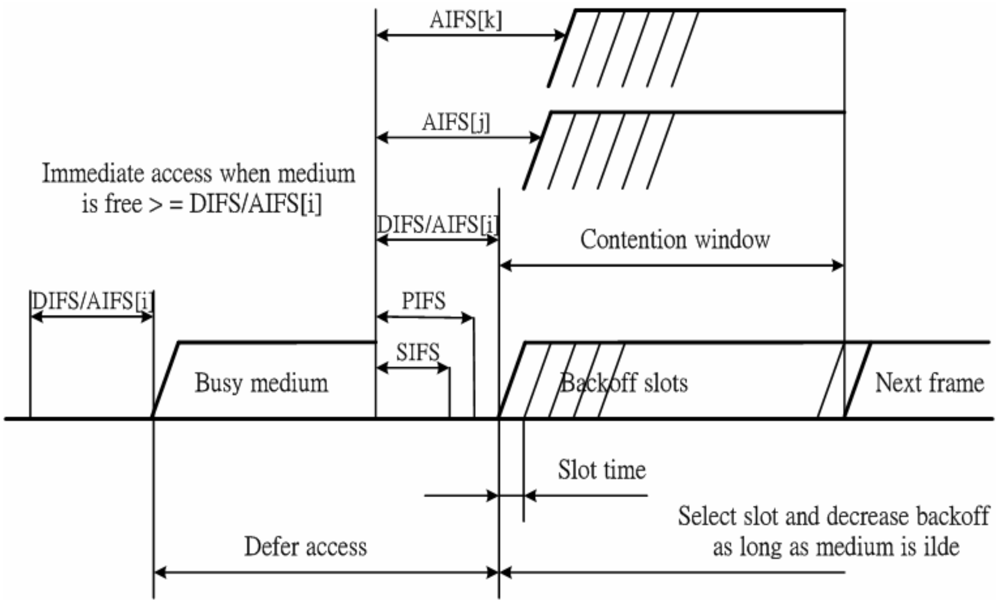


Fig. 2: The IFS relationships diagram of 802.11e EDCA [6].

Table 1: Four access categories and parameters [6].

Priority	Access category (AC)	CW_{min}	CW_{max}	AIFSN
Lowest	AC_BK	aCW_{min}	aCW_{max}	7
↓	AC_BE	aCW_{min}	aCW_{max}	3
	AC_VI	$\frac{aCW_{min}+1}{2}-1$	aCW_{min}	2
Highest	AC_VO	$\frac{aCW_{min}+1}{2}-1$	$\frac{aCW_{min}+1}{2}-1$	2

2.1.2 HCCA [6][8][7]

The HCCA mechanism uses a centralized coordinator, called *hybrid coordinator* (HC). The HC is a QoS access point (QAP). A QAP manages the access of the wireless medium and allocates a transmission opportunity (TXOP) to a QoS station (QSTA). The HCCA mechanism provides polling-based access in the CAP, which allows QAPs to enable the contention-free frame exchange with QSTAs. A QSTA sends a traffic request to the QAP using the traffic specification (TSPEC). The TSPEC element is shown in Fig. 3. After the QAP acknowledges the admission of this request, the QAP will poll the QSTA periodically, allowing the QSTA to make transmission during the granted TXOP. A TXOP is an interval of time when a particular QSTA has the right to initiate frame exchange sequences onto the wireless medium (WM) and it is defined by a starting time and a maximum duration [6]. If the QSTA has no frames to send or the MPDUs (MAC Protocol Data Units) are too long to be sent under the specific TXOP limit, it will send a Null frame. MPDUs are partitioned from a MSDU (MAC Service Data Unit), which is smaller than the original MSDU.

	Element ID	Length	TS Info	Nominal MSDU	Maximum MSDU	Minimum Service	Maximum Service	Inactivity Interval	Suspension Interval
Octets:	1	1	3	2	2	4	4	4	4

	Service Start Time	Minimum Data Rate	Mean Data Rate	Peak Data Rate	Burst Size	Delay Bound	Minimum PHY Rate	Surplus Bandwidth Allowance	Medium Time
Octets:	4	4	4	4	4	4	4	2	2

Fig. 3: The TSPEC element format [6].

2.2 Speech Models

2.2.1 Six-state Brady’s Speech Model [9][10]

This model consists of all scenarios, *double-talk*, *mutual-silence*, *downlink-only* and *uplink-only*. The double-talk state indicates that the uplink and downlink are both talking. The mutual-silence state indicates that the uplink and downlink are both silent. The downlink-only state indicates that only the downlink is talking and the uplink is silent. The uplink-only state indicates that only the uplink is talking and the downlink is silent. Fig. 4 shows the six-state Brady’s model that illustrates the interaction between two speakers.

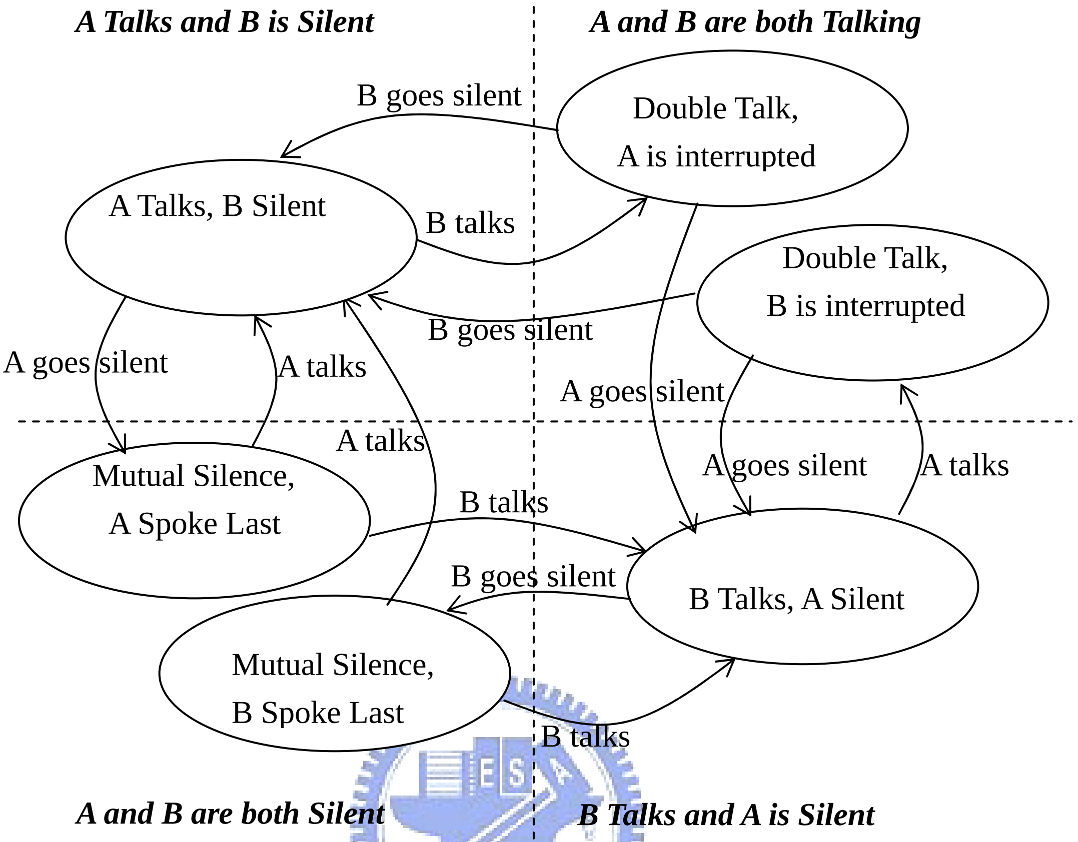


Fig. 4: The Brady's Speech model with two speakers A and B [10].

2.2.2 A Simple Two-State On-Off Speech Model

The six-state Brady's model can be simplified to a two-state speech model. This speech model is often used [11][12][13]. The two-state on-off speech model is shown in Fig. 5. This speech model ignores events such mutual silence and double talk of the six-state Brady's model. User A alternates between the state of "talk-spurt" and "silence period". The speech model of our proposed approach is also based on this model.

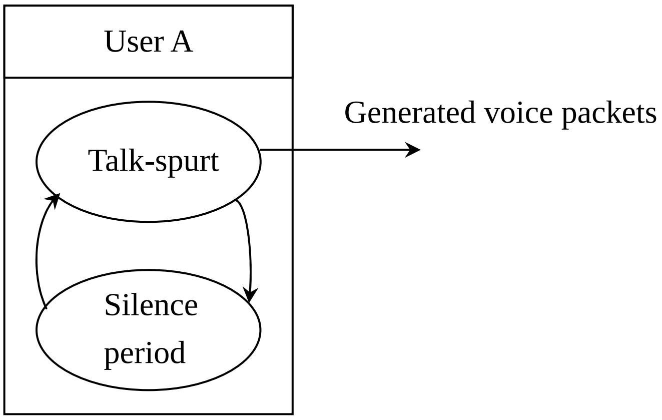


Fig. 5: A simple two state on-off speech model [14].

Chapter 3

Related Work

In recent years, several researches focused on the capacity of VoIP over IEEE 802.11 WLANs. Shin et al. [15] proposed a dynamic PCF to improve the capacity of VoIP over WLANs. It used a dynamic polling list to minimize the waste of bandwidth by sending CF-Polls and Null packets when STAs have no packets to send. In 802.11 DCF, Wang et al. [16] proposed a voice multiplex-multicast (M-M) scheme to overcome the large overhead of VoIP over WLANs. This scheme combines several downlink data into one single packet. By a single transmission of multicasting the multiplexed packet, each station can receive it by a single transmission.

Some researches focused on power saving for VoIP over IEEE 802.11 WLANs. Chen et al. [17] proposed Unscheduled Power Save Delivery (UPSD) to save power. They defined an unscheduled service period, which allows a STA to transmit data continuously. At the end of a period, the AP sets the more data bit to FALSE in the downlink frame, allowing the STA to go to sleep. This scheme permits a lower duty cycle and provides better VoIP capacity than legacy techniques. Wang et al. [18] used a power saving real-time gateway (POWSAR gateway). The gateway was installed on the wired infrastructure and it filtered all traffic towards a set of APs. It can improve the real-time and power saving performance of compatible voice stations (VSs). With respect to integrating the cellular network and VoWLAN, Huang et al. [19] implemented a cellular/VoWLAN dual mode service for enterprises. VoWLAN is regarded as one of the killer applications, but it suffers from the problem of limited coverage. The combination of cellular/VoWLAN has the advantage of low cost of VoWLAN and high mobility of cellular systems. They also proposed power saving strategies for VoWLAN. Shih et al. [9] proposed a power efficient MAC protocol over

802.11e HCF. Using on-demand polling (ODP) scheme, it supports integrated voice and data service over WLAN. Their speech model is the four-state Brady's Speech model. This scheme reduces excess CF-Poll and Null frames in order to save power.

3.1 Existing Polling Schemes

3.1.1 The Round Robin Polling Scheme (RRP) [11]

The round-robin polling (RRP) scheme was adopted to schedule voice sources. The QAP polls a QSTA according to its polling list, even if the QSTA doesn't have any frame to send. It may cause power waste due to sending excess CF-Poll and Null frames when QSTAs have no frames to send, as shown in Fig. 6.

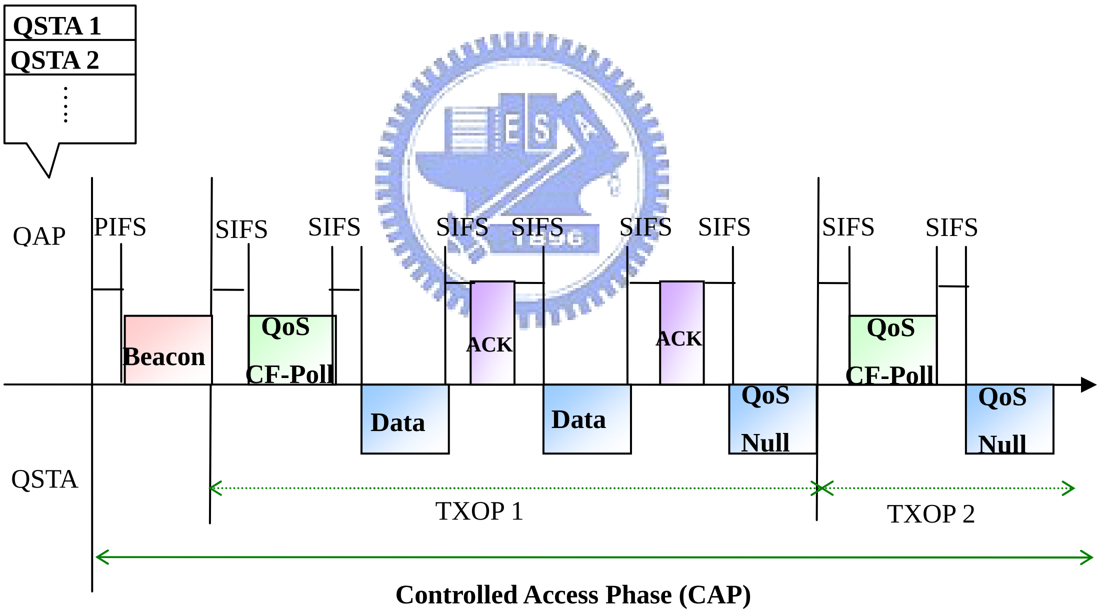


Fig. 6: An example of the RRP scheme [11].

3.1.2 The On-demand Polling Scheme (ODP) [9]

The on-demand polling (ODP) scheme maintains a polling list dynamically. The QAP only keeps active QSTAs in its polling list. When a QSTA enters the silence period, the QAP will remove it from the polling list. When QSTAs are initiating a talkspurt, they will use higher access priority in EDCA to send voice frames for joining the polling list. When the QAP receives two consecutive Null frames from a QSTA, the QSTA will be regarded as entering the silence period. Fig. 7 depicts the operation of the ODP scheme, where a QSTA was removed from the polling list if it entered the silence period. This scheme improves the RRP scheme. Nevertheless, the ODP scheme still has a power waste problem due to some excess CF-Poll and Null frames.

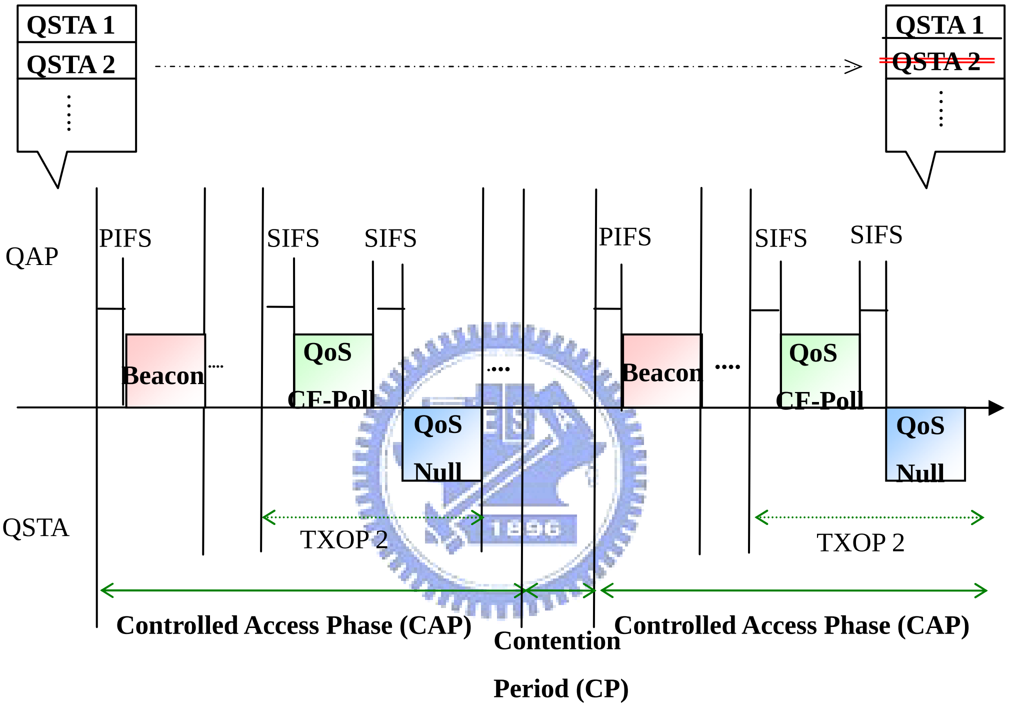


Fig. 7: An example of the ODP scheme [9].

3.1.3 Comparison of Existing Polling Schemes

We highlight the major differences among these existing polling schemes, including the proposed PEP scheme in Table 2. Except the RRP scheme, the ODP and the PEP schemes maintain a polling list dynamically. Therefore, the complexity of implementing of the ODP and the PEP schemes is higher than the RRP scheme. The PEP scheme consumes less power than the others, without reducing the throughput. In Chapter 4, we will describe the PEP scheme in detail.

Table 2: Comparison of the three polling schemes.

Scheme	Round-robin polling (RRP) scheme [11]	On-demand polling (ODP) scheme [9]	Power-efficient polling (PEP) scheme (Proposed)
Characteristics of polling scheme	Static	Dynamic	Dynamic
Complexity of implementation	Easy	Medium	Medium
Normalized power consumption	Highest	Medium	Lowest
Aggregate throughput	Higher	Lower	Slightly lower than RRP
Average end-to-end delay	Lowest	Highest	Medium

Chapter 4

Design Approach

4.1 Basic Idea

We propose a *power-efficient polling* (PEP) scheme to improve the ODP scheme. The IEEE 802.11e standard [6] defines the MAC frame format, as shown in Fig. 8. We will use the QoS control field for power saving purpose. The QoS control field is used to identify which *traffic stream* (TS) or *traffic category* (TC) a frame belongs to. A TS is defined as a set of MAC service data units (MSDUs) to be delivered subject to the QoS parameter values provided to the MAC in a particular TSPEC. A TC is defined as a label for MSDUs that has a distinct user priority (UP). Each QoS control field contains five subfields that identify the sender frame type and subtype. These subfields are shown in Table 3. The *TID* subfield identifies a TC or TS to which the corresponding MSDU in the Frame Body field belongs. The *EOSP* (end of service period) subfield is used by the HC to indicate the end of the current service period. The *Ack policy* identifies the acknowledgement policy.

Octets:2	2	6	6	6	2	6	2	0-23124	4
Frame Control	Duration ID	Address 1	Address 2	Address 3	Sequence Control	Address 4	QoS Control	Frame Body	FCS

MAC Header

Fig. 8: MAC frame format [6].

We will use the *queue size* subfield in the QoS control field. The queue size subfield indicates the amount of buffered traffic for a given TC or TS at the QSTA sending a MAC frame. A QSTA can request a TXOP by setting the queue size. If this field is set to zero, it represents that no buffered traffic in the QSTA’s queue. We suppose if this field is set to zero, a QSTA may have no frames to send when it enters the CAP again. When the QSTA have no frame to send or the size of the frame exceeds the given TXOP limit, the QSTA will send a Null frame to the QAP.

Table 3: QoS control field [6].

Applicable frame (sub) types	Bits 0-3	Bit 4	Bits 5-6	Bit 7	Bits 8-15
QoS (+) CF-Poll frames sent by HC	TID	EOSP	Ack policy	Reserved	TXOP limit
QoS Data, QoS Null, and QoS Data + CF-Ack frames sent by HC	TID	EOSP	Ack policy	Reserved	QAP PS buffer state
QoS data type frames sent by non-AP QSTAs	TID	0	Ack policy	Reserved	TXOP duration requested
	TID	1	Ack policy	Reserved	Queue size

In our proposed scheme, as shown in Fig. 9, non-real time data traffic is only transmitted during EDCA. When a QAP accepts a new voice call from a QSTA, the QAP will add the QSTA to the polling list. Then the QAP in HCCA will periodically poll a QSTA according to the polling list and wait for transmission of uplink voice packets. The QAP will check the Null frame from the QSTA if the queue size field in the QoS control field is set to zero. The QAP will remove a QSTA from the polling list if this field is set to zero and the TXOP is not used up. When a removed QSTA starts to talk, it will use a higher access priority in EDCA to send a voice packet for joining the polling list. The proposed scheme makes sure that QSTAs in the polling list have frames to send. It avoids unnecessary waste of CF-Poll and Null frames and achieves the goal of power saving.

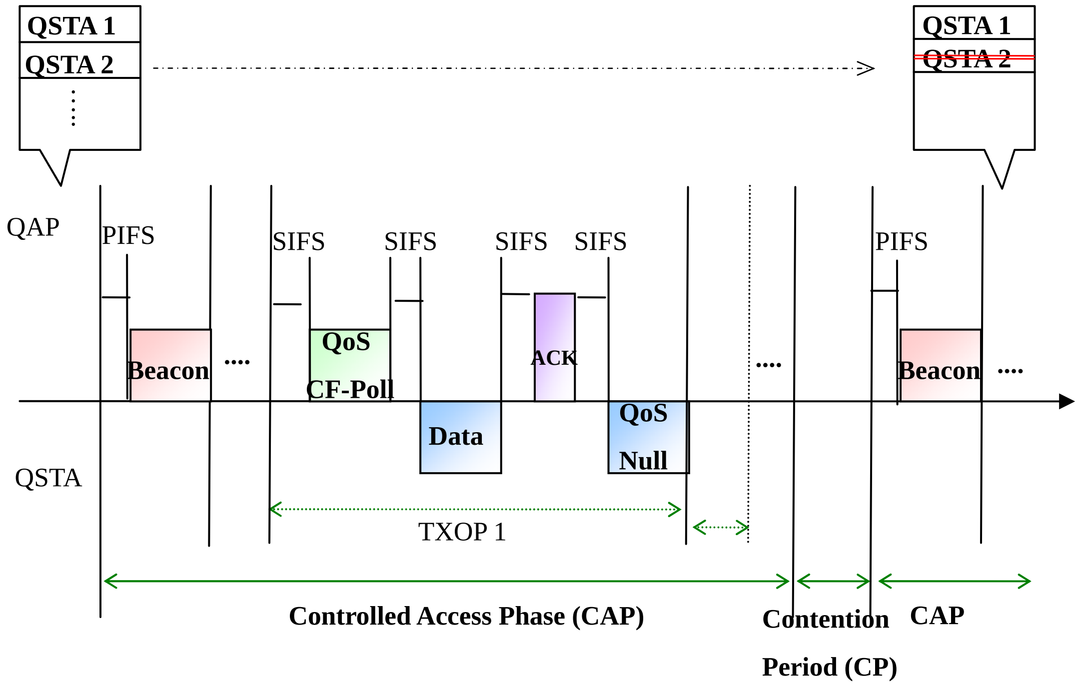


Fig. 9: An example of the PEP scheme.

4.2 A Heuristic Method for Prediction Accuracy Enhancement

In order to predict silent QSTAs correctly, we add a heuristic method of allocated TXOP to the PEP polling scheme. According to the concept of six-state Brady's speech model and the speech behavior in the real world, we set a criterion for removing QSTAs from the polling list. We first define the utilization of allocated TXOP for a QSTA.

$$Utilization = \frac{allocated\ TXOP - remaining\ TXOP}{allocated\ TXOP} \times 100\%$$

where *allocated TXOP* means the TXOP assigned for a QSTA by the QAP.

Remaining TXOP means the portion of a given TXOP that is not used up by the QSTA.

By simulations, we derived the following rules:

(1). Utilization of allocated TXOP < 20%

In this case, we assume that it is in the downlink-only state which represents one station seldom talks. The QSTA will be removed from the polling list immediately. It represents that the QSTA seldom talks.

(2). 20% ≦ Utilization of allocated TXOP ≦ 70%

In this case, we assume that it is in the mutual-talk state which is between the uplink-only state and downlink-only state. The QSTA won't be removed from the polling list at the moment. If this situation happens in two consecutive beacon intervals, the QSTA will be removed from the polling list.

(3). Utilization of allocated TXOP > 70%

In this case, we assume that it is in the uplink-only state which represents that one station always talks. The QSTA won't be removed from the polling list at the moment. If this situation happens in three consecutive beacon intervals, the QSTA will be removed from the polling list.

4.3 The Operation of the PEP Scheme

Fig. 10 depicts the operation of the PEP scheme. When sending a Beacon frame by a QAP, the CAP begins. If it is not the end of the CAP, the QAP will send a CF-Poll to a QSTA in the polling list. The QSTA will send a QoS Null frame to the QAP after its transmission end. The QAP will check if the queue size of the QoS Null frame is zero and calculate the utilization of allocated TXOP of this QSTA. By the three rules described in the last sec`tion, the QAP will make a decision whether or not to remove the QSTA from the polling list. When the CAP ends, the CP follows. If it is not the end of the Beacon interval, all QSTA can transmit data based on the CSMA/CA mechanism. If the QAP received a voice packet sent by a QSTA, the QSTA will be added to the polling list.

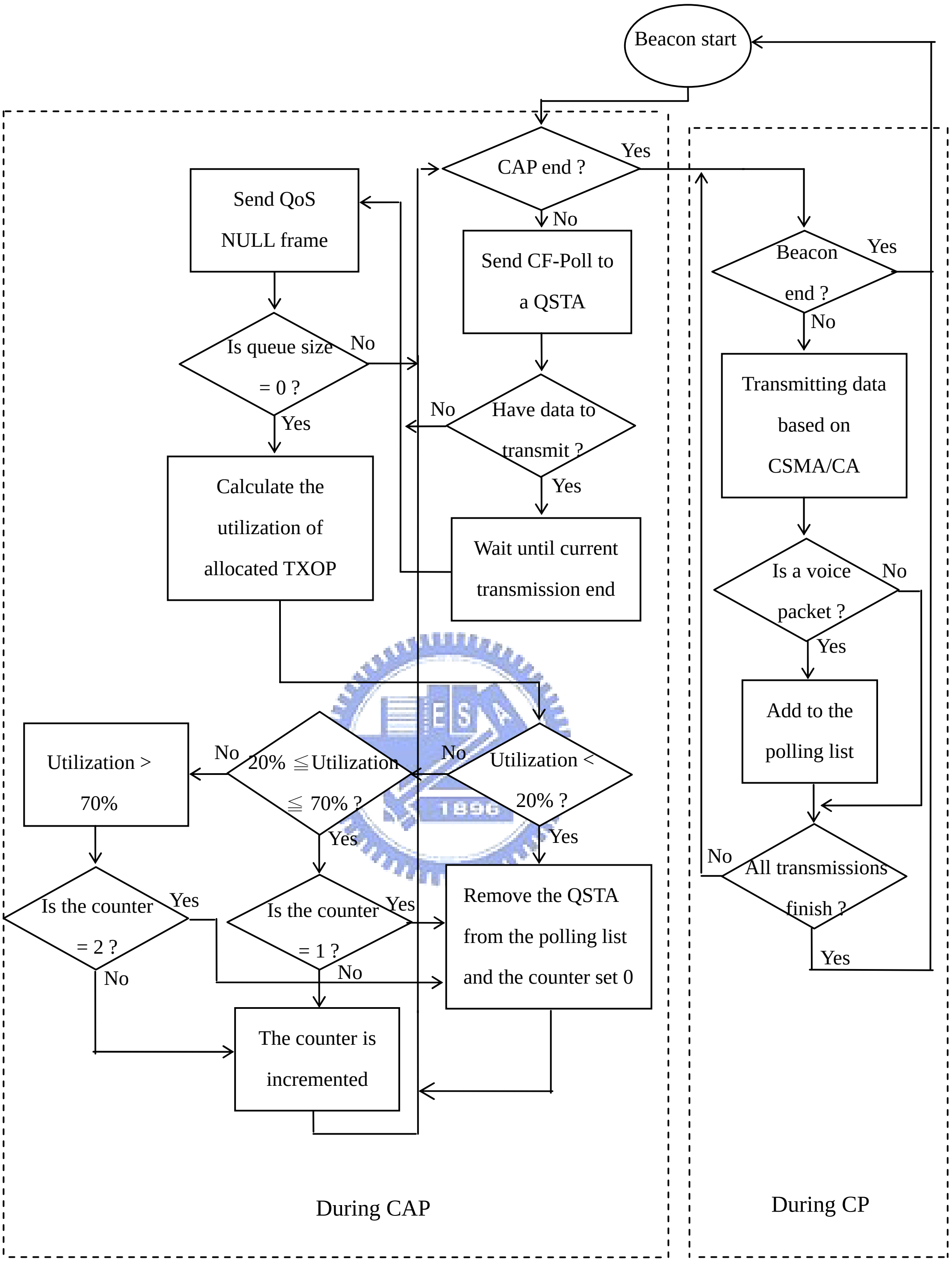


Fig. 10: The flowchart of the PEP scheme.

Chapter 5

Simulation and Discussion

5.1 Simulation Model

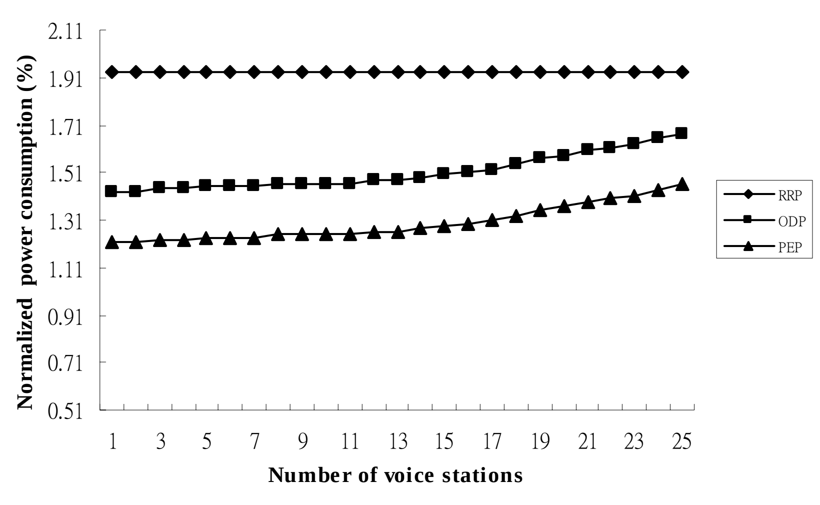
For evaluation, we used the *ns-2* simulator [20]. Simulation parameters are showed in Table 4 and the values of PHY-related parameters were from [9]. The length of a beacon interval is 20 *ms*. We used the G.723.1A codec with a payload of 20 bytes for our simulation [15]. Each station generates variable-bit-rate (VBR) traffic according to the two-state on-off speech model [11][12]. We also used the parameters specified in [12] to set time to “talk-spurt” = 1 sec and time to “silence period” = 1.35 sec. In other words, the percentage of time spent in the talking state is 43% and the percentage of time spent in the silence state is 57%. Three performance metrics — *normalized power consumption (%), aggregate throughput* (*Kb/sec*) and *average end to end delay* (*msec*) — have used to evaluate the merits of each scheme. We simulated and compared the round-robin polling scheme (RRP), the on-demand polling scheme (ODP), and the proposed power-efficient polling scheme (PEP).

Table 4: Simulation parameters.

Parameter	**Value**
Duration of the superframe	20 ms
Voice coding rate in bps	5.3 K
Transmission rate in bits/sec	11 M
MAC header (QoS data type) in bits	30 x 8
Header overheads (IP+UDP+RTP) in bits	40 x 8
Physical overhead in seconds (including preamble length and header length)	192 µs
Beacon size in bit	40 x 8
SIFS	10 µs
PIFS	30 µs
Slot time	20 µs
Payload	20 bytes

5.2 Simulation Results and Discussion

We compare our PEP with the RRP and ODP quantitatively. Fig. 11 shows the normalized power consumption versus the number of voice stations. The normalized power consumption is defined as the percentage of a voice QSTA that is in active mode during a superframe [9]. We can see that the PEP scheme consumes less power than the RR and ODP schemes. The power consumption of the ODP and PEP schemes increased with the number of voice stations, which is due to the increased mean contention time. The PEP scheme outperforms the RR and ODP schemes by a margin of 24.5% to 37.1% and 12.9% to 15.1%, respectively.



.

Fig. 11: Normalized power consumption of voice stations.

In Fig. 12, we can see that the aggregate throughputs of three schemes are very close. The aggregate throughput is computed by summarizing the throughput of all connection flows. The aggregate throughput of the PEP scheme is slightly higher than that of the ODP scheme, but is slightly lower than that of the RRP scheme. This represents that the PEP scheme can reduce power consumption without sacrificing the aggregate throughput.

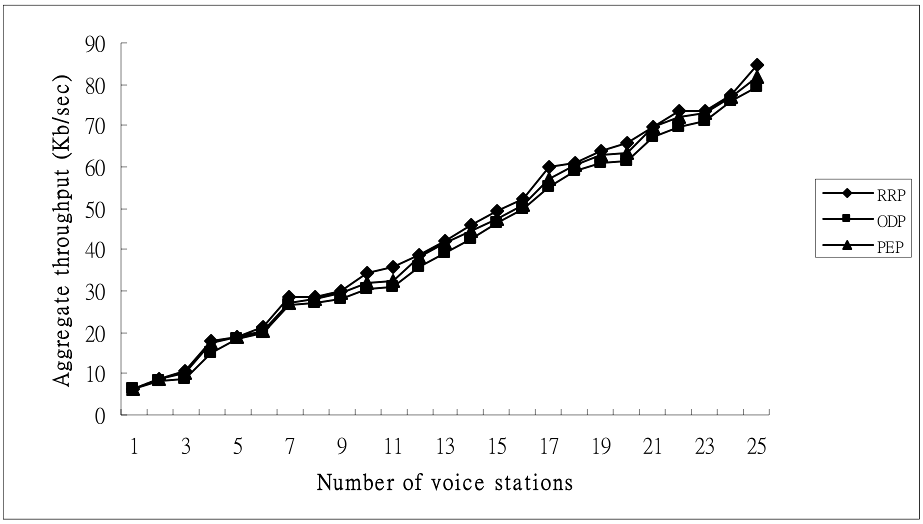


Fig. 12: Aggregate throughput of voice stations.

We also measured the average end-to-end delay of voice stations. The average end to end delay is computed by summarizing the end to end delay of all connection flows and averaging it. If a removed QSTA has packets to send, it will be a penalty that the delay of this QSTA will increase. In Fig. 13, we observe that the RRP scheme has lower average end-to-end delay than the other two schemes, because the RRP scheme will not remove a QSTA from the polling list. The average end-to-end delay of the PEP scheme is slightly higher than that of the RRP scheme, but is lower than that of the ODP scheme. This is because the prediction accuracy of the PEP scheme is higher than that of the ODP scheme.

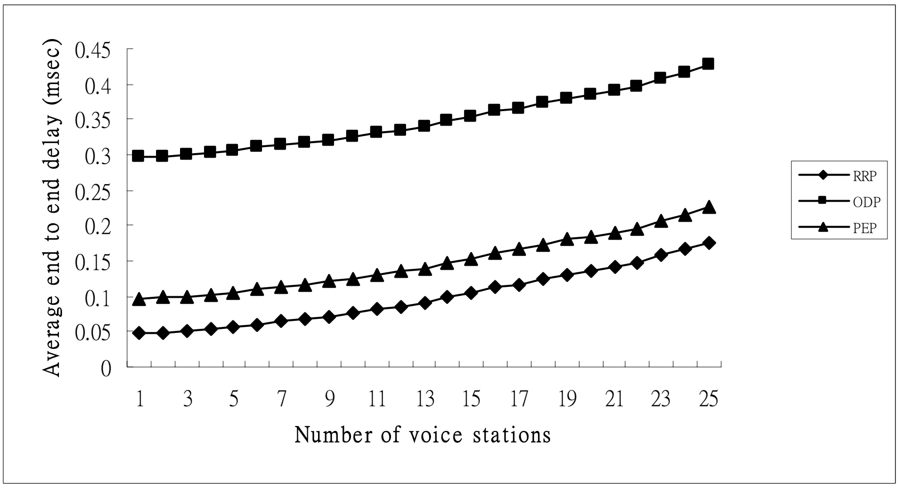


Fig. 13: Average end-to-end delay of voice stations.

Chapter 6

Conclusions and Future Work

6.1 Concluding Remarks

In this thesis, we have presented a power-efficient polling (PEP) scheme for VoIP traffic over IEEE 802.11e HCF. A QAP can maintain its polling list dynamically. This scheme will reduce the unnecessary polling of silent QSTAs to achieve power saving by checking the queue size field in the Null frame that a QSTA sends to the QAP and the utilization of allocated TXOP. To increase the prediction accuracy of a QSTA entering the silence period, we have also added a heuristic method to evaluate the utilization of allocated TXOP in the PEP scheme. Simulation results have shown that the PEP scheme in terms of the normalized power consumption outperforms the RRP and ODP schemes from 24.5% to 37.1% and from 12.9% to 15.1%, respectively, without sacrificing the aggregate throughput.

6.2 Future Work

In our proposed PEP scheme, the thresholds of the utilization of allocated TXOP were derived from simulations. A more systematic way of deriving such thresholds deserves to further study. In addition to voice traffic, video traffic is also an important category of real time traffic, but the characteristics of these two types of traffic are different. Voice traffic is delay-sensitive, while video traffic can be buffered and then played. The future work is to consider both voice traffic and video traffic to further investigate power efficiency techniques for mobile handheld devices.

Bibliography

[1] Rong Zheng, J.C Hou. and Lui Sha, “On time-out driven power management policies in wireless networks”, in *Proc. IEEE GLOBECOM*, Nov.-Dec. 2004, vol. 6.

[2] Huan Chen and Chen-Wei Huang, “Power management modeling and optimal policy for IEEE 802.11 WLAN systems”, in *Proc. IEEE VTC*, Sept. 2004, vol. 6, pp. 4416-4421.

[3] H. Lei and A.A Nilsson, “A power management scheme for the IEEE 802.11 based WLANs”, in *Proc. IEEE IPCCC*, April 2005, pp. 123-127.

[4] Eun-Sun Jung and Nitin H. Vaidya, “A power control MAC protocol for ad hoc networks”, in *Proc. ACM Mobile Computing and Networking*, 2002, pp. 36-47.

[5] Vikas Kawadia and P.R. Kumar, “ Power control and clustering in ad hoc networks”, in *Proc. IEEE INFOCOM*, March-April 2003, vol. 1, pp. 459-469.

[6] IEEE std. 802.11e, Medium Access Control (MAC) Enhancements for Quality of Service (QoS), http://standards.ieee.org/catalog/olis/new.html

[7] L. Yang, “Enhanced HCCA for real-time traffic with QoS in IEEE 802.11e based networks”, in *Proc. IEEE Intelligent Environments*, June 2005, pp. 203-209.

[8] L.W. Lim, R. Malik, P.Y. Tan, C. Apichaichalermwongse and K. Ando and Y. Harada, “A QoS scheduler for IEEE 802.11e WLANs”, in *Proc.* IEEE CCNC, Jan. 2004, pp. 199-204.

[9] Chih-Yung Shih, Yih-Shen Chen, Ray-Guang Cheng and Chung-Ju Chang, “A power-efficient MAC protocol for integrated voice and data services over 802.11e HCF,” in *Proc. IEEE Vehicular Technology Conference*, 2004.

[10] Harold P. Stern, Samy A. Mahmoud and Kin-Kwok Wong, “A comprehensive model for voice activity in conversational speech—development and application to performance analysis of new-generation wireless communication systems”, in *ACM Wireless Networks*, Dec. 1996, vol. 2, pp. 359–367.

[11] M. Veeraraghavan, N. Cocker and T. Moors, "Support of voice services in IEEE 802.11 wireless LANs", in *Proc. IEEE INFOCOM*, 2001, vol. 1, pp. 488–497.

[12] M.A. Visser and M. El Zarki, "Voice and data transmission over an 802.11 wireless network", in *Proc. IEEE Personal, Indoor and Mobile Radio Communications*, Sept. 1995, vol. 2, pp. 648–652.

[13] S. Nanda, D.J. Goodman and U. Timor, "Performance of PRMA: a packet voice protocol for cellular systems", in *the IEEE Transactions on Vehicular Technology*, Aug. 1991, vol. 40, pp. 584-598.

[14] P.M. Fiorini, "Voice over IP (VoIP) for enterprise networks: performance implications & traffic models", [Online]. Avaliable: http://www.bmc.com/offers/performance/whitepapers/docs/2000/voice_over_ip_pm.pdf.

[15] T. Kawata, S. Shin, A.G. Forte and H. Schulzrinne, "Using dynamic PCF to improve the capacity for VoIP traffic in IEEE 802.11 networks," in *Proc. IEEE Wireless Communications and Networking Conference*, 2005.

[16] Wei Wang, Soung Chang Liew, and V.O.K Li, "Solutions to performance problems in VoIP over a 802.11 wireless LAN," in *the IEEE Transactions on Vehicular Technology*, Jan. 2005, vol. 54, pp. 366 - 384.

[17] Y. Chen, N. Smavatkul and S. Emeott, "Power management for VoIP over IEEE 802.11 WLAN," in *Proc. IEEE Wireless Communications and Networking Conference*, 2004, vol.3, pp. 1648 - 1653.

[18] Xiaofan Wang, T.D. Todd, D. Zhao and V. Kezys, "Power saving gateways for real-time voice handset support in IEEE 802.11 wireless LANs," in *Proc. IEEE Communications Conference*, June 2004, vol 1, pp.164–169.

[19] Chung-Huei Huang, Chih-Chien Hsu, Li-Wei Huang, Pang-Hsiang Lo, You-Lin Chen and Shiao-Li Tsao, "The design and implementation of cellular/VoWLAN dual mode service for enterprises," *Mobile Computing Workshop*, March 2005.

[20] The network simulator – ns-2, [Online]. Avaliable: http://www.isi.edu/nsnam/ns/.