A Power-Efficient MAC Protocol for VoIP Traffic over IEEE 802.11e WLANs[1]

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ABSTRACT

Power saving is a critical issue for VoIP over WLANs, especially when using mobile devices. In this paper, 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. 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. 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 RRP (Round-Robin Polling) and ODP schemes from 24.5% to 37.1% and 12.9% to 15.1%, without sacrificing the throughput.

Keyword — HCF, IEEE 802.11e, MAC protocol, power efficient, VoIP.

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.

IEEE 802.11 is the most widely used standard for WLANs. It specifies two operation modes：(1) infrastructure mode and (2) ad hoc mode, 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, denoted 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.

2: RELATED WORK

In recent years, several researches focused on the capacity of VoIP over IEEE 802.11 WLANs. Kawata et al. [1] 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

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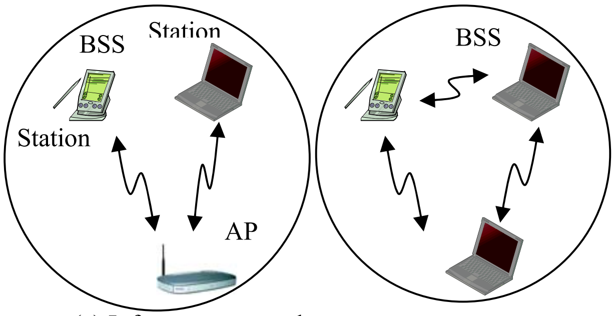
Null packets when STAs have no packets to send. In 802.11 DCF, Wang et al. [2] proposed a voice multiplex-multicast (M-M) scheme to overcome the large overhead of VoIP over WLANs. This scheme combines several downlink data into one single packet. By a single transmission of multicasting the multiplexed packet, each station can receive it by a single transmission.



(a) Infrastructure mode (b) Ad hoc

Fig. 1: Two operation modes of IEEE 802.11.

Some researches focused on power saving for VoIP over IEEE 802.11 WLANs. Chen et al. [3] 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. [4] 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. [5] 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. [6] proposed a power efficient MAC protocol over 802.11e HCF. Using the 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.

In this paper, 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 a polling list dynamically to achieve power saving without sacrificing the throughput. This paper is organized as follows. In section 3: , the HCCA mechanism and Brady's speech model are overviewed. Two existing polling approaches, the round-robin polling (RRP) scheme and on-demand polling (ODP) scheme, are briefly reviewed and compared in section 4: . In section 5: and 6: , the design approach of our proposed power saving scheme is described. In section 7: , we compare our scheme with other existing schemes and show the results of our scheme. Finally, we conclude this paper in section 8: .

3: SYSTEM OVERVIEW

3.1: HCCA [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). 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. 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.

3.2: Six-state Brady's Speech Model [6][8]

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.

Table 1: QoS control field [7].

Applicable Frame (sub) Types	Bits 0-3	Bits 4	Bits 5-6	Bits 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

4: EXISTING POLLING SCHEMES

4.1: The Round Robin Polling Scheme (RRP) [9]

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. 2.

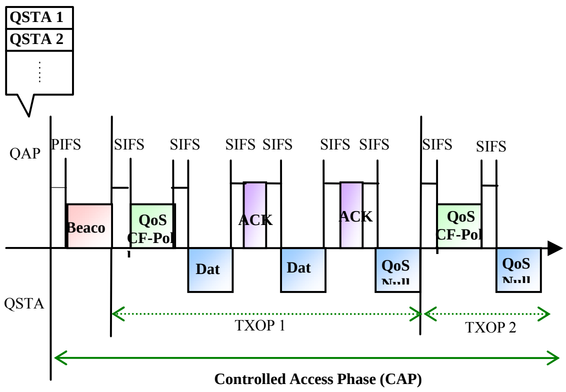


Fig. 2: An example of the RRP scheme [9].

4.2: The On-demand Polling Scheme (ODP) [6]

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. 3 depicts the operation of the ODP scheme, where a QSTA was removed from the polling list when 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.

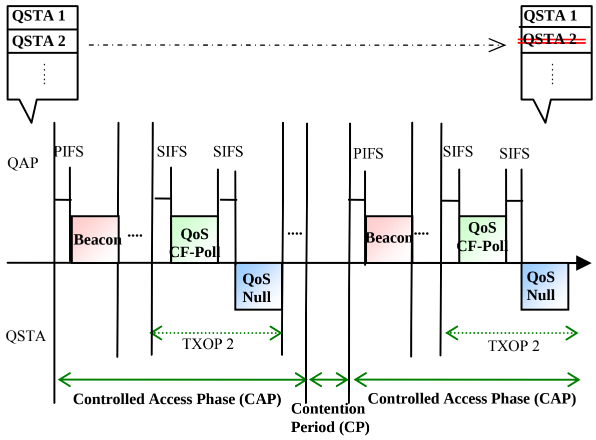


Fig. 3: An example of the ODP scheme [6].

4.3: Comparison of Existing Polling Schemes

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.

Table 2: Comparison of the three polling schemes.

Scheme	Round-robin polling (RRP) scheme [9]	On-demand polling (ODP) scheme [6]	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

5: DESIGN APPROACH

We propose a *power-efficient polling* (PEP) scheme to improve the ODP scheme. The IEEE 802.11e standard [7] defines the MAC frame format, as shown in Fig 4. 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 1.

Octets:	2	6	6	6
Frame control	Duration ID	Address 1	Address 2	Address 3

MAC Header

2	6	2	0-23124	4
Sequence Control	Address 4	QoS Control	Frame Body	FCS

Fig. 4: MAC frame format[7].

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 has 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.

In our proposed scheme as shown in Fig. 5, non-real time data traffic is only transmitted during EDCA. The voice packets depending on the voice model are transmitted during EDCA or HCCA. When the QAP accepts a new voice call, the QAP will add the QSTA to the polling list. Then the QAP will periodically poll the QSTA according to the list and wait for transmission of uplink voice packets. The QAP will check the Null frame from the QSTA to see if the queue size field in the QoS control field is set to zero. The QAP will remove the QSTA from the polling list if this field is set to zero and the TXOP is not used up. It is to make sure the QSTAs in the polling list have frames to send. This scheme avoids unnecessary waste of CF-Poll and Null frames and achieves the goal of power saving.

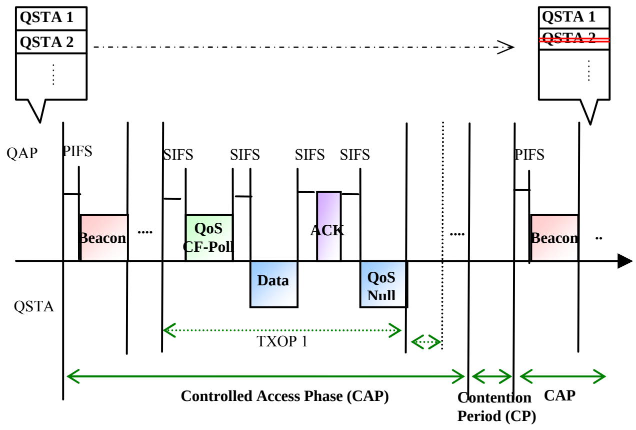


Fig. 5: An example of the PEP scheme.

6: A HEURISTIC METHOD FOR PREDICTION ACCURACY ENHANCEMENT

In order to predict silent QSTAs correctly, we add a heuristic method regarding to the utilization 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 a 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.

7: SIMULATION AND RESULTS

For evaluation, we used the *ns-2* simulator [10]. Simulation parameters are shown in Table 3 and the values of PHY-related parameters were from [6]. 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 0. Each station generates variable-bit-rate (VBR) traffic according to the two-state on-off speech model [9][11]. We also used the parameters specified in [11] to set time to "talk-spurt" = 1 sec and time to "silence period" = 1.35 sec. 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 3: 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

Fig. 6 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 [6]. We can see that the PEP scheme consumed 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.

In Fig. 7 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.

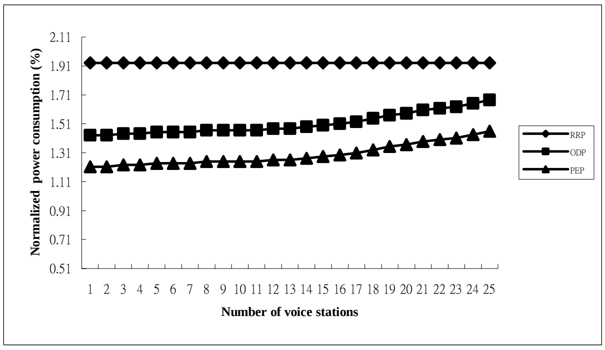


Fig. 6: Normalized power consumption for voice stations.

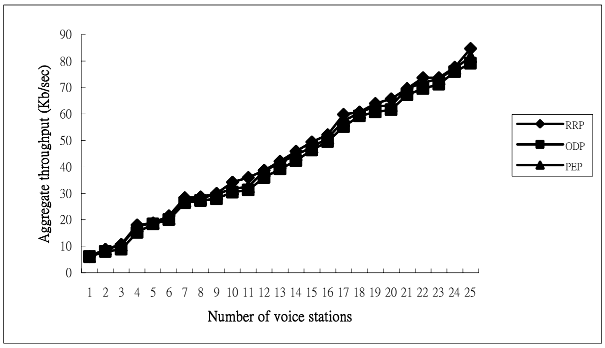


Fig. 7: Aggregate throughput of voice stations.

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 and the delay of this QSTA will increase. In Fig. 8, 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.

8: CONCLUSION

In this paper, 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.

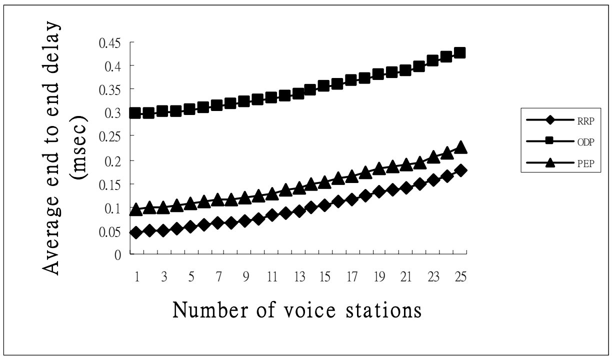


Fig. 8: Average end-to-end delay of voice stations.

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