Link-Adaptable Polling-based MAC Protocol for Wireless LANs

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Abstract-**The IEEE 802.11 standard defines a centralized polling-based channel access method, the Point Coordination Function (PCF), to support time-bounded services. This approach is not efficient due to inefficient polling and large overhead. To design an efficient polling scheme, the Point Coordinator (PC) needs to obtain information about the current transmission status and channel condition for each station. To reduce overhead, it is better to poll all stations using one polling frame containing the transmission sequence. In this paper, we propose an efficient polling scheme, referred to as *Two-Step MultiPolling (TS-MP)*, for the PCF in WLANs. In this new scheme, we propose to use two multi-polling frames for different purposes. The first frame is broadcasted to collect information such as the numbers of pending frames and the physical layer transmission rates for the communication links among all stations. The second frame is broadcasted with a polling sequence for data transmissions designed by utilizing the collected information. Extensive simulation studies show that TS-MP not only overcomes the aforementioned deficiencies, but also help to implement rate adaptation over a time-varying wireless channel.**

Keywords-Wieless LAN; MAC; Rate-Adaptive Protocol; PCF.

1. INTRODUCTION

The Medium Access Control (MAC) protocol in IEEE 802.11 [2] consists of two coordination functions: Distributed Coordination Function (DCF) and Point Coordination Function (PCF). In the DCF, a set of wireless stations (STAs) communicates directly with each other using a contention-based channel access method, namely, *Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA)*. In the PCF, the channel access of each station is controlled by polling from a Point Coordinator (PC) at the access point (AC). The DCF and PCF can coexist by alternating Contention Free Period (CFP) ruled by PCF and Contention Period (CP) ruled by DCF.

Since the controlled channel access can reduce the amount of time wasted for accessing the channel during the backoff process in the DCF, the PCF is a more appropriate scheme for real-time multimedia applications. In fact, the PCF is mainly intended to transmit time-bounded services such as voice and video. However, in IEEE 802.11 MAC, scheduling algorithm for the determination of a polling sequence is based on the Round-Robin scheme, which is not suitable to handle real-time applications with various QoS requirements. Furthermore, the polling scheme in the PCF introduces significant overhead. This overhead increases the transmission delays on time-bounded traffics and wastes the scarce wireless channel bandwidth. The overhead is caused not only by the polling frames themselves (since one polling frame polls only one station at a time), but also by polling the stations with no frame to transmit. Consequently, most studies on the PCF in WLAN [3]-[8] have been focused on these two factors: the scheduling scheme and the overheads.

Since a typical wireless channel is time-varying and most wireless networks support several different data rates in the physical layer, an efficient communication system can be designed by selecting the data rate according to the channel condition as proposed in [9] [10]. Nevertheless, rate-adaptive polling-based MAC protocols for WLANs have not been investigated yet.

In this paper, we propose an efficient polling-based MAC protocol, *Two-Step Multi-Polling (TS-MP)*, to support real-time applications. In this protocol, we use two multipolling frames for different purposes, which are describing in Section 3. The proposed protocol not only overcomes the deficiencies of existing polling schemes, but also helps to implement rate adaptation. The rest of this paper is organized as follows. Section 2 reviews the protocols for the CFP in the IEEE 802.11 and 802.11e standards and some known multipolling schemes. The proposed TS-MP protocol with an efficient scheduling algorithm is presented in Section 3. Section 4 describes the simulation environment under which the performance of the proposed protocol is evaluated. In Section 5, conclusions are provided.

2. RELATED WORK

2.1 Point Coordination Function of IEEE 802. 11 MAC

The CFP begins with a beacon frame containing parameters needed to control the superframe. The PC keeps the list of stations registered in its Basic Service Set (BSS), which is the set of stations controlled by the PC. The PC polls one station at a time. Hereafter, the polling scheme used in the PCF is called *Contention Free Single Polling (CF-SP)*. To announce the end of the CFP, the PC sends a specific control frame, called Contention-Free (CF) End frame, to signal the end of the CFP. Although the PCF is capable of supporting time-bounded services, the following problems may arise:

1) Due to overhead induced by the polling frames, the throughput is low.
2) The Round-Robin scheduling algorithm is inefficient.
3) Information, such as the current number of pending frames in a station and the data rate in the physical layer

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with respect to the channel conditions, is not available to the PC.
4) Potential collisions may be caused by stations in a neighboring BSS.
5) The transmission time of a polled station is unpredictable.

The IEEE 802.11e Task Group (TG) recently proposes some enhancements to overcome the problems 4) and 5). The Hybrid Coordination Function (HCF) proposed by the IEEE 802.11e TG controls transmissions of stations in the CFP as well as in the CP. The HCF in the CFP uses the CF-SP scheme in the PCF with two enhancements. The first one is the use of RTS/CTS handshaking. The stations overhearing the RTS or CTS frame in a neighboring BSS will not transmit during the time specified by the Network Allocation Vector (NAV) in the RTS or CTS frame. As a consequence, collisions caused by stations in neighboring BSS are prevented. The second enhancement is the use of *Transmission Opportunity* (TXOP). TXOP is the maximum time duration in which a polled station can transmit its frames and prevents any station from dominating the CFP.

2.2 Multipolling Schemes

A number of MultiPolling (MP) schemes have been proposed in [6]-[8] to reduce the overhead due to the polling frames. The first proposed multipolling scheme is Contention Free MultiPolling (CF-MP) in [6]. In this scheme, the PC sends a multipolling frame with a polling sequence and time duration assigned to each station for frame transmissions after the beacon frame in the CFP. However, if a polled station does not have enough pending frames to utilize the assigned time duration, the remaining time is wasted. The polling scheme in [7] focuses on the case when a polled station fails to receive a multipolling frame from the PC. To increase the reliability of receiving the polling information, each station sends its data frame appending the polling information. In this way, a station that fails to receive a multipolling frame from the PC has chances to obtain the polling information from the transmissions of other stations. Of course, this introduces additional overhead due to the redundant polling information.

The CP-MP protocol proposed recently in [8] applies the channel access scheme in the DCF of IEEE 802.11 to the PCF. After broadcasting the beacon frame, the PC sends a multipolling frame containing the allocated TXOP and the initial backoff time for each station to be polled. After receiving the polling frame, each station follows the rule of CSMA/CA with backoff time assigned by the multipolling frame and with RTS/CTS handshaking in order to avoid collision with the transmission from a station in a neighboring BSS.

3. TWO-STEP MULTI-POLLING SCHEME (TS-MP)

3.1 Motivation

While the polling schemes in the HCF and the CP-MP scheme solve the collision problem caused by a station in a neighboring BSS, they introduce more overheads due to the RTS/CTS exchanges. In addition, the CP-MP may introduce collision between stations in the same BSS due to carrier sensing based channel access.

The scheduling scheme for the polling sequence and the TXOP allocation are not clearly specified in any of aforementioned polling schemes. Moreover, although many rate-adaptive MAC protocols for wireless networks have been proposed [9][10] to adapt to time varying wireless channels, there are no rate-adaptive MAC protocols for the PCF proposed in the current literature.

3.2 TS-MP

We refer to the proposed multipolling scheme as *Two-Step MultiPolling (TS-MP).* Fig. 1 illustrates the operation of the proposed TS-MP MAC protocol. The CFP period is divided into two sub-periods: Status Collection Period (SCP) and Data Transmission Period (DTP).

After broadcasting the beacon frame at the beginning of the CFP, the PC transmits the first multipolling frame, called *Status-Request Multi-Poll* (SRMP), using the frame structure as shown in Fig. 2(a). The *Polling Count* subfield indicates the number of stations to be polled and the *AID* subfield is an association identifier in the BSS. The stations to be polled are selected by the first scheduling scheme to be explained in Section 3.3. Each station polled by the SRMP frame sends a Status-Response (SR) frame back to the PC as shown in Fig. 2(b). The *Tentative-NAV* field indicates the tentative time duration used for temporal NAV allocation of stations belonging to a neighboring BSS that overhear the transmission of the sender. This is to avoid the collision caused by the transmission of a station in the neighboring BSS. When the station in a neighboring BSS receives a data frame from the same station, the NAV value is reset to the value in the *Duration* field of the data frame. The value of *Tentative-NAV* field may indicate the end of the CFP. For a polled station with no pending frame, the value of the *Tentative-NAV* field is set to zero since this station will not be polled for a data frame transmission at the second multipolling period. The *More-Frame* field indicates the number of pending frames in the buffer of a station. This information is important for the PC to set the TXOP for each station in the incoming data transmission period. Moreover, it

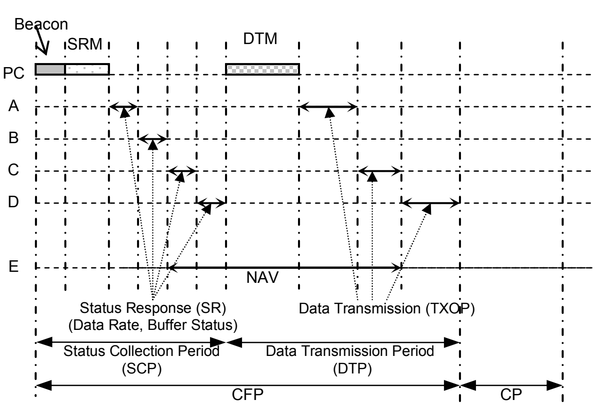

Figure. 1. Time line of TS-MP protocol.

Byte : 2	6	1	2	•••	2	4
Frame Control	BSSID	Polling Count (N)	AID 1	•••	AID N	FCS

(a)

Byte : 2	6	2	1	1	2	4
Frame Control	BSSID	Tentative NAV	Buffer Status	Down-Rate	AID	FCS

(b)

Byte : 2	6	1	5 x Polling Count (N)			4
Frame Control	BSSID	Polling Count (N)	Polling Control			FCS
			AID (2bytes)	Up-Rate (1byte)	TXOP (2bytes)	

(c)

Figure. 2. Frame Structures of (a) SRMP frame, (b) SR frame, and (c) DTMP frame.

reduces the time loss due to the polling of stations with no pending frames because these stations are removed from the polling sequence for the data transmission in the DTP. The *Down-Rate* subfield indicates a physical data rate for the downlink transmissions (transmissions from the PC). After each device estimates the downlink channel with the received SRMP frame, this subfield is set to the appropriate rate.

After receiving the last SR frame, the PC sends a *Data Transmission Multi-Poll* (DTMP) frame. A polling sequence in the DTMP frame is constructed by the second scheduler based on the information obtained from the SR frames. The operation of this scheduler will be described in Section 3.3. The frame format is illustrated in Fig. 2(c). The *Polling Count* field contains the number of stations to be polled in the Data Transmission Period (DTP). The *Polling Control* field consists of three sub-fields: *AID*, *TXOP*, and *Up-Rate*. These three sub-fields specify the ID of a station to be polled, the time duration assigned to the station for transmission of pending frames, and the data rate for uplink frames, respectively. After the PC estimates the channel with the received SR frames in the SCP, an appropriate data rate is chosen for the transmission of the polled station. In comparison to the inaccurate TXOP allocations in the HCF and CP-MP, the PC can accurately allocate TXOPs to stations based on the information obtained from SR frames such as the number of polling frames and the selected physical transmission rate. Therefore, the time wasted due to the inaccurate allocation of TXOP is reduced. Each polled station transmits data frames with the given data rate from the DTMP frame after the predecessor's TXOP expires.

We illustrate an example of the proposed multipolling MAC protocol through Fig. 1. We assume that there are one PC and four real time traffic stations (A, B, C, and D) in the BSS. Station E is a station in a neighboring BSS and can hear the transmission from Station C. In the beginning of the CFP, The PC sends a SRMP frame with the transmission sequence A → B → C → D. After the SRMP transmission and SIFS, each station sends a SR frame back to the PC. When Station E hears the SR frame from Station C, it sets its NAV to the value of the *Tentative-NAV* field. In this example, it is assumed that Station B has no frame to transmit. As a consequence, Station B is removed from the polling sequence of the DTMP frame. All stations except Station B, start to transmit according to the sequence given in the DTMP frame, and their physical layer frames are generated using the data rates specified in the DTMP. When Station E hears the transmission of the data frame from Station C, it resets its NAV to the value of the *Duration* field in the MAC header.

3.3 Polling Scheduler

We introduce two main factors for the proposed scheduling process. The first factor is the Service Period of Station i, SP_i. The SP_i is the estimated inter-arrival time of frames at Station i and is given by

$$SP_i = \left\lfloor \frac{P_i \cdot 8}{M_i \cdot T_{SF}} \right\rfloor, \qquad (1)$$

where P_i, M_i and T_{SF} are the payload in the MAC frame in bytes, the average data arrival rate in the MAC layer at node *i*, and the time duration of a superframe, respectively. P_i, M_i, and SP_i are obtained from the admission control unit. Note that SP_i is expressed in the number of superframes. We define a variable parameter ω_i related to SP_i in order to manage the polling time of Station i. The polling time will be illustrated in detail in Section 3.3.1. ω_i is initialized to SP_i and is decreased by one as every superframe passes by until its value reaches one. When ω_i becomes one, it is reset to SP_i at the next superframe.

The second factor, E_i^k, is the normalized number of transmitted frames during the previous *W* superframes at Station *i* in superframe k. This parameter is defined as

$$E_i^k = \sum_{j=k-W}^{k-1} e_i^j / M_i , \qquad (2)$$

where *W, the averaging window size,* is the number of previous superframes to be considered for the averaging, and e_i^j is the number of transmitted frames at Station *i* in superframe j. This parameter is tracked and updated by the PC in every superframe.

3.3.1 First Scheduler for SRMP

When the number of stations to be polled by SRMP is very large, a large amount of time is spent during the SCP, thus leading to excessive overhead and poor performance of the polling scheme. In order to avoid this situation, the following scheduler for SRMP is proposed:

At the first step, the number of stations to be polled in the current CFP *i*, N_i, is determined from the information obtained in the previous CFPs. When the PC experiences a shortage of the DTP to poll all stations with frames to transmit in the previous CFP, the number of stations to be polled by SRMP is reduced by one. The number is increased by one when the DTP is long enough to poll all stations with frames to transmit in the previous CFP.

In the second step, the polling sequence for the SCP is determined. Since a lower value of ω_i indicates that Station *i* has a higher probability of having frames to transmit, the stations with lower ω_i value are polled with higher priority. Therefore, the PC chooses N_i stations with low ω_i for the sequence. For stations that have the same ω_i value, the stations with lower E_i^k values should have higher priority to be polled because those stations have higher probabilities to have pending frames.

We define the polling time instant as the time instant when a station is polled. Since ω_i is estimated by the admission control unit, the polling instant in the time line is not synchronized with the actual time instant of frame generation. Consequently, in the third step, we need to adjust the polling instant to minimize the delay. This process is called *synchronization of polling instant*. We define the frame delay, T_d^i, to be the time duration from the time instant when one frame is generated in the MAC layer to the time instant when the frame is transmitted at Station *i*. When T_d^i is larger than T_{SF}, the PC changes the polling instant by updating ω_i as follows:

$$\omega_i = \begin{cases} SP_i - 1, & \text{if } T_d^i > \frac{(SP_i \cdot T_{SF})}{2} \text{ and } \omega_i = 1 \\ SP_i + 1, & \text{if } T_d^i \le \frac{(SP_i \cdot T_{SF})}{2} \text{ and } \omega_i = 1 \\ \omega_i - 1, & \text{if } T_d^i > \frac{(SP_i \cdot T_{SF})}{2} \text{ and } \omega_i > 1 \\ \omega_i + 1, & \text{if } T_d^i \le \frac{(SP_i \cdot T_{SF})}{2} \text{ and } \omega_i > 1 \end{cases} \quad (3)$$

T_d^i is reported by each station when its value is larger than T_{SF}. For this purpose, the *Subtype* subfield in the *frame control* field of the MAC header is used by the uplink frames. If the value of T_d^i is larger than $(SP_i \cdot T_{SF})/2$, the value of the *Subtype* subfield is set to 1000. Otherwise, the value of the *Subtype* subfield is set to 1001.

3.3.2 Second Scheduler for DTMP

From the stations polled by SRMP, the PC obtains information such as the data rate in the physical layer and the number of frames in the buffer at the MAC layer. According to these information, the PC allocates a TXOP to each station that has frames to transmit, with value of ω_i to be one. The TXOP for Station *i* is

$$TXOP_i = (T_{pre} + T_{PHY\_hdr} + T_{MAC\_hdr} + 2 \cdot T_{SIFS} + T_{ACK} + \frac{L_{Payload}}{R}) \cdot Q_i, \quad (4)$$

where T_{pre}, T_{PHY_hdr}, T_{MAC_hdr}, and T_{ACK} are the time durations of the preamble, the PHY header, the MAC header and the ACK frame, respectively. T_{SIFS} is the SIFS idle time. L_i is the length of the payload in bits, R_i is the data rate in the physical layer, and Q_i is the number of frames in the buffer of Station *i*.

4. PERFORMANCE EVALUATION

4.1 Simulation Model

We assume that all stations are uniformly distributed in the coverage area of an independent BSS with a diameter of 250 meters. One BSS and only uplink traffic are considered in this simulation. The parameters used in this simulation study are chosen based on the IEEE 802.11b DSSS standards [1]. The duration of the CFP varies depending on the number of stations, but it is not exceed *aCFPMaxDuration*, which is set to 30ms. We study two real-time traffic types, constant bit rate (CBR) and variable bit rate (VBR), in the simulation. The CBR traffic alternates between the two states, ON and OFF, and their durations are exponentially distributed with mean values of 1.0 sec and 1.35 sec, respectively. The CBR traffic generates a frame of 200 bytes payload at every 0.1 seconds. For the VBR traffic model, actual MPRG-4 video streams of Star Wars IV with a mean bit rate of 53Kbps and a peak rate of 940Kbps, are used [11]. The size of each video packet is set to 800 bytes based on [8]. According to the mean bit rate of 53 Kbps, one video packet is generated every 0.12 seconds. The delay limits of the voice and video packets are set to 0.1 and 0.12 seconds, respectively so that all frames must be transmitted before the next frame arrives. Each station has either one CBR or one VBR flow.

We use the log-normal shadowing channel model [12]. We set the path loss exponent to 2.56 and the standard deviation to 7.67 [12]. The received Signal-to-Noise Ratio (SNR) is varied according to the Ricean fading model. In this simulation, all stations are moving around with a slow pedestrian speed of 1m/s, within the coverage area of the BSS. Herein, it is assumed that the channel is constant during the period of one superframe. For the data rate of the physical layer of each communication link, we assume that the system adapts the data rate by properly choosing one from a set of modulation schemes according to the channel condition as described in [10].

4.2 Performance Comparison

Figs. 3(a) and (c) show the dropping probabilities, and Figs. 3(b) and (d) show the average delays for the CBR and VBR traffic. In this simulation, all stations in the BSS have same traffic type. The average delay is defined as the time duration from the arrival of a frame in the MAC layer to the departure of the frame. It is assumed that the instant that a frame is generated is the same as that of the frame arrival in the MAC layer. The performance of our proposed protocol is compared with those of two existing protocols. The first protocol is the contention free single polling (CF-SP) scheme with RTS/CTS frames in 802.11e and the second protocol is CP-MP. As the number of stations increases, the dropping probability of TS-MP reduces down to 4.5 % of that of CF-SP and 6% of that of CP-MP for the CBR traffic type. For the VBR traffic type, the dropping probability of TS-MP reduces down to 30 % of that of CF-SP and 38% of that of CP-MP for the CBR traffic type. However, we observe that the average delay of TS-MP with a small number of stations is larger than those of the other protocols. This is caused by the SCP in TS-MP. In each CFP, the first data frame in TS-MP is transmitted after the transmission of the DTMP frame. That is, most of the overhead in TS-MP is placed in the front of the CFP, whilst the overhead is distributed to each data frame transmission in CF-SP and CP-MP. Therefore, when the number of stations is small, the delay due to the overhead of the TS-MP protocol

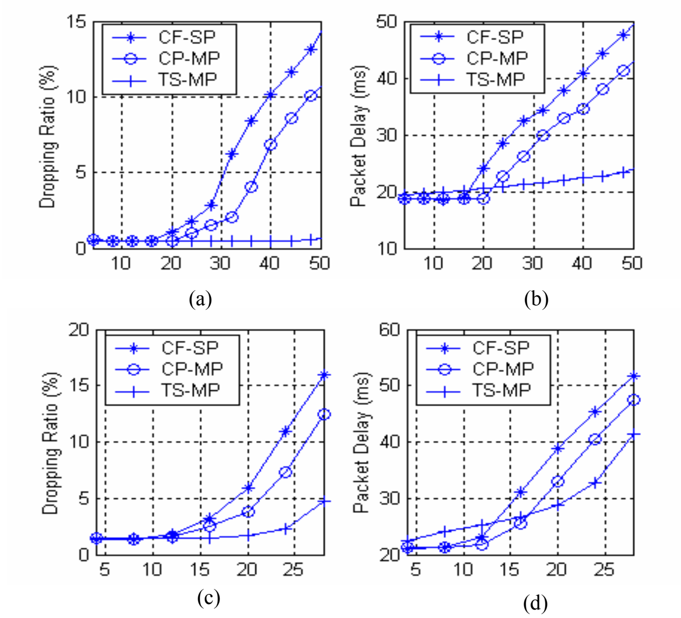

Figure. 3. Dropping probability and average delay as functions of the number of stations in (a), (b) for CBR traffic and (c), (d) for VBR traffic.

appears prominently. However, as the number of stations increases, all stations in CF-SP and CP-MP cannot be served during the current CFP because the required time to serve all stations passes over the maximum duration of the CFP due to the overheads. Thus, some of the stations are polled in the next CFP, which causes an additional delay. On the other hand, in TS-MP, most of stations are served in the current CFP so that the delay increases slowly as shown in Figs. 3(c) and (d).

Fig. 4 shows the frame dropping probabilities of TSMP with Rate Adaptation (RA) and without RA. In this simulation, stations with CBR or VBR traffic exist together in a BSS and the number of stations with CBR traffic is same as that of stations with VBR traffic. Using the rate adaptation function of TS-MP, we can reduce the dropping probability by

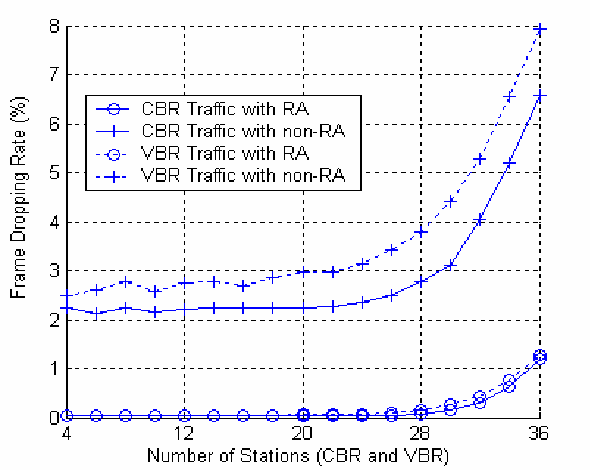

Figure 4. Comparison of dropping probabilities between TS-MP with rate adaptation and without rate adaptation

70% ~ 98% comparing to that of TSMP without rate adaptation. This shows our polling scheme adapts to the time varying wireless channel.

5. CONCLUSIONS

In this paper, we propose a new polling-based MAC protocol for the PCF in IEEE 802.11 WLAN. The major innovation is the use of two multipolling frames with different purposes. Through the first multipolling, the PC obtains information required to schedule the polling sequence for data transmission. The second multipolling coordinates data transmissions to avoid collision. Comparing with the single polling scheme, the proposed scheme can reduce the overhead caused by the polling frames. Furthermore, since the PC is able to obtain information about the stations and communication links, the proposed protocol supports more efficient scheduling schemes as well as rate adaptation. From simulation, we have shown that the proposed polling-based MAC protocol gives significant performance improvements over the other polling-based MAC protocols.

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