HMM: Hybrid Multipolling Mechanism with Pre-allocation Admission Control for Real-Time Transmissions in WLANs

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Abstract— **The need of multimedia applications inspirits the IEEE 802.11e medium access control (MAC) protocol being an emerging supplement to wireless local area networks (WLANs) for supporting quality-of-service (QoS) transmissions. In recent years, the demand of supporting real-time communications has become more and more important in multimedia wireless networks. However, the IEEE 802.11e Standard doesn't provide a sufficient real-time scheduling algorithm to support dynamic admission control of bounded delay requirement of the real-time traffic. Thus, in this paper, we propose a dynamic requirement allocation scheme named *hybrid multipolling mechanism* (HMM), which is based on the hybrid coordination function (HCF) of the IEEE 802.11e, to enhance the utilization of network bandwidth. Moreover, in order to make better use of the HMM, we will provide an admission control named pre-allocated admission control (PAC) to provide more real-time services. The simulation results show that the proposed HMM increases the channel utilization and reduces the control overhead very well. We also show that our scheme guarantees time bounded services as well as maximizes the network utilization.**

I. INTRODUCTION

With the advent of wireless broadband technologies providing higher channel data rates, the wireless multimedia market is poised for rapid growth. Recently, the real-time multimedia applications are very popular, such as voice over IP (VoIP) and video-on-demand (VOD). Among the above, the flow type of VoIP needs bidirectional and constant bit rate (CBR) service requests. It needs higher time sensitivity to make the communication of telephone smoothly. Thus, the requirement of schedule time is very strict. As for VOD, it needs unidirectional variable bit rate (VBR) service requests. Compared with CBR, VBR needs a dynamic channel access allocation mechanism to guarantee varied length of data frame.

The IEEE 802.11e medium access control (MAC) protocol [3] enables wireless local area networks (WLANs) to support quality-of-service (QoS) transmissions. A new hybrid coordination function (HCF) has been proposed in the IEEE 802.11e draft. The HCF includes two channel access mechanisms. One is contention-based channel access and the other is controlled channel access. The contention-based channel access, also called enhance distributed channel access (EDCA), provides different and distributed access to the wireless medium (WM) for QoS stations (QSTAs) using eight different user priorities.

Besides, the controlled channel access, called HCF controlled channel access (HCCA), uses a QoS-aware centralized coordinator, called a hybrid coordinator (HC). The HC can operate during the contention period (CP) and contention free period (CFP) to coordinate the medium access. During the CP, when the station receives a QoS contention-free poll (CF-Poll) frame from the HC, channel starts controlled access phase (CAP) for contention-free transfer of QoS, and ends when each QSTA receives a CF-END frame. During the CFP, the starting time and maximum duration of each transmission opportunity (TXOP) is specified by the HC using CF-Poll frame.

However, the IEEE 802.11e does not provide an efficient polling mechanism to support real-time services and an admission control mechanism to enhance the channel utilization. Therefore, in this paper, we first propose hybrid multipolling mechanism (HMM) with pre-allocation admission control (PAC) to improve the performance of IEEE 802.11e protocol. The proposed HMM not only enhance the aggregate throughput of ordinary IEEE 802.11e but admit more concurrent connections at the same time. Furthermore, the HMM reduces the blocking probability of requested connections as well as lowers the delay of requested services.

II. RELATED WORK

Whenever a QSTA wants to request a real-time service, it would try to send an add traffic stream request (ADDTS-Request) frame R to the HC in a basic service set (BSS). The ADDTS-Request means a QSTA wants to add a real-time connection into the HC and has three important fields: the TXOP, the minimum service interval $I_{\min}$, and the maximum service interval $I_{\max}$ based on IEEE 802.11e. The HC depends on these requests information to decide schedule strategy. In order to schedule these real-time connections more efficiently, [5] designs a scheduling algorithm called schedule contention free burst (S-CFB) that chooses the joint I of these real-time requests into the same group, named contention free burst (CFB), and transmits the real-time data in each group according to a predefined schedule base on HCF. The algorithm can satisfied the time bounded services. However, the control

octets: 2	2	6	2	2	6 x Record Count			4
Frame Control	Duration /ID	BSSID	CBR Record Count (0~255)	Record Count (0~255)	Poll Record (6 octets)			FCS
					AID (2)	backoff (2)	TXOP (2)	

Fig. 1. The hybrid multipolling frame format.

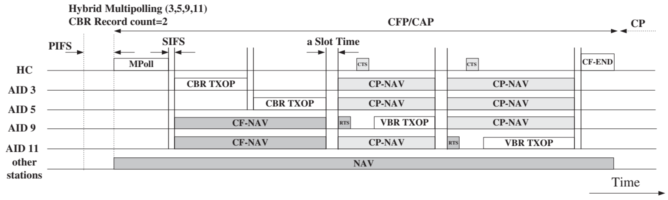

Fig. 2. An example of hybrid multipolling mechanism.

overhead of the S-CFB could be reduced further if it involves some efficient polling mechanisms.

In order to reduce control overhead efficiently, there have been two multipolling mechanisms, which are contention free multipolling (CF-MPoll) [1], [2] and contention period multi-polling (CP-MPoll) [4]. In the CF-MPoll mechanism, after HC sends a CF-MPoll frame, each polled QSTA needs to monitor the channel activity and if a QSTA wants to transmit data, it has to wait for a SIFS period after its predecessor completes transmission in the polling order. When QSTAs transmit VBR data, the bandwidth cannot be effectively allocated because of not knowing each duration information of each transmission. Therefore, it might allocate too much bandwidth and cause the bandwidth waste. In short, the advantage of this mechanism can reduce control overhead but can't support the VBR connections effectively.

The CP-MPoll mechanism incorporates the DCF access scheme into the polling scheme. The basic idea is to send the polling order into the contending order which determines the order of winning the channel contention. Different backoff time values have been assigned to the flows in the polling group. The corresponding QSTAs execute the backoff procedures after receiving the CP-MPoll frame. The contending order of these STAs is the same as the ascending order of the assigned backoff time values. When HC wins the channel contention, RTS and CTS frames with proper duration information are exchanged. The advantage of this mechanism is that QSTA can use RTS and CTS frames flexibly for channel access and it is suitable for transmitting VBR connections. But, if it transmits CBR data, RTS and CTS frames are unnecessary and cause bandwidth waste.

III. The Hybrid Multipolling Mechanism

A. Hybrid Multipolling

This section will describe our proposed hybrid multipolling mechanism (HMM) in detail. The HMM compiles the CBR data and VBR data polling information into a beacon frame named hybrid mulitpolling (H-MPoll) to indicate the transmission order in the time interval. Each QSTA would follow the recorded information of the H-MPoll to transmit its data frame after receiving the H-MPoll information from HC. The frame format of H-MPoll is shown in Fig. 1. The CBR Record Count (CRC) field indicates the number of CBR connections and the Record Count (RC) field records the number of QSTAs in this beacon interval. And the Poll Record records polling information of each QSTA that includes: 1) the associate identifier (AID) subfield contains an association identifier which identifies an QSTA in the basic service set (BSS), 2) the Backoff subfield specifies the backoff time value, and 3) the TXOP Limit T subfield specifies the maximum duration in which the polled QSTA could transmit frames.

The HMM divides the CFP into fixed and unfixed time interval for two different kinds of data transmissions CBR and VBR. Each QSTA which has CBR data and polled by HC will transmit its data frame orderly according to the present order in the H-MPoll. The transmission is divided by a time interval equals short inter-frame space (SIFS). The VBR connection of QSTAs will set the contention free network allocation vector (CF-NAV) value and equals $\sum_{i=1}^{k}(T_{\mathrm{CBR},i} + \mathrm{SIFS})$, where k is the number of polled CBR connections. After sensing a idle slot followed by CF-NAV, QSTAs, which has VBR data frames, start to reserve the bandwidth for transmission. The HMM uses backoff mechanism to set the access order of QSTAs. The transmission duration of each VBR connection is controlled by using the request-to-send/clear-to-send (RTS/CTS) mechanism to inform other QSTAs of the duration of transmission. We note that the CTS is sent by HC since all QSTAs in the BSS is covered by HC to prevent hidden terminal problems. If a polled QSTA does not react within a point inter-frame space (PIFS) interval, the HC then resends the H-MPoll frame to re-poll the rest members.

Fig. 2 illustrates the proposed HMM. There are four QSTAs in the polling list. AID3 and AID5 are CBR connections and AID9 and AID11 are VBR connections. In the H-MPoll frame, the number of CRC is 2, and the backoff time of AID3, AID5, AID9, and AID11 are 0, 0, 1, and 2, and the corresponding TXOP Limit are 10, 10, 20, and 20 respectively. At the beginning, AID9 and AID11 is paused by CF-NAV and AID3 and AID5 sends data according to the H-MPoll. When the CF-NAV expires, AID9 and AID11 start to execute the backoff procedure. After finishing the backoff countdown, AID9 sends a RTS frame to inform HC of its transmission duration and HC then uses CTS to retrain other QSTAs in the BSS to transmit data. The AID11 transmit its data after AID9 finishes its transmission. Finally, HC will send a CF-END frame to end the polling procedure when all polled transmission are finished.

B. Pre-allocation Admission Control

The blocking probability and channel utilization would be further improved if we adopt an efficient admission control algorithm to program the requested connection. Therefore, in this section, we provide a dynamic scheduling algorithm named pre-allocated admission control (PAC) to provide more real-time services. In order to serve more real-time requests, we use the $I_{\max}$ of each real-time request to determine an appropriate beacon interval (BI) when a real-time request R_i of node i into the HC. The process procedure are shown as follows.

Step 1: Determination of the basic BI. To reduce the complexity of this method, we have to define BI B as a fixed length, which is determined when the HC is established. This will be in favor of admission control. The value is suggested to be the minimum $I_{\max}$ of the current real-time requests and is equal to $\min\{I_{\max,i} | i = 1, \ldots, n\}$, where n is the number of admitted connections.

Step 2: Determination of the factor ω of each request. Since the $I_{\max}$ of each request might be bigger than the basic BI, the appearance in which BI should be determined before the request is allocated. We use ω_i to represent the relationship between each connection i and the basic BI and use it to execute the admission control test. The factor ω_i is derived as

$$\omega_i = \left\lfloor \frac{I_{\max,i}}{B} \right\rfloor. \quad (1)$$

Step 3: Calculation of the channel utilization. In order to perform admission control test, we have to precalculate the ratio of channel utilization U of $\mathrm{BI}_{i+1}, \ldots, \mathrm{BI}_{i+\omega}$ to check out whether the request r would be admitted or not. The channel utilization is derived as

$$U = \frac{t_{\mathrm{CBR}} + t_{\mathrm{VBR}} + T_r}{B}, \quad (2)$$

where t_{CBR} and t_{VBR} represent the total transmission time of CBR and VBR connections, and the T_r is the requested time quantum, respectively. The t_{CBR} can be obtained by

$$t_{\mathrm{CBR}} = \sum_{i=1}^{k} (\mathrm{SIFS} + T_{\mathrm{CBR},i}), \quad (3)$$

where $T_{\mathrm{CBR},i}$ represents the duration of AIDi's transmission. In addition, the calculation of the total transmission time of VBR denoted as t_{VBR} is given by

$$t_{\mathrm{VBR}} = \sum_{i=1}^{v} (\mathrm{slot} + T_{\mathrm{VBR},i} + t_{\mathrm{RTS}} + t_{\mathrm{CTS}} + 2\mathrm{SIFS}), \quad (4)$$

where v is the number of admitted VBR connections and equal to $n - k$. The t_{RTS} and t_{CTS} represent the transmission time of RTS and CTS control frame. We note that the corresponding transmission time of T_{CBR} and T_{VBR} is determined by the channel bit rate. If the calculated value of U is smaller than 1, the request r will be admitted.

Step 4: Selection of an initial BI. After executing the admission control test, the HC will select the minimum U as the pre-allocation BI. The selection of minimum of U can be obtained by

$$U_{\min} = \min \left\{ U_j \leq 1 \;\middle|\; j = i+1, i+2, \ldots, i+\omega \right\}, \quad (5)$$

where i represents the current BI. If the set of $U_{\min}$ is empty, the request r would not be admitted. If $U_{\min}$ has more than one element, the HC will allocate the request r to the preceding BI.

IV. Simulation Models and Results

A. Simulation Environment

Our simulation environment is based on IEEE 802.11e standard. There are 30 QSTAs and a HC placed in the environment. The system parameters of our considered environment are listed in Table I. These values are referred to the IEEE 802.11e standard. The real-time traffic parameters are shown in Table II. In order to evaluate the performance of our proposed mechanism, we will use two scenarios in our simulation.

TABLE I
System Parameters Used in the Simulation

Parameters	Values
Channel bit rate	11 Mbps
Superframe length (BI)	25 μs
PLCP preamble and header length	96 μs
SIFS	10 μs
PIFS	30 μs
AIFS	50 or 70 μs
Slot Time	20 μs
RTS frame length	20 bytes
CTS frame length	14 bytes
ACK frame length	14 bytes
HMM frame size	$18 + 6\times$polling list size
CF-End fame length	20 bytes

TABLE II
Traffic Parameters

Parameters	Voice	Video
Peak Data Rate	64 Kbps	420 Kbps
Mean Data Rate	64 Kbps	240 Kbps
Minimum Data Rate	64 Kbps	120 Kbps
Maximum SI	25 ms	75 ms
Minimum SI	20 ms	60 ms

Scenario I: The goal of this scenario is to show the characteristic of providing more opportunities to serve the real-time requests by using proposed HMM. In this scenario, each QSTA will only transmit two kinds of real-time connections, which are voice (CBR) and video (VBR). Excepting these two kinds of real-time connections, no other kinds of data connections are generated. We set the ratio of voice and video data, which request for connection, as 4:1 and 1:4. The data arrival rate is increased from low (0.1) to high (1). Each admissive connection of voice transmission will persist for 30 seconds and each video connection will persist for 60 seconds. Each simulation runs 180 seconds. After transmission is completed, the bandwidth will release for other QSTA to compete for creating connections. In the following experiments, we compare our mechanism with S-CFB [5].

Three important performance metrics are investigated: 1) Blocking probability: That is the probability of each QSTA which is not admitted to create a connection. From this, we can know the relationship between numbers of admitted connections and blocking probability. 2) Average queuing delay: This is the average queuing time needed from a QSTA generating a request to starting polling. From this, we can know the average

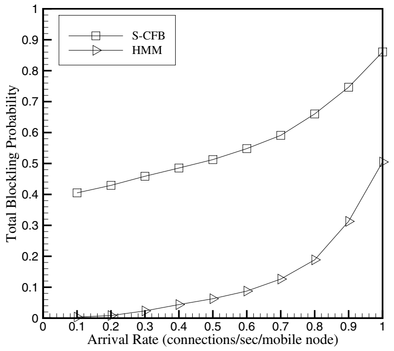

Fig. 3. The comparison of blocking probability of proposed HMM and S-CFB in each request by varying data arrival rate when voice:video = 4:1.

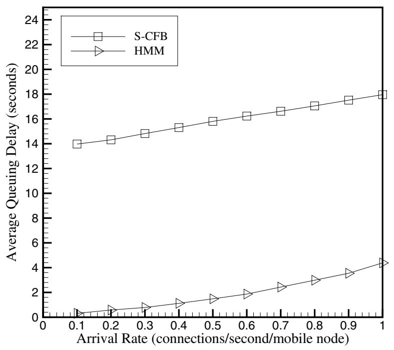

Fig. 4. The comparison of average queuing delay of proposed HMM and S-CFB in each request by varying data arrival rate when voice:video = 4:1.

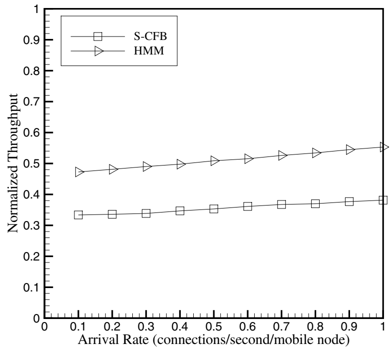

Fig. 5. The comparison of normalized throughput of proposed HMM and S-CFB by varying data arrival rate when voice:video = 4:1.

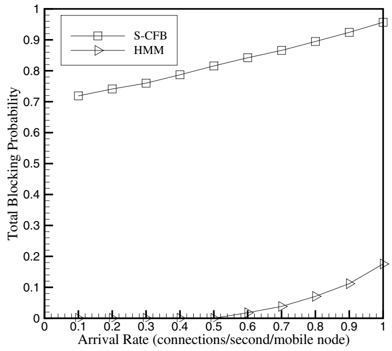

Fig. 6. The comparison of blocking probability of proposed HMM and S-CFB in each request by varying data arrival rate when voice:video = 1:4.

queuing time each QSTA needs when it wants to create a connection successfully. 3) Normalized throughput: This is the data transfer rate in our simulation. From this, we can know the performance of this system.

Model 1: voice:video = 4:1. In this simulation model, only small number of video connections is allowed. Because in the proposed PAC, HC can only allocate a few numbers of video connections to BIs, numbers of connections which is admitted are reduced. In the Fig. 3, when the desire to create a connection is low, the blocking probability of our mechanism is smaller than S-CFB. When the desire to create a connection is high, the blocking probability is still smaller than S-CFB. In the Fig. 4, we can see that the average queuing delay is smaller than S-CFB because our mechanism can serve more connections. In the Fig. 5, we can see that the throughput is higher than S-CFB because of our mechanism serving more connections and distributing connections to different BIs.

Model 2: voice:video = 1:4. We set admitted connections are mainly video connections in this model. The proposed PAC can distribute video connections to each BI efficiently. Therefore, HC can serve much more video connections than S-CFB. In the Fig. 6, we can see that in our mechanism, the blocking probability keeps very low in this situation. On the contrary, in the same condition, the blocking probability of S-CFB is quite high because S-CFB serves more video connections and spends more time while transmitting data. In the Fig. 7, we can see that when a connection is established, the queuing time shrinks because HC can serve more video connections. In the Fig. 8, we can see that the throughput is effectively raised.

Scenario II: In this scenario, the transmission performance of three polling mechanisms: HMM, CF-MPoll [2] and CP-MPoll [4] is investigated. We restrict the numbers of the real-time connections of the HC and, in addition, QSTA has to transmit non-real-time data to keep the traffic load on 1.5. Also, we set that the HC serves the voice and video connections in the rate of 4:1 and 1:4, and each real-time connection will not stop transmitting data until the simulation ends. The simulation will last for 60 seconds. In the conditions we set, we want to observe the throughput of the channel in these three polling mechanism.

Model 1: voice:video = 4:1. In this setting, most of the connections are voice connections. In CP-MPoll mechanism, QSTA needs to transmit RTS and CTS control frame to inform QSTAs of each transmission time. It will waste bandwidth and lower the throughput in such setting. In CF-MPoll mechanism,

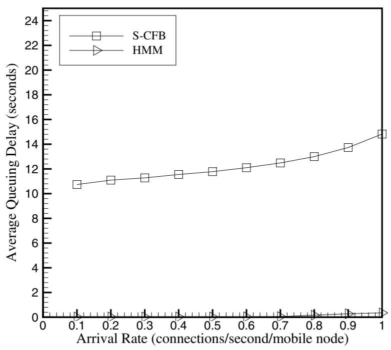

Fig. 7. The comparison of average queuing delay of proposed HMM and S-CFB in each request by varying data arrival rate when voice:video = 1:4.

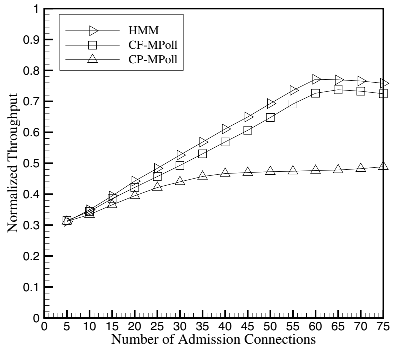

Fig. 9. The comparison of normalized throughput of proposed HMM, CF-MPoll, and CP-MPoll when voice:video = 4:1.

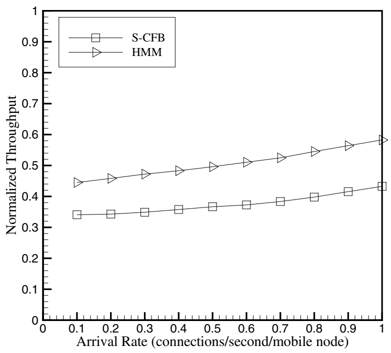

Fig. 8. The comparison of normalized throughput of proposed HMM and S-CFB by varying data arrival rate when voice:video = 1:4.

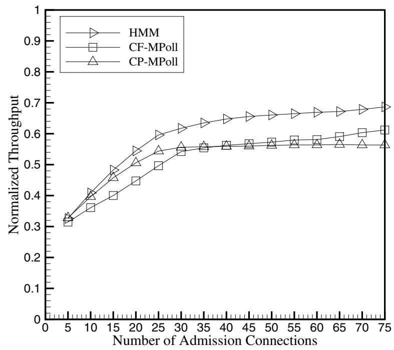

Fig. 10. The comparison of normalized throughput of proposed HMM, CF-MPoll, and CP-MPoll when voice:video = 1:4.

QSTA will decide when to start transmitting data according to the TXOP of each connection, and therefore, it doesn't need to send RTS and CTS control frame. Consequently, the throughput in CF-MPoll mechanism is higher than CP-MPoll. In our HMM, HC will choose different polling mechanism according to the characteristics of CBR and VBR connection. When serving CBR connections, QSTA is able to decide when to start transmitting data. While serving VBR connections, QSTA can send RTS and CTS control frame to release bandwidth for other QSTA to transmit non-real-time data. Therefore, under such setting, the throughput in HMM is higher than other two mechanism. We can see these phenomena in Fig. 9.

Model 2: voice:video = 1:4. In this setting, most transmission types are video (VBR) connections. In the Fig. 10, we can see that when the numbers of total connections are less than 25, the throughput in CP-MPoll mechanism is higher than in CF-MPoll mechanism because VBR connections can release bandwidth in CP-MPoll mechanism. But, when the numbers of total connections are over 35, CP-MPoll can't serve connections any more. Therefore, the throughput in CF-MPoll mechanism is higher than which in CP-MPoll mechanism. However, the throughput in HMM is still higher than other two mechanisms. Therefore, HMM can serve connections in any kinds of setting effectively.

V. Conclusions

In this paper, according to CBR/VBR characteristics, we designed a hybrid multipolling mechanism (HMM) with pre-allocation admission control, which can reduce control overhead, release bandwidth dynamically and increase admitted real-time service requests. Simulation results showed that the proposed HMM does increased the channel utilization and reduced the control overhead very well.

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