

Admission Control in IEEE 802.11e Wireless LANs

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Abstract—Although IEEE 802.11 based wireless local area networks (WLANs) have become more and more popular due to low cost and easy deployment, they can only provide best effort services and do not have quality of service (QoS) supports for multimedia applications. Recently, a new standard, IEEE 802.11e, has been proposed, which introduces a so-called hybrid coordination function (HCF) containing two medium access mechanisms: contention-based channel access (EDCA) and controlled channel access (HCCA). In this paper, we first give a brief tutorial on the various MAC-layer QoS mechanisms provided by 802.11e. We show that the 802.11e standard provides a very powerful platform for QoS supports in WLANs. Then, we provide an extensive survey of recent advances in admission control algorithms/protocols in IEEE 802.11e WLANs. Our survey covers the research work of admission control for both EDCA and HCCA. We show that those new MAC-layer QoS schemes and parameters provided in EDCA and HCCA can be well utilized to fulfill the requirements of admission control so that QoS for multimedia applications can be provided in WLANs. Last, we give a summary of the design of admission control in EDCA and HCCA, and point out the remaining challenges.

I. INTRODUCTION

WITH the diminishing costs of electronic hardware, IEEE 802.11 based wireless local area networks (WLANs) have been massively deployed in public and residential places such as classrooms, airports and apartments, and more and more devices and peripherals are integrated with WLAN access capability. On the other hand, with the increasing popularity of multimedia applications, quality of service (QoS) support in communication networks has become more and more important. QoS can be interpreted as the ability for a network to provide some consistent services for multimedia delivery. The internet engineering task force (IETF) has defined two different frameworks, integrated services (IntServ) [1] and differentiated services (DiffServ) [2], for Internet traffic with QoS. Compared with wired networks, to provide QoS in wireless networks is even more challenging since wireless networks have limited bandwidth, and radio channels are error-prone environment affected by multi-path, shadowing, interference, weather and so on.

For WLANs, IEEE 802.11 is designed for best effort services. The 802.11 standard specifies two medium access control (MAC) mechanisms: the mandatory Distributed Coordination Function (DCF) and the optional Point Coordination Function (PCF) [3]. The lack of a built-in mechanism for supporting real-time services makes it very difficult to provide QoS guarantees for multimedia applications. To enhance the

QoS support in 802.11, the IEEE 802.11 working group is currently working on a new standard, known as the IEEE 802.11e [4]–[6] which introduces the so-called hybrid coordination function (HCF). HCF includes two medium access mechanisms: contention-based channel access, controlled channel access (includes polling). Contention-based channel access is referred as enhanced distributed channel access (EDCA), and controlled channel access is referred as HCF controlled channel access (HCCA).

Although the 802.11e standard has defined the QoS-enabled MAC mechanisms, how to apply these mechanisms in different QoS issues is not specified. Among various QoS issues, admission control is an important component for the provision of guaranteed QoS parameters. The purpose of admission control is to limit the amount of traffic admitted into a particular service class so that the QoS of the existing flows will not be degraded while at the same time the medium resources can be maximally utilized. In this article, we provide a survey of recent advances in admission control algorithms/protocols in IEEE 802.11e WLANs. Our survey covers the research work of admission control for both EDCA and HCCA. Our purpose is to study how those new QoS schemes and parameters provided in EDCA and HCCA can be well utilized to fulfill the requirements of admission control so that QoS for multimedia applications can be provided in WLANs.

The paper is organized as follows. In Section II, we give an overview of 802.11, introducing the legacy DCF and PCF schemes. In Section III, we introduce the 802.11e QoS-enabled MAC mechanisms including EDCA, HCCA and some other schemes. After that, in Section IV and V, we survey the recent research work of admission control for both EDCA and HCCA. Finally, in Section VI, we conclude this paper with some discussions.

II. AN OVERVIEW OF IEEE 802.11

802.11 refers to a family of specifications developed by the IEEE for the WLAN technology, which operates at either the 2.4 GHz ISM band or the 5 GHz UNII band. Since the release of the first 802.11 standard in 1997, many task groups have been formed, aiming at enhancing either the MAC layer or the PHY layer. Up to date, there are three major amendments of 802.11:

- 1) 802.11b, which provides data rates ranging from 1 to 11 Mbps and operates at the 2.4 GHz band with the direct sequence spread spectrum (DSSS) technology [7];
- 2) 802.11a, which provides data rates up to 54 Mbps and operates in the 5 GHz band with the orthogonal frequency division multiplexing (OFDM) technology [8].

This research is partially supported by Singapore A*STAR SERC Grant (032 101 0006).

- 3) 802.11g, which increases 802.11b's data rates up to 54 Mbps within the 2.4 GHz band by using the OFDM technology [9].

In 802.11 WLAN, the MAC layer defines the procedures for 802.11 stations to share a common radio channel. DCF is a contention based access control scheme targeted at delivering classic data services, while PCF is a contention-free access control scheme targeted for time-bounded services. In practice, most 802.11 products in the market only support DCF. Note that in 802.11 there are two ways to organize stations of WLANs: the infrastructure mode and the ad-hoc mode. In this article we only consider the infrastructure mode.

A. Distributed Coordination Function

DCF works as a "listen-before-talk" scheme based on CSMA/CA where stations listen to the medium to determine when it is free. If a station that has packets to send senses the medium is busy, it will defer its transmission and initiate a backoff counter. The backoff counter is a uniformly distributed random number between 0 and contention window (CW). Once the station detects that the medium has been free for a duration of DCF Interframe Space (DIFS), it starts a backoff procedure, i.e., decrementing its back-off counter as long as the channel is idle. If the backoff counter has reduced to zero and the medium is still free, the station begins to transmit. If the medium becomes busy in the middle of the decrement, the station freezes its backoff counter, and resumes the countdown after deferring for a period of time, which is indicated by the so-called network allocation vector (NAV) stored in the winning station's packet header.

It is possible that two or more stations begin to transmit at the same time. In such a case, a collision occurs. Collisions are inferred by no acknowledgement (ACK) from the receiver. After a collision occurs, all the involved stations double their CWs (up to a maximum value, CW_{max}) and compete to gain control of the medium next time. If a station succeeds in channel access (inferred by the reception of an ACK), the station resets its contention window CW to CW_{min} .

We can see that DCF does not provide QoS supports since all stations operate with the same channel access parameters and have the same medium access priority. There is no mechanism to differentiate different stations and different traffic.

B. Point Coordination Function

PCF provides contention-free transmission. In PCF, time is divided into superframes. A superframe includes a contention period (CP), where DCF is used, and a contention-free period (CFP), where PCF is used. A superframe starts with a beacon management frame transmitted by the access point (AP), which acts as a point coordinator. The time used by the AP to generate beacon frames is called target beacon transmission time (TBTT), which is announced in the previous beacon frame. PCF uses the point interframe space (PIFS), which is longer than short interframe space (SIFS) but shorter than DIFS, to provide point coordinators higher priority in medium access than DCF stations.

During the CFP, the AP polls its associated stations according to a pre-determined order called polling-list (usually in a round-robin manner). No station is allowed to transmit unless it is polled. If there is no pending transmission in a polled station, the response is a null frame containing no payload. The CFP ends when the AP sends a CF-end message. If the CFP terminates before all stations have been polled, the polling list will be resumed at the next CFP cycle from the previous stopping point. If the AP receives no response from a polled station after waiting for a PIFS, it will poll the next station or end the CFP. In this way, no idle period longer than a PIFS occurs during a CFP.

Compared with DCF, PCF is more complicated and requires central control. As for supporting QoS, PCF still has some problems [10], [11]. For example, PCF has the unpredictable beacon delay problem. That is a beacon has to be delayed if there is an unfinished DCF frame at the end of the previous superframe. Another problem is that it is very difficult to predict the transmission time of a polled station because the polled station can transmit a frame of any length between 0 and the size of the maximum MAC service data unit (MSDU).

III. IEEE 802.11E QoS MECHANISMS

Due to the limitations of DCF and PCF, the 802.11e defines a single coordination function, HCF, which combines the functions from both DCF and PCF for QoS data transmission. In 802.11e, a superframe still consists of the two phases of operations, i.e., CP and CFP. EDCA is only used in the CP while HCCA can be used in both phases. The major benefits offered by the 802.11e standard are

- 1) Reducing the latency through prioritizing different types of traffic packets;
- 2) Enabling access points (APs) to allocate resources based on data rate and latency requirements from each individual station;
- 3) Improving wireless bandwidth efficiency and reducing packet overheads.

A. HCF Contention-Based Channel Access

In EDCA, the QoS support is realized through introducing multiple access categories (ACs) in each QoS station (QSTA). EDCA defines four ACs, and different ACs have different priorities, servicing different types of traffic. Table I [4] shows the mapping between the user priorities (UPs) specified in IEEE 802.1D [12] and the ACs in 802.11e.

As shown in Fig. 1, each AC is an enhanced variant of DCF that contends for transmission opportunity (TXOP) using AC-specified channel access parameters from the EDCA parameter set, which includes

- Minimal CW value for a given AC ($CW_{min}[AC]$): CW_{min} can be different for different ACs. Assigning smaller values of CW_{min} to high priority classes can ensure that high priority classes obtain more TXOPs than low priority ones.
- Maximal CW value for a given AC ($CW_{max}[AC]$): Similar to CW_{min} , CW_{max} is also on a per AC basis.

TABLE I

THE MAPPING BETWEEN THE USER PRIORITIES IN 802.1D AND THE ACCESS CATEGORIES IN 802.11E.

Priority	User priority in 802.1D	Access Category (AC)	Designation (Informative)
Lowest	1	AC[0]	Background
	2	AC[0]	Background
	0	AC[1]	Best Effort
	3	AC[1]	Video
	4	AC[2]	Video
	5	AC[2]	Video
Highest	6	AC[3]	Voice
	7	AC[3]	Voice

- **Arbitration Interframe Space ($AIFS[AC]$):** Each AC starts its backoff procedure after the channel is idle for a period of $AIFS[AC]$ instead of DIFS. The $AIFS[AC]$ for a given AC should be equal to a short interframe space (SIFS) plus multiple time slots, i.e., $AIFS[AC] = aSIFSTime + AIFSN[AC] * aSlotTime$. Considering $DIFS = aSIFSTime + 2 * aSlotTime$ in legacy 802.11, $AIFSN[AC]$ is typically set to not less than 2 such that the shortest waiting time is DIFS.
- **$TXOPlimit[AC]$:** TXOPs obtained via EDCA are referred as EDCA-TXOPs. During an EDCA-TXOP, a station may be allowed to transmit multiple data frames from the same AC with a SIFS gap between an ACK and the subsequent data frame transmission. $TXOPlimit[AC]$ gives the limit for such a consecutive transmission.
- **“Virtual Collision”:** If the backoff counters of two or more co-located ACs in one station elapse at the same time, a scheduler inside the station treats the event as a virtual collision. The TXOP is given to the AC with the highest priority among the “colliding” ACs, and the other colliding ACs defer and try again later as if the collision occurred in the real medium.

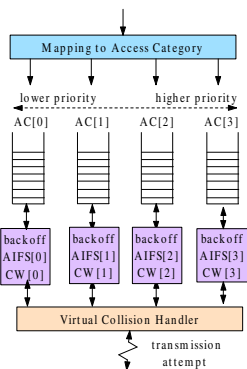


Fig. 1. The virtual backoff of the four access categories.

B. HCF Controlled Channel Access

Although EDCA improves the legacy DCF, it is not sufficient to provide effective traffic protection and QoS guarantees, especially under high traffic loads. Here comes the need for the polling-based medium access mechanism, HCCA.

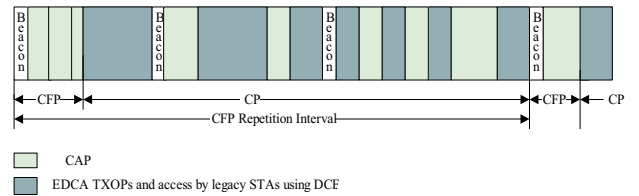


Fig. 2. The CAP/CFP/CP periods.

Similar to the legacy PCF, HCCA provides polled access to the wireless medium. In particular, HCCA uses a QoS-aware hybrid coordinator (HC), which is typically located at the QoS access point (QAP) in infrastructure WLANs. HC uses PIFS to gain control of the channel and then allocates TXOPs to QSTAs, which are referred as HCCA TXOPs or polled TXOPs. Unlike PCF, HCCA can poll the QSTAs during contention periods (CPs), and HCCA takes into account QSTAs’ specific flow requirements in packet scheduling. Fig. 2 illustrates the different periods under HCCA. Note that the CAP (controlled access phase) is defined as the time period when HC maintains the control of the medium. It can be seen that CAPs consist of not only CFPs but also parts of CPs.

After grabbing the channel, the HC polls QSTAs in turn according to its polling list. In order to be included in the polling list of the HC, a QSTA must send a QoS reservation request using the special QoS management frame, and each individual flow needs one particular reservation request. Fig. 3 depicts a common frame format for carrying traffic specification (TSPEC) parameters. The major TSPEC parameters [4], [13] include

- **Mean data rate (ρ):** the average bit rate for packet transmission, in bits per second (bps);
- **Delay bound (D):** the maximum delay allowed to transport a packet across the wireless interface (including queuing delay), in milliseconds;
- **Maximum service interval (SI_{max}):** the maximum time allowed between neighbor TXOPs allocated to the same station, in microseconds;
- **Nominal MSDU size (L):** the nominal size of a packet, in octets;
- **Minimum PHY rate (R):** the minimum physical bit rate assumed by the scheduler for calculating transmission time, in bps.

For the definitions of other parameters, details can be found in the 802.11e draft [4].

Note that, although the QAP decision is based on the characteristics of individual flows, the HCCA TXOPs are actually assigned on a per QSTA basis instead of per flow, and each QSTA is then responsible for allocating the TXOPs to its individual flows.

C. Other QoS Mechanisms

In addition to EDCA and HCCA, the 802.11e draft also provides some other MAC mechanisms for QoS enhancements.

Block acknowledgement (Block ACK): Block ACK can be initiated through a setup and negotiation process between a

Element ID	Length	TS Info	Nominal MSDU Size	Maximum MSDU Size	Minimum Service Interval	Maximum Service Interval	Inactivity Interval	Suspension Interval
Service Start Time	Minimum Data Rate	Mean Data rate	Peak Data Rate	Maximum Burst Size	Delay Bound	Minimum PHY Rate	Surplus Bandwidth Allowance	Medium Time

Fig. 3. A common management frame format for traffic specification.

QSTA and the QAP. Once the block ACK has been established, multiple QoS data frames are transmitted in a contention free burst with a SIFS interval between adjacent frames. This mechanism helps to reduce the bandwidth overheads imposed by the conventional acknowledgement mechanism, which requires an individual ACK to every successful data frame.

Direct link protocol (DLP): DLP allows two stations associated with the same QAP to directly transmit data to each other. This facilitates the efficient use of the transmission medium as transmissions do not need to be directed through the QAP any more.

No acknowledgement (No ACK): For certain applications, 802.11e allows no ACK to be sent. This feature is very useful for the applications which have stringent delay requirements but can tolerate a significant amount of packet loss (e.g., voice over IP).

Piggyback: 802.11e allows to send data “piggybacked” on polls and ACKs to reduce overhead. This feature can improve the overall network performance.

Through combining the various MAC QoS mechanisms in 802.11 together, it is possible to provide QoS and efficiently utilize medium resources at the same time.

IV. ADMISSION CONTROL FOR EDCA

Similar to DCF, EDCA is very likely to be the dominant channel access mechanism in WLANs because it is a distributed MAC scheme and is easy to implement. In the past few years, we have seen many research works focusing on admission control in EDCA. Basically, the existing EDCA admission control schemes can be classified into two categories: measurement-based admission control and model-based admission control. In the measurement-based schemes, admission control decisions are made based on the continuously measured network conditions such as throughput and delay. On the other hand, the model-based schemes construct certain performance metrics to evaluate the status of the network.

A. Measurement-Based Admission Control

1) *Distributed Admission Control (DAC)* [14], [15]: The DAC was proposed by the 802.11e working group to protect active QoS flows. Even though it is not supported in the latest draft, it is a good start point to study admission control mechanisms in EDCA.

In the DAC, via beacons the QAP announces the transmission budget, which is the additional amount of time available for each AC during the next beacon interval. In order to calculate transmission budget, the QAP needs to measure the

amount of the time occupied by the transmission of each AC during each beacon interval. Then, the QAP computes the transmission budget for each AC by subtracting the occupied time from the transmission limit of this AC. Each station determines an internal transmission limit per AC for each beacon interval based on the successfully used transmission time during the previous beacon period and the transmission budget announced from the QAP. When the transmission budget for an AC is depleted, a new flow will not be able to obtain any transmission time, and existing flows will not be able to increase their transmission time too.

One problem of the DAC scheme is that it is difficult to avoid network performance vibration because a station always adjusts its transmission parameters at every beacon interval. Another shortcoming of the DAC scheme is that it can only protect existing flows when the traffic load is not very heavy. In addition, this scheme does not provide direct relationships between those TXOP parameters and the QoS requirements from applications.

2) *Two-Level Protection and Guarantee Mechanism* [16]: Based on the DAC scheme, the authors further proposed a two-level protection and guarantee scheme. The purpose of the first-level protection is to protect each existing voice or video flow from new and other existing QoS flows, while the purpose of the second-level protection is to protect the existing QoS flows from best-effort traffic.

In particular, two enhancements, *tried-and-known* and *early-protection*, are introduced in the original DAC scheme. In the *tried-and-known* mechanism, a new voice/video flow is first accepted tentatively, and then tries to measure throughput and delay performances for some beacon intervals. If the average throughput and/or delay do not meet reasonable requirements, the flow will kill or reject itself. In the *early-protection* mechanism, when the budget is below a certain threshold, new flows are not allowed to enter. This first-level protection performs well on protecting each individual existing QoS flow from new and other existing QoS flows.

However, too many best-effort data transmissions can also degrade the existing QoS flows since many collisions might occur. Therefore, the second-level protection, i.e., dynamically controlling the EDCA parameters, is introduced. The basic idea is to increase the initial contention window size and inter-frame space for best-effort traffic when the number of active stations is large. In this way, the number of collisions can be kept relatively small.

Because this two-level protection scheme is based on the DAC, it also has the problems of performance oscillation and lack of direct QoS relationships with applications. Moreover, it introduces more adjustable parameters and finding the optimized parameters is not a trivial task.

3) *Virtual MAC and Virtual Source Algorithms* [17], [18]: The basic idea of the virtual MAC and virtual source algorithms is to virtually run the applications and the MAC processes in order to measure the achievable service qualities. Based on the virtually measured service qualities, QSTAs determine whether a new flow should be admitted or not.

The Virtual MAC (VMAC) algorithm operates in parallel to the real MAC in a station, and it handles “virtual packets”

instead of real packets. The VMAC schedules virtual packets on the radio channel in the same way as real packets. However, unlike the case of real packets, when the VMAC decides to send a virtual packet, it does not transmit anything but estimates the probability of collision if the virtual packet were “really” sent. When a collision is “detected”, the VMAC enters a backoff procedure, just like what a real MAC would do.

The virtual source (VS) algorithm consists of a virtual application, a interface queue, and the VMAC. The virtual application generates virtual packets like a real application (e.g., generating virtual voice packets at a constant rate). Packets are time-stamped and placed in a virtual buffer. After a virtual packet has been processed in the VMAC, the total delay is calculated by comparing the current time with the time-stamp stored in the packet.

The advantage of these virtual algorithms is that they do not cost any channel bandwidth. However, they need a lot of extra processing in each mobile host. And, the main criteria for the admission decision is based on delay and collision estimations. No achievable throughput information is available.

4) *Threshold-Based Admission Control [19]*: In this scheme, each station needs to measure the traffic condition on the wireless link. Depending on how the traffic condition is measured and computed, the admission control can be implemented in the following two ways:

- **Using relative occupied bandwidth:** T_{Busy} is defined as the amount of time when the wireless medium is busy. The relative occupied bandwidth is defined as $B_{occu} = \frac{T_{Busy}}{T} \times 100\%$, where T is a fixed sampling period. Let B_{lo} , B_{up} be the given lower and upper thresholds for B_{occu} . Let an active AC denote an admitted AC and an inactive AC denote an AC refused to be admitted. We summarize the criteria to admit data flows as
 - $B_{occu} \leq B_{lo}$: Admit the inactive AC with the highest priority during the next period of T .
 - $B_{lo} \leq B_{occu} \leq B_{up}$: No action taken.
 - $B_{occu} \geq B_{up}$: Stop the transmission of the lowest active AC during the next period of T .
- **Using average collision:** In this case, instead of using the relative occupied bandwidth, a new variable, average collision ratio, is employed for admission control. The average collision ratio is defined as $R_c = N_c/N_t$, where N_c is the number of collisions occurred and N_t is the total number of transmissions. Similarly, there are two thresholds: the lower threshold R_{lo} and the upper threshold R_{up} . Except using the new parameters R_c , R_{lo} and R_{up} , the criteria for admission control is the same as that in the case of using relative occupied bandwidth.

Although this threshold-based admission control is very easy to implement, the threshold values are difficult to set. In addition, since the transmission of data flows will be stopped when network resources are unavailable or resumed when network resource are available, there is no way to guarantee the instantaneous QoS metrics.

5) *HARMONICA [20], [21]*: In the HARMONICA scheme, the AP periodically samples the link-layer quality indicator (LQI) parameters, which includes drop rate, link-

layer end-to-end delay and throughput, for each traffic class. Two adaptation algorithms over different time scales are employed to select the channel access parameters, which can best match the QoS requirements of each traffic class and the current channel contention level. In particular, one adaptation algorithm adjusts the relative differences between the channel access parameters of different classes for the purpose of QoS guarantee. The other adaptation algorithm synchronously adapts the channel access parameters of all the classes (increase all or decrease all) to achieve high channel utilization.

HARMONICA employs a simple and flexible admission control mechanism to avoid congestion. Whenever a new real-time application requires admission, the HARMONICA will select a traffic class i that best matches its QoS requirement and then execute an admission control process. The decision of admission control is based on the throughput requirement ($Req_{throughput}$) of the flow and the monitored LQI parameters. The key idea is to check whether it is possible to squeeze some bandwidth out of the current throughput for the best effort class ($BE_{throughput}$) on the condition of guaranteeing a minimal bandwidth (BE_{Min}) for the best-effort traffic class. In particular, in order to admit a new QoS flow, three requirements need to be satisfied:

- The relative adaptation has reached a stable state;
- $BE_{throughput} - Req_{throughput} \geq BE_{Min}$;
- The bandwidth in $BE_{throughput}$ can be “translated” into Class i without loss.

The HARMONICA scheme shows that, through dynamically adjusting channel access parameters, it is possible to simultaneously match the QoS requirements, maximally utilize network resources and guarantee a minimal bandwidth for the best-effort traffic. However, how to find the optimal increment or decrement of the channel access parameters is still a challenging problem. If the chose increment or decrement is too large, the systems will oscillate. On the other hand, if the chose increment or decrement is too small, the system will take long time to reach the optimal status.

B. Model-Based Admission Control

1) Markov Chain Model Based Admission Control [22]:

In this scheme, the admission control is performed based on the predicted achievable throughput for each flow, which is calculated by

$$S_i = \frac{P_{si} \times E[P]}{P_c \times T_c + P_{idle} \times aSlotTime + P_s \times T_s}. \quad (1)$$

P_{si} is the probability of a successful transmission for the flow i , which is given by the product of the probability that the flow i is transmitting and another probability that no other flows is transmitting. On the other hand, if multiple flows transmit at the same time slot, a collision occurs. P_c , P_s and P_{idle} are the overall collision probability, the overall successful transmission probability and the overall idle (no transmission) probability, respectively. T_c and T_s are the collision time and the successful transmission time, respectively. $E[P]$ is the data payload.

From the definitions of P_{si} , P_c , P_s and P_{idle} , we can see that in order to calculate these probabilities, we need to first find a way to obtain the transmission probability for a flow. Luckily, based on the two-state Markov Chain model proposed in [23], the transmission probability for a flow i can be derived as

$$P_{ti} = \frac{2(1 - 2p_i)}{(1 - 2p_i)(W + 1) + p_i W(1 - (2p_i)^b)} \quad (2)$$

where p_i is the long term collision probability for the flow i , W is the CW_{min} size for the flow i , and b is maximum backoff stage. p_i can be obtained by using a counter for each active flow to keep track of the collision rate.

There are several problems in this algorithm. The first one is that the analytical model is derived under saturation conditions, where each station always has packets to transmit. In fact, this is not always true since in practice we often experience non-saturation conditions. Another problem is that the analytical model in [22], [23] does not take account of “virtual collision” between different AC queues in one station. Thus, if there are more than one flow in one station, the analytical model is not accurate at all.

2) Contention Window Based Admission Control [24]:

The key idea of this scheme is to adjust the CW values for different stations so that the goals of admission control can be fulfilled. In particular, suppose an IEEE 802.11e WLAN is operating with a contention window set $\{CW_1, \dots, CW_n\}$ that meets the throughput requirements $\{R_1, \dots, R_n\}$ for all stations. Let r_i denote the actual throughput experienced by the station i , where $r_i \geq R_i$. When a new station $(n + 1)$ wants to join the network with a throughput requirement of R_{n+1} , based on the proposed analytical model in [24], a new contention window set $\{CW'_1, \dots, CW'_n, CW'_{n+1}\}$ will be first calculated and then used to compute the throughput. If the resulting throughput meets the requirements, then the station $(n + 1)$ is accepted and the new contention window set is distributed to all the stations. Otherwise, the station $(n + 1)$ is rejected.

Similar to the Markov chain based scheme [22], this contention window based scheme also has the problems of not considering non-saturation conditions and “virtual collision”. In addition, only using CW to adjust throughput is somewhat limited in term of fully utilizing the capability of 802.11e.

V. ADMISSION CONTROL FOR HCCA

Unlike EDCA, there are not many research works on the admission control issue in HCCA. This is mainly due to the centralized control of HCCA, which results in the deterministic nature of admission control in HCCA. Thus, in term of research, the admission control of HCCA is not as challenging as that of EDCA. Another reason could be that the distributed MAC mechanism is much more popular than the centralized mechanism in practice. In the following, we will introduce a reference admission control scheme in 802.11e and our previous work in this area.

A. Reference Scheme

A reference admission control algorithm is developed in the 802.11e draft [4], [13]. In particular, the admission control is

based on a simple scheduler, which uses the mandatory set of the TSPEC parameters to generate a schedule. The mandatory set of the TSPEC parameters are Mean Data Rate (ρ), Nominal MSDU Size (L) and Maximum Service Interval (SI_{max}) or Delay Bound (D).

When a new flow requests for admission, the admission control process is performed in three steps.

- Step 1: The admission control unit (ACU) calculates the number of MSDUs that arrives at the mean data rate during the scheduled service interval SI as

$$N_i = \left\lceil \frac{SI \times \rho_i}{L_i} \right\rceil. \quad (3)$$

Note that the scheduled service interval SI must be a number lower than the minimum value of all the maximum service intervals for all the admitted flows, and must also be a sub-multiple of the beacon interval.

- Step 2: For a flow i , $TXOP_i$ is calculated as

$$TXOP_i = \max \left(\frac{N_i \times L_i}{R_i} + O, \frac{M}{R_i} + O \right), \quad (4)$$

where R_i is the minimum physical transmission rate, M is the maximum size of a MSDU, and O is the overhead in time units. The overhead includes interframe spaces, ACKs and etc.

- Step 3: Assuming there are k admitted flows, a new flow $k + 1$ is accepted if it satisfies

$$\frac{TXOP_{k+1}}{SI} + \sum_{i=1}^k \frac{TXOP_i}{SI} \leq \frac{T - T_{CP}}{T} \quad (5)$$

where T is the beacon interval and T_{CP} is the time for EDCA traffic.

B. Physical Rate Based Admission Control

The above reference design is somewhat inefficient because it is implemented based on the minimum physical rate. The actual physical rate of a station is quite different from the minimum physical rate at most of the time. Therefore, in our previous work [25], we proposed a more efficient admission control algorithm named physical rate-based admission control (PRBAC), which considers physical rate variance due to station mobility and wireless channel characteristics.

Most WLAN products adjust their physical rates according to the estimated wireless channel conditions [26], [27]. Stations use lower rates when they are far away from the AP and use higher rates when they move nearer to the AP. Low rates could also be selected in the cases of high path loss, high background noise, and extreme multipath effects in order to increase the robustness. In our proposed PRBAC, the basic idea is to use the long-term average physical rates for admission control, and at the same time use the instantaneous physical rates to distribute TXOPs to individual stations. In this way, our algorithm can admit more flows than the reference scheme, while the performance of each individual station is not degraded too much because the instantaneous physical rate is used to calculate TXOPs.

Note that in our proposed scheme, sometimes we have to drop packets. For example, when a lot of stations move away from the AP, it is very likely that the network resources will become insufficient and thus dropping packets is unavoidable. We handle such a problem by random selecting a QoS session and reducing its TXOPs by the amount of time for one packet. The same process is repeated continuously until Eqn. (5) is satisfied.

We have compared our proposed scheme with the reference scheme by simulation. In our simulation, 51 stations form a QBSS with one station being the QAP. We assume that the arrival of QoS session requests from QSTAs to the QAP is a Poisson process, and one QSTA has at most one QoS session at a time. In addition, each QSTA transfers background data traffic to the QAP, which employs the EDCA mechanism to access the medium. All the QSTAs move in a pattern according to the “random way-point” mobility model [28]. The QoS sessions arrival interval is changed from 5s to 12s in the simulation. Figure 4 and 5 show the session blocking probability and the packet drop probability for our proposed scheme and the reference scheme. We can see that our proposed scheme utilizes network resources much better than the reference scheme with only small performance degradation. More details can be found in [25].

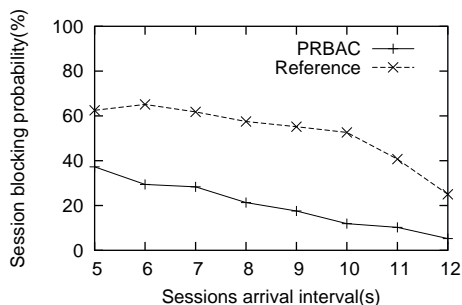


Fig. 4. The QoS session blocking probability for PRBAC and the reference scheme.

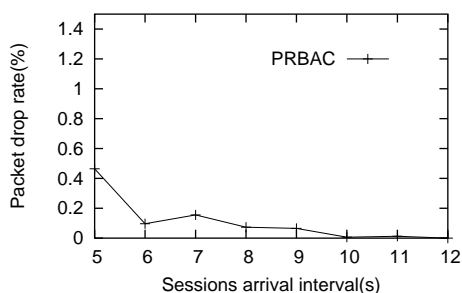


Fig. 5. The packet drop rate for PRBAC.

C. Admission Control for VBR Traffic

The above two schemes only consider the mean sending rate and the mean packet size of a flow. However, for VBR traffic, the instantaneous sending rate and the packet size are usually quite different from the corresponding mean values. Thus, a new admission control scheme for VBR traffic was

further proposed in [29]. The key idea is to introduce a new variable, effective TXOP (T_e) to replace TXOP in Eqn. (5). T_e is defined as the necessary TXOPs which can statistically guarantee that the packet loss probability is less than a threshold. In particular, there are two cases in calculating the packet loss probability.

VBR traffic with constant packet size: For the case of constant packet size, only the packet arrival rate is varying and the packet loss rate can be expressed as the mean number of packets loss during SI over the mean number of packets arrived during SI . Thus, the packet loss rate only depends on the probability distribution of the number of arrived packets.

VBR traffic with variable packet size: For the case of variable packet size, both the packet arrival rate and the packet size are varying. The packet loss rate should be expressed in term of packet transmission time rather than number of packets, i.e., the mean transmission time of the lost packets during SI over the mean transmission time of all the arrived packets during SI .

Given a desired packet loss probability, the effective TXOP duration of a newly arrived VBR flow can be inversely derived from the packet loss rate expression. Then, the same procedure as that in the reference scheme is applied for admission control except that we use the effective TXOP durations in Eqn. (5).

Besides our proposed admission controls scheme for VBR traffic, the work in [30] also takes the characteristics of VBR traffic into consideration. In [30], a fair scheduling algorithm named fair HCF (FHCF) was proposed to replace the simple round-robin scheduler in HCF. In particular, the FHCF scheme consists of two types of schedulers: QAP scheduler and node scheduler. The QAP scheduler estimates the queue length for each QSTA before the next SI . Based on these estimated queue lengths, the QAP adapts the computation of TXOPs accordingly. The node scheduler is to redistribute the unused time among its different traffic streams. We believe this FHCF scheme can be combined with the scheme in [29] to enable dynamic admission control and traffic scheduling for VBR traffic.

VI. CONCLUSION

In this paper, we have briefly introduced many MAC-layer QoS mechanisms provided in the upcoming 802.11e standard. These MAC-layer QoS mechanisms make the 802.11e standard a very powerful platform to support QoS in WLANs for multimedia applications. After that, we have surveyed various admission control schemes for both EDCA and HCCA. In particular, for EDCA, we have classified the admission control into two categories: measurement-based admission control and model-based admission control. The measurement-based schemes are usually effective and simple to implement in practice. However, without a theoretical foundation, it is very difficult to achieve an overall optimization. On the contrary, the model-based admission control schemes are based on some analytical models and it is possible to optimize the entire system. However, those analytical models are usually derived based on some unrealistic assumptions such as error-free physical channels for the purpose of simplifying the derivation.

Thus, the optimal solutions obtained by the analytical models might not be suitable for practical system. We believe a joint measurement and model based approach will be a good way for admission control in EDCA.

As we pointed out earlier, for HCCA, there are not many research works on the admission control issue. This is mainly due to the centralized control of HCCA, which results in the deterministic nature of admission control in HCCA. Thus, in term of research, the admission control of HCCA is not as challenging as that of EDCA. For HCCA, we have described the reference scheme of admission control in the 802.11e draft, our previous proposed physical rate based admission control, and the admission control schemes for VBR traffic.

Similar to the relationship between DCF and PCF, EDCA performs better at light traffic load due to less overhead while HCCA performs better at heavy traffic load due to less collision. Thus, EDCA and HCCA cannot replace each other and they can only complement to each other. As for the design of admission control, there are some fundamental differences between EDCA and HCCA. For example,

- HCCA provides deterministic QoS performance for applications with admission control while EDCA only provides statistics QoS performance. This is because of the contention-free nature of HCCA and the contention-based nature of EDCA.
- Admission control for HCCA can only be used in the infrastructure mode, while many admission control schemes in EDCA can be used in both the infrastructure mode and the ad hoc mode.

Although many admission control schemes have been proposed for EDCA and HCCA, a complete and comprehensive solution is still not available. There are many challenges remaining. For instance, in HCCA, it is not clear how to optimal select the effective TXOPs to tradeoff between flow QoS and network utilization. Another challenge is how to tradeoff between HCCA and EDCA in a mixed HCCA and EDCA scenario. For EDCA, the major challenge is how to optimally map the QoS requirements from applications into the channel access parameters. With the trend of all-IP networks in the future, it is even more challenging to develop admission control schemes under heterogenous wireless networks.

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