Achieving Per-Stream QoS with Distributed Airtime Allocation and Admission Control in IEEE 802.11e Wireless LANs

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***Abstract*— To support the transmission of (high-rate and often-bursty) multimedia data with performance guarantees in an IEEE 802.11e wireless local area network (LAN), it is crucial to design judicious algorithms for admission control and resource allocation. The traffic specification element (TSPEC) of the new IEEE 802.11e standard is used to facilitate the design of the admission control. Based on the traffic profile given in the TSPEC and the dual-token bucket regulation, a guaranteed rate is derived for our airtime-based admission control. The admission control is integrated with the contention-based Enhanced Distributed Channel Access (EDCA), which together can provide so-called "parameterized QoS" — as in the polling-based HCF Controlled Channel Access (HCCA) — via a new distributed, quantitative control of stations' airtime usage. We also extend the current QoS signaling of HCCA defined in IEEE 802.11e to perform admission control for this enhanced EDCA. Furthermore, we extend the integrated scheme for QoS provisioning in ad hoc wireless LANs and design appropriate signaling procedures. We evaluate via simulation the effectiveness of this parameterized QoS-capable EDCA scheme, and demonstrate its advantages over the centralized, polling-based HCCA scheme.**

I. INTRODUCTION

QoS and multimedia support are critical to wireless home and enterprise networks where voice, video and audio will be delivered across multiple networked electronic devices. Broadband service providers view QoS and multimedia-capable home networks as an essential ingredient to offer residential customers video-on-demand, audio-on-demand, voice-over-IP and high-speed Internet access. In order to support QoS, one needs an admission-control algorithm which makes decision on whether or not to admit a QoS stream based on the stream's requirements and channel usage conditions. Moreover, an effective resource allocation algorithm is also required in order to decide which stream and what frame in that stream should be transmitted at what time, such that the required QoS could be guaranteed.

Over the past few years, significant research efforts have been made on the problem of guaranteeing QoS for multimedia traffic in a packet-switched network. The goal has been to develop traffic management schemes that allow for high link utilization while simultaneously guaranteeing QoS. The general result of the extensive research on traffic management in wired networks states that the QoS can be guaranteed if and only if the traffic can be regulated using techniques, such as token and/or leaky buckets [1]-[6]. Providing QoS guarantees in a deterministic way to regulated sources that are statistically multiplexed in a shared buffer is also addressed in [1], [4], [5]. The deterministic QoS guarantees typically imply admission of a small number of bursty multimedia streams that results in poor resource utilization. Along with this problem is QoS provisioning in the wireless domain where one might have to design integrated admission control and resource allocation that can work in a distributed manner, and deal with the users or applications using time-varying transmission rates on wireless channels that exhibit location-dependent errors. Some solutions to this problem have been proposed in form of different scheduling schemes in [7]-[20].

In this paper, we focus on the problem of QoS provisioning in the upcoming IEEE 802.11e wireless LAN [21], primarily because of its popularity and increasing market share. The new MAC protocol in the 802.11e standard is called *Hybrid Coordination Function* (HCF). The word "hybrid" comes from the fact that it combines a contention-based channel access mechanism, referred to as *Enhanced Distributed Channel Access* (EDCA), and a polling-based channel access mechanism, referred to as *HCF Controlled Channel Access* (HCCA), each of which operates disjointedly during alternating subsets of the beacon interval. These two access mechanisms provide two distinct levels of QoS: prioritized and parameterized QoS. EDCA is used to provide the prioritized QoS service. With EDCA, frames with different priorities are transmitted using different carrier sense multiple access/collision avoidance (CSMA/CA) parameters. HCCA is used to provide a parameterized QoS service. With HCCA, a station negotiates the QoS requirements of its stream(s) with the Hybrid Coordinator (HC). Once the stream is established, the HC allocates transmission opportunities (TXOPs) via polling, to the station, in order to guarantee the stream's QoS.

Although EDCA is designed to provide prioritized QoS only, it is desirable to have EDCA provide parameterized QoS because (1) EDCA uses CSMA/CA for channel access and does not require centralized control as HCCA does, hence making it suitable for potential QoS support in an ad hoc wireless

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LAN and (2) there is no need for coordination between two contention-based wireless LANs operating on the same channel in an overlapping space while resource coordination is needed for two overlapping HC-coordinated wireless LANs. However, there are some challenges to overcome in providing parameterized QoS under EDCA. One of the biggest challenges is that a quantitative control of stations' medium occupancy (i.e, airtime usage) cannot be achieved via the current EDCA. Such a control, which is crucial to the parameterized QoS, is only provided by the HC in HCCA. What makes the airtime usage control even harder is that the link adaptation in the 802.11 standard allows stations to vary their PHY transmission rates based on the link condition. As a result, the amount of airtime required to transmit a fixed-size data frame may be different for different stations, and may even vary with time for the same station. For example, if a station reduces the PHY rate due to link errors, the number of data frames transmitted during each access to the wireless medium is reduced, which may compromise the negotiated QoS.

To address the above issues, we adopt the TSPEC element in the IEEE 802.11e standard to derive a "guaranteed rate." This rate includes a stream's traffic characteristics and serves as an overall QoS expectation from the stream's perspective. Based on this rate information and a negotiated PHY transmission rate, we propose an airtime-based admission control to solve the problems resulting from the link adaptation. This admission control is integrated with a "parameterized QoS-capable" EDCA, which provides a quantitative control of stations' channel access (and thus, their airtime usage) in a distributed manner. By using the proposed scheme, we are able to provide the parameterized QoS — in addition to the prioritized QoS — in EDCA without using the polling-based HCCA. We also compare the polling-based HCCA and the contention-based EDCA, in terms of their support for parameterized QoS via simulation, and show the effectiveness of the integrated airtime-based admission control and the enhanced EDCA.

The rest of this paper is organized as follows. In Section II, we briefly introduce the IEEE 802.11e standard, especially EDCA/HCCA and their support for QoS provisioning. Section III derives the guaranteed rate and describes the proposed airtime-based admission control. In Section IV, we give an overview of how to regulate the EDCA parameters for precise, quantitative airtime usage control. In Section V, we describe the signaling for QoS provisioning in HCCA, EDCA, and ad hoc wireless LANs. Our in-depth simulation results are presented in Section VI and the paper is concluded in Section VII.

II. OVERVIEW OF THE IEEE 802.11E STANDARD

The most important tasks of providing parameterized QoS in an IEEE 802.11e wireless LAN are to (1) determine the amount of TXOPs needed to meet streams' QoS requirements, and (2) decide how the TXOPs are allocated to those streams. In what follows, we will give an overview of how these tasks may be achieved in an IEEE 802.11e wireless LAN. Although our main focus is on how to provide parameterized QoS in EDCA, we also briefly explain HCCA for a comparative purpose.

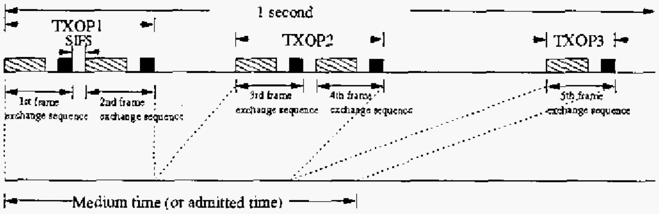

Fig. 1. Contention for TXOPs in EDCA: a station has to compete with others for TXOPs via CSMA/CA with exponential random backoff.

A. *Enhanced Distributed Channel Access (EDCA)*

The current EDCA provides distributed and differentiated access to the wireless medium for 8 user priorities. In order to do this, EDCA defines access categories (ACs) that provide support for the delivery of traffic with user priorities at wireless stations. Each AC is, in fact, an enhanced variant of the IEEE 802.11 DCF (referred to as the "legacy" DCF) [22], which uses CSMA/CA with random backoff to access the wireless medium. The most significant difference between an AC and the legacy DCF is that different ACs use different access parameters (e.g., minimum/maximum contention window size, interframe space (IFS)) to acquire prioritized access to the wireless medium while the legacy DCF only provides egalitarian access to the wireless medium.

For each TXOP won by an AC via EDCA, the wireless station may initiate multiple frame-exchange sequences, separated by a short inter-frame space (SIFS), to transmit traffic within the same AC. However, the total duration of the frame-exchange sequences must not exceed the TXOP limit whose value could be obtained in the beacon frames from the access point (AP). In order to support parameterized QoS, the admission control in the AP needs to determine the fraction of every one-second period (so called the *Medium Time* in the AP's response frame to a station's QoS request) that is needed by a wireless station to deliver the traffic from a stream. The station receiving the response frame records this medium time as the admitted time, which is the amount of time the station must win (via contention) to transmit frames within a one-second period. This procedure is illustrated in Figure 1.

The problem here is that, although the AP can determine the values of the medium time for wireless stations, it does not have control on how the stations obtain the required medium time. Instead, each station (or its ACs) uses EDCA to acquire the TXOPs, and hopefully obtains enough transmission time (at least not less than the allocated time) while not over-occupying the wireless medium to comprise other stations' QoS. Therefore, it calls for the need of a quantitative control on stations's TXOP usage, not just a prioritized EDCA in the current 802.11e standard, so that the stations can obtain the exact amount of TXOPs in a distributed manner.

B. *HCF-Controlled Channel Access (HCCA)*

HCCA uses a QoS-aware centralized coordinator, namely, the hybrid coordinator (HC), as a polling master to allocate TXOPs to itself and other stations. Because of this polling-based mechanism, stations can easily obtain their required amount of

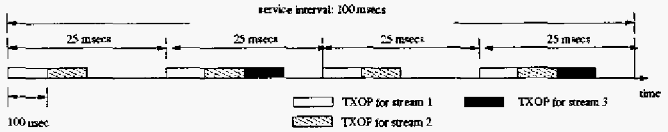

Fig. 2. Service schedule in HCCA: the required TXOPs are calculated by the HC and then allocated to streams via polling.

medium access time as compared to that under EDCA. What the HC needs to compute are the polling order and the amount of TXOPs granted to a station for each polling (together called a "service schedule" in the 802.11e standard), and polls each station to initiate frame-exchange sequences. To give an example of how a service schedule is computed, let us consider 3 multimedia streams that generate packets with size of 600 bytes every 25, 25, and 50 msecs with delay bounds of 100, 100, and 200 msecs, respectively. For an illustrative purpose, we do not include any polling frames or control overhead in computation, and we assume all streams are transmitted at 48Mbps. To provide the delay-bound guarantee, one can choose the polling period (i.e., "service interval" in the 802.11e standard) as the minimum of all streams' delay bounds. In this example, we have a service interval of 100=min(100,100,200) msecs. Within this interval, the first two streams need $\frac{100}{25} * 600 * 8/48 * 10^6 = 400$ μsecs to transmit four data frames while the last stream only needs 200 μsecs to transmit two frames. One possible implementation of the service schedule in this example is illustrated in Figure 2.

Although HCCA is recommended for parameterized QoS in the IEEE 802.11 wireless LANs primarily because of its efficiency, it is less flexible in the sense that the HC may need to recompute the service schedule when a traffic stream is added to, or deleted from, the wireless LAN, or a station on the wireless LAN changes the physical transmission rate. Moreover, when two wireless LANs using HCCA operate on the same channel, it requires additional coordination between them. On the other hand, EDCA is more flexible as we will discuss later. We will detail the advantages/disadvantages of these two channel-access mechanisms in terms of QoS provisioning and system complexity after introducing our admission control and resource allocation algorithms.

III. AIRTIME-BASED ADMISSION CONTROL

Although EDCA and HCCA use different channel-access mechanisms to allocate TXOPs to wireless stations, they both need admission control to determine how much traffic a wireless LAN can handle so that the prescribed QoS for each traffic stream can be maintained. Of course, an admission decision should be made according to both admission policies and QoS requirements supplied by a higher-layer entity of a wireless station, usually the application layer. These requirements are specified in the TSPEC element in the IEEE 802.11e standard and are submitted to the admission control unit (ACU) by stations carrying the streams. Since the TSPEC element plays a crucial role in our admission control, we first introduce some of its important fields which will be used later in deriving the guaranteed rate.

A. Overview of the TSPEC Element

A station can request parameterized QoS using the TSPEC element [21]. The TSPEC element contains the set of parameters that characterize the traffic stream that the station wishes to establish. These parameters are used by the admission-control algorithm and are negotiable between the station and the ACU. There are six important fields in the TSPEC used in our admission-control algorithm. We first discuss these fields and show how to use them to derive the guaranteed rate.

- The *Mean Data Rate* (ρ) field specifies the average data rate of a traffic stream, in bits per second, for transport of MAC service data units (MSDUs) of this stream.
- The *Peak Data Rate (P)* field specifies the maximum allowable data rate in bits per second, for transfer of the MSDUs of a traffic stream.
- The *Maximum Burst Size* (σ) field specifies the maximum data burst in bits that arrive at the MAC service access point (SAP) at the *peak data rate* for transport of MSDUs of a traffic stream. This definition is different from the conventional definition for burst size defined in the Resource Reservation Setup Protocol (RSVP) and other protocols where burst may arrive at an infinite rate.
- The *Minimum PHY TX Rate (R)* field specifies the minimum physical transmission rate, in bits per second, required to be operated by the station or the AP in order to guarantee the QoS. As an example, let us consider the IEEE 802.11b physical (PHY) layer which has 4 physical transmission rates. Assume that a CBR (constant bit rate) video stream with a bandwidth request of 2 Mbps is admitted into the wireless LAN. During the TSPEC negotiation, the station and the ACU agree that the QoS will be guaranteed if and only if the minimum PHY transmission rate is not below 5.5 Mbps. If the station now moves very far away from the AP and has to lower its rate to 2 Mbps, the AP will not guarantee its QoS for that stream. This is a very important parameter that is taken at the time of admission control, and we will use it to develop our admission-control policies.
- The *Delay Bound (d)* field specifies the maximum amount of time in units of microseconds allowed to transport an MSDU of a traffic stream, measured between the arrival of the MSDU at the local MAC layer and the start of successful transmission or retransmission of the MSDU.
- *MSDU Size (L)* field specifies the size of the frame in a traffic stream. The maximum value of L is fixed in the standard at 2304 bytes.

The Mean Data Rate, Peak Data Rate, Maximum Burst Size, Minimum PHY Rate, and Delay Bound fields in a TSPEC represent the QoS expectations requested by a stream when these fields are specified with non-zero values. Unspecified parameters in these fields indicate that the station does not have any requirements on these parameters.

With the TSPEC element provided by a wireless station requesting QoS for a traffic stream, the problem left for the ACU is simple — can the ACU admit that stream into the network and support QoS guarantees for all admitted streams? The ACU may decide to admit a stream only if its peak data rate can be supported (for the best QoS) or may simply admit the stream as long as the mean data rate is available. The former approach ends up with admitting fewer streams and the latter approach barely supports QoS for bursty streams. Therefore, we derive a *guaranteed rate* based on the stream's TSPEC parameters and the dual-token bucket traffic regulation. The dual-token bucket is associated with each stream and is situated at the entrance of the MAC buffer. It takes into account the mean/peak data rate and maximum burst size parameters from the TSPEC element to ensure that the actual arriving frames of the corresponding stream comply with these TSPEC parameters. Figure 3 shows the dual-token bucket filter where the bucket size is set as $B = \sigma \cdot (1 - \rho/P)$.

One can easily have the arrival process of a stream passing through the dual-token bucket filter constrained by

$$A(t, t+\tau) = Min(P\tau, B + \rho\tau), \tag{1}$$

where $A(t, t+\tau)$ is the cumulative number of arrivals during $(t,\ t+\tau)$. From Eq. (1) we can construct the arrival rate curve which is drawn in Figure 4. Since the guaranteed rate has to be less than the peak rate but large enough to satisfy a stream's delay requirement, the relation between the guaranteed rate (g) and the delay bound (d) can be found as illustrated in Figure 4. Using the distance formula, one can easily derive the guaranteed rate g_i for stream i

$$g_i = \frac{\sigma_i}{d_i + \frac{\sigma_i}{P_i}}, \tag{2}$$

where σ_i, d_i and P_i are the maximum burst size, delay bound and peak data rate of stream i.

Since transmissions on the wireless medium are prone to errors, one may want to provide a larger guaranteed rate to compensate the stream for the failed transmission. By taking into account the error probability of stream i, $P_{e,i}$, we can obtain the new guaranteed rate as

$$g_i = \frac{\sigma_i}{(d_i + \frac{\sigma_i}{P_i})(1 - P_{e,i})}. \tag{3}$$

How to estimate $P_{e,i}$ is beyond the scope of this paper. One simple way is to use the RSSI value from a received data or acknowledgement frame to estimate the error probability.

One may want to use this guaranteed rate and conventional rate-based admission control so that stream i is admitted if

$$g_{i+1} + \sum_{k=1}^{i} g_i \le C, \tag{4}$$

where C is the channel capacity. However, the channel capacity depends on the PHY rates that stations are using in a multi-rate 802.11 wireless LAN. If all stations are only able to support PHY rates up to 36 Mbps, the channel capacity is 36 Mbps instead of 54 Mbps.[1] Therefore, such a simple admission control is impractical and we need an admission control that takes into account the stations' varying PHY rates of the multi-rate 802.11 wireless LAN.

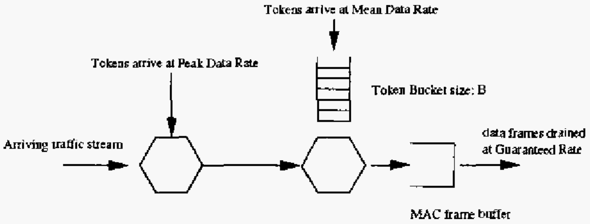

Fig. 3. The dual-token bucket filter for traffic policing.

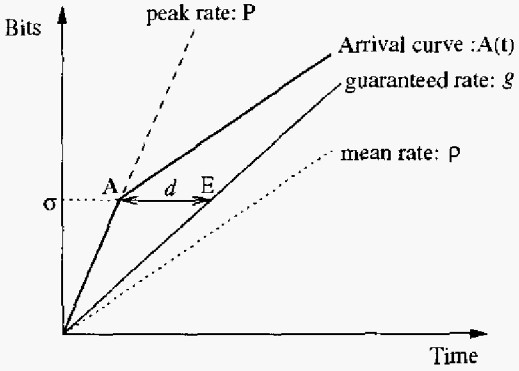

Fig. 4. Arrival curve at the entrance of MAC buffer and the guaranteed rate for a traffic stream.

B. *The Admission-Control Algorithm*

As discussed earlier, a wireless station may adapt its physical transmission rate to link conditions. If the ACU prescribes a guaranteed rate to a stream but the station carrying that stream transmits at a rate lower than the guaranteed rate, it is impossible to achieve the required QoS. For example, if stream A's guaranteed rate is 5 Mbps but the station carrying that stream is transmitting at 1 Mbps (the lowest rate in an IEEE 802.11b wireless LAN), it is impossible for Stream A to obtain the desired throughput of 5 Mbps. To remedy this problem, the proposed ACU only guarantees the QoS for a traffic stream subject to some constraints on the station's PHY transmission rate. That is, the wireless station can only receive QoS guarantees if and only if it maintains its PHY transmission rate higher than a pre-negotiated rate, namely, the minimum PHY TX rate (R) in the TSPEC.

Let us consider an HDTV stream in an IEEE 802.11 wireless LAN using 802.11a PHY layer. If the guaranteed rate for the HDTV stream including the overheads is 30 Mbps, the ACU may set the minimum PHY rate at 48 Mbps, meaning that the ACU allows the station to occupy 62.5 $(=frac3048)\%$ of the airtime for this HDTV stream. The ACU may also set the minimum PHY rate at 36 Mbps, meaning that 83 $(=frac3036)\%$ of the airtime is used by that HDTV stream. The more airtime a stream gets (e.g., 83%, as compared to 62.5%), the lower the PHY rate (e.g, 36 Mbps, as compared to 48 Mbps) a wireless station is allowed to use in order to still receive the guaranteed QoS (i.e., 30 Mbps). However, the wireless LAN may end up with admitting a very few traffic streams if the ACU provides such wide-range (in terms of the PHY rates) QoS guarantees. Such a trade-off between QoS guarantees and system utilization, due to the link adaptation, has to be made when

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[1] An 802.11a wireless LAN may support PHY rates of 6, 9, 12, 18, 24, 36, 48 and 54 Mbps.

one deals with the admission-control problem in the multi-rate IEEE 802.11 wireless LAN. As implied in this example, R_i (for station i) has to satisfy

$$R_i \geq \sum_{j=1}^{K} g_{i,j}, \tag{5}$$

where $g_{i,j}$ is the guaranteed rate for stream j in station i, and K is the total number of streams carried by station i. In this paper, the value of R_i is determined by the amount of wireless medium occupancy time (i.e., the airtime) that the AP is willing to allocate to the station.

With the guaranteed rate derived from the TSPEC, the amount of airtime, required by station i for its stream j in a one-second time interval, can be computed by

$$r_{i,j} = \frac{g_{i,j}}{R_i}. \tag{6}$$

Obviously, $r_{i,j}$ is less than 1 according to Eq. (5). With Eq. (6), whether or not to admit a new stream q from station p — for the parameterized QoS — is determined by

$$r_{p,q} + \sum_i \sum_j r_{i,j} \leq EA. \tag{7}$$

Here, the EA is the effective airtime ratio which is the percentage of airtime allocatable to wireless stations. Ideally, the value of EA is 1, but the actual value of EA is always less than 1 because of the control overhead incurred by the resource-allocation mechanisms. One can expect that using HCCA can achieve a higher EA than EDCA because of inevitable collisions caused by the contention in EDCA. We will compare the values of EA in HCCA and EDCA via stimulation in Section VI. The flowchart for QoS negotiation and admission control is depicted in Figure 5.

IV. ALLOCATION OF AIRTIME IN IEEE 802.11 WIRELESS LANS

The admission control by Eq. (7) requires an effective airtime allocation mechanism to ensure that each station acquires its share of airtime, r_i. Since HCCA relies on a polling-based mechanism, it can easily allocate the required amount of airtime to wireless stations. As in the example of Section II-B, the HC needs to calculate the Service Interval (SI) as:

$$SI = \frac{1}{2}\min\{d_1, d_2, \ldots, d_{k+1}\}, \tag{8}$$

where d_i is stream i's delay bound. To calculate the required amount of TXOPs for stream i, we need to determine the number of frames that have to be drained from this stream at the guaranteed rate. The number of frames N_i is given by

$$N_i = \left\lceil \frac{SI \times g_i}{L_i} \right\rceil, \tag{9}$$

where L_i is stream i's frame size. Then, the TXOP for this stream is obtained as

$$TXOP_i = max\left(\frac{N_i L_i}{R_i}, \frac{M}{R_i}\right) + O, \tag{10}$$

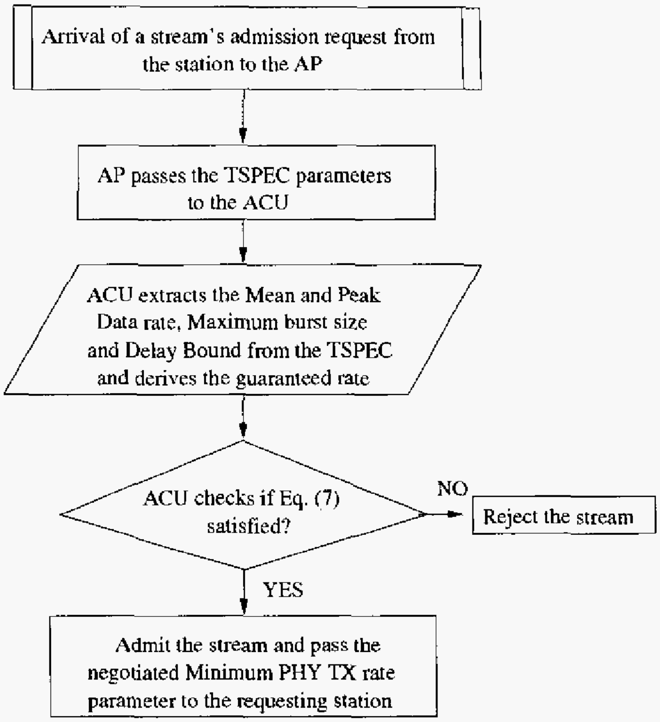

Fig. 5. Airtime-based admission control for both EDCA and HCCA.

where R_i is the negotiated minimum PHY rate for stream i, M is the maximum frame size, and O is the overhead in time units, including the inter-frame spaces, acknowledgement frame and polling overheads. Due to space limitation, details for the overhead calculations are omitted here.

Unlike the polling-based HCCA, EDCA relies on a distributed, contention-based mechanism. To realize the parameterized QoS, we need each wireless station (or its ACs) to use adequate EDCA parameters. In what follows, we focus on how to determine the EDCA parameters for stations based on the airtime ratio r_i in the admission control. Then, we will compare HCCA and EDCA from the perspectives of QoS provisioning and system complexity.

A. *Controlled Airtime Usage in EDCA*

To control a station's airtime usage in EDCA, one may choose to control (1) the TXOP limit of each station and (2) the frequency of a station's access to the wireless medium. With the first method, all stations choose the same EDCA parameters, but each station can occupy the wireless medium for a different amount of time during each access. With the second method, each station occupies the medium for the same amount of time during each access but has a different medium "accessing frequency".

1) Controlling the TXOP Limit: Let r_i' be the fraction of airtime that station i should obtain and $TXOP_i$ be the value of station i's TXOP limit. Let T_i be the amount of time required to transmit a frame with size of L_i (excluding the frame header) from stream i at the negotiated minimum PHY rate R_i. T_i is

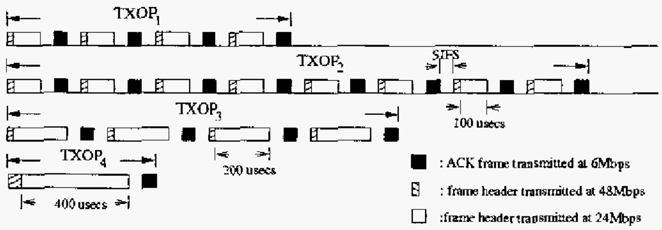

Fig. 6. Example 1 — selection of TXOP limits: given $SIFS$=16 μsecs, frame header size =34 bytes, and ACK frame size = 14 bytes in the IEEE 802.11a standard, we have $TXOP_1$=619.6 μsecs, $TXOP_2$=1255.2 μsecs, $TXOP_3$=1019.6 μsecs, and $TXOP_4$= 512.5 μsecs. *Physical layer overhead is not included in the computation.

obtained by

$$T_i = \frac{L_i}{R_i}. \tag{11}$$

Let M be the index of the stream such that $T_M = \max_i T_i$. Then, one can choose $TXOP_i$ as

$$TXOP_i = \frac{r_i T_M}{r_M T_i}\frac{L_i+H}{R_i} + (2\left\lceil\frac{r_i T_M}{r_M T_i}\right\rceil - 1)SIFS + \left\lceil\frac{r_i T_M}{r_M T_i}\right\rceil T_{ack} \tag{12}$$

where H is the MAC frame header size and T_{ack} is the amount of time to transmit an acknowledgement frame. For example, consider four streams with L_i = 600, 600, 1200 and 1200 bytes, respectively. We assume these four streams are required to transmit at least at the PHY rates of 48, 48, 48 and 24Mbps, respectively. Based on Eq. (11), we have $T_M = 1200 * 8/24 * 10^{-6} =$ 400 μsecs. If we assume r_i for each stream to be 0.1, 0.2, 0.2, and 0.1, respectively, then $N_i = \frac{r_i T_M}{r_M T_i}$ = 4, 8, 4, and 1, and N_i is actually the number of data frames that stream i should transmit during each access to the medium. The values of $TXOP_i$ are illustrated in Figure 6. If N_i is not an integer, a frame needs to be fragmented for precise airtime control.

With the values of $TXOP_i$ chosen by Eq. (12) and the fact that each station has a statistically equal probability to access the medium (because of using the same EDCA parameters), each station will obtain the amount of airtime proportional to its r_i' value. The maximum amount of airtime station i can get within an one-second period $r_{max,i}$ is

$$r_{max,i} = \frac{r_i}{\sum_i r_i} EA \geq \frac{r_i}{\sum_i r_i} \sum_i r_i \geq r_i, \tag{13}$$

given that Eq. (7) is held true by the ACU. Eq. (13) shows that each station can always obtain the required amount of airtime (determined by the ACU) by using this simple control method. In fact, one of the greatest advantages of using EDCA is that the amount of airtime a station can get is determined by the ratio of stations' r_i values, not the absolute value of r_i. For example, assume that station 1 needs 0.1 sec out of every one-second period (i.e., $r_1 = 0.1$) for a stream and station 2 needs 0.2 sec (i.e., $r_1 = 0.2$) for another stream. Based on Eq. (13) and given that $EA = 0.6$, the actual amount of airtime station 1 can obtain is 0.2 sec and that for station 2 is 0.4. When more streams join the wireless LAN, the amount of airtime station 1 can get decreases (automatically adjusted by EDCA via Eq. 13), but it will not become less than 0.1 according to Eq. (7).

2) Controlling the Accessing Frequency: Instead of controlling the duration of a TXOP, we can use a fixed TXOP duration for all stations but control their access frequencies, AF_i, so that stations can still acquire the desired amount of airtime. This TXOP has to be chosen so that each station uses the same amount of airtime — during each access to the wireless medium — to transmit data frames at the negotiated minimum PHY rate. Therefore, the TXOP limit is chosen as

$$\text{TXOP limit} = \max_i \left\{ \left\lceil\frac{T_M}{T_i}\right\rceil \frac{L_i+H}{R_i} + (2\left\lceil\frac{T_M}{T_i}\right\rceil - 1)SIFS + \left\lceil\frac{T_M}{T_i}\right\rceil T_{ack} \right\}. \tag{14}$$

As shown in Figure 7, the TXOP limit of the above example is 619.6 μsecs and all four streams will transmit 400 μsec-worth data frames given this TXOP limit (i.e., streams 1 and 2 send 4 frames, stream 3 sends 2 frames and stream 4 sends one frame).

Several EDCA parameters can be used for controlling AF_i, including minimum/maximum contention window size ($CW_{min,i}/CW_{max,i}$) and arbitration inter-frame space ($AIFS_i$). The relation between these parameters and the access frequency can be found (also shown in [24]):

$$\sum_{i=1}^{n_1} BT_i^{(1)} = \sum_{j=1}^{n_2} BT_j^{(2)} + \sum_{h=1}^{n_1+n_2-1} D_h, \tag{15}$$

where $BT_i^{(j)}$ is the i-th backoff time chosen by STA j and is mainly determined by $CW_{min,j}$ and $CW_{max,j}$, D_h is referred to as the "decrementing lag" in [23], [24] and is mainly decided by $AIFS_i$ value, and n_i represents the total number of times STA i has backed off during the observing time interval and is proportional to AF_i. Based on Eq. (15) and by setting

$$\frac{AF_i}{AF_j} = \frac{r_i}{r_j} = \frac{n_i}{n_j}, \tag{16}$$

we can determine the adequate EDCA parameters using the algorithms given in [24]. One approximate but very simple solution is to choose CW_{min} as

$$\frac{CW_{min,i}}{CW_{min,j}} = \frac{r_j}{r_i}, \tag{17}$$

which will give a very good control on AF_i. On can easily reach the same conclusion drawn from Eq. (13) that stations can always acquire at least the required amount of airtime in a distributed manner.

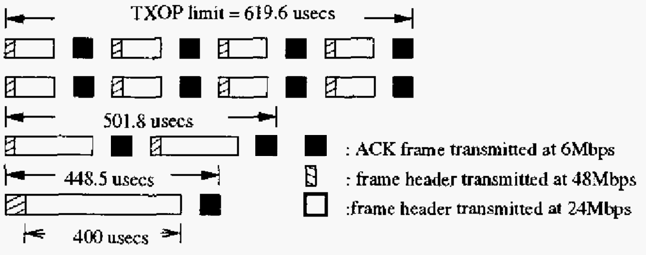

Fig. 7. Example 2 — selection of the network-wide unified TXOP limit. In this example, the TXOP limit for all stations is 619.6 μsecs.

B. Comparison of EDCA and HCCA

The greatest advantage of using HCCA for QoS guarantees is its high system efficiency (i.e., a higher *EA* value compared to using EDCA) than others, thanks to the HCCA's contention-free nature. Due to this higher efficiency, HCCA can provide more resource and may admit more traffic streams than EDCA. However, there are several potential problems of using HCCA due primarily to its centralized control over stations' access to the wireless medium.

1) As pointed out in the IEEE 802.11 standard, the operation of the polling-based channel access may require additional coordination to permit efficient operation when multiple polling-based wireless LANs are operating on the same channel in an overlapping physical space. New standard supplements such as 802.11k are being developed to facilitate the required coordination, but additional operations such as monitoring the channel activity (via 802.11k) may incur control overhead, hence degrading the system efficiency. On the other hand, EDCA does not need any coordination between wireless LANs using the same channel since EDCA is designed to solve the channel-sharing problem.
2) The hybrid coordinator (HC) in HCCA needs to recompute the service schedule whenever a new traffic stream is added to, or deleted from a wireless LAN. However, the ACU in EDCA assigns the appropriate EDCA parameters set to the new stream and the existing streams may not need to make any adjustment[2] as explained in the previous subsection.
3) As mention earlier, the QoS of a traffic stream can only be guaranteed if the wireless station transmits at a (physical) rate higher than the negotiated minimum physical rate. If a station lowers its physical transmission rate (below the negotiated rate), the amount of airtime originally allocated to the stream (by the HC) may not suffice to support the required QoS even though the HC may still have enough unallocated resource to support that stream's QoS at this lower rate. Of course, the HC can temporarily allocate more airtime (by recomputing the service schedule) to support that stream's QoS at this lower rate. However, if more new streams request for QoS later, the HC needs to reduce the stream's airtime allocation back to the originally-negotiated amount since the HC needs airtime for new streams. However, using EDCA will not require the AP or the ACU to reallocate airtime because wireless stations can automatically obtain the extra amount of airtime according to Eq. (13). Consider the previous example again. Stations 1 and 2 can actually halve their PHY rates and still meet the QoS requirements. In other words, the QoS can be automatically provided by EDCA, regardless of the transmission rate a station is using, as long as the system airtime resource allows. The new streams will not have any problem in getting their required amount of airtime as the airtime allocation is adjusted automatically according to Eq. (13).

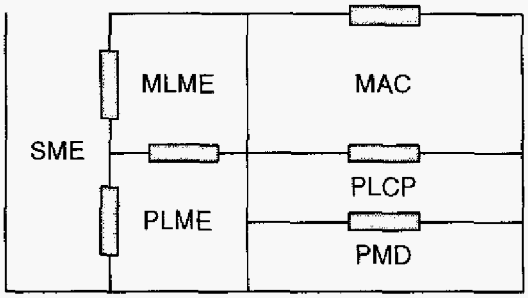

Fig. 8. Architecture and layer management of IEEE 802.11e standard — SME: Station Management Entity, MLME: MAC Layer Management Entity, PLME: Physical Layer Management Entity, PLCP: Physical Layer Convergence Protocol, PMD: Physical Medium Dependent.

V. QoS SIGNALING FOR ADMISSION CONTROL AND PARAMETER NEGOTIATION

The IEEE 802.11e standard has specified a set of signaling procedures for adding new QoS streams into an HC-coordinated wireless LAN. We can use these procedures, with little modification, for QoS signaling in EDCA. In order to better understand how these procedure is implemented in the IEEE 802.11e standard, we briefly introduce the architecture and layer management in the IEEE 802.11e standard.

A. Architecture and Layer Management of the IEEE 802.11e Standard

Both the MAC sublayer and PHY in the 802.11 standard conceptually include management entities, called MLME (MAC Layer Management Entity) and PLME (Physical Layer Management Entity), respectively. These entities provide the layer-management service interfaces through which layer-management functions may be invoked. In order to provide correct MAC operation, a station management entity (SME) will be present within each station. The SME is a layer-independent entity that may be viewed as residing in a separate management plane. The SME is responsible for gathering layer-dependent status information from various layer-management entities (LMEs), and similarly setting the value of layer-specific parameters. The SME would perform functions on behalf of general system-management entities and would implement standard management protocols. Figure 8 shows the relationship among the management entities. With the overall picture of 802.11e layer management, we can now explain the QoS signaling procedures.

B. QoS Signaling for Setting Up a Stream

Figure 9 shows the sequence of messages exchanged during the setup of a traffic stream (TS). The SME at the wireless station creates a TS based on the request from the higher layer.[3] The SME also obtains the TSPEC parameters from the higher layer. The SME generates an MLME-ADDTS.request containing the TSPEC. The station's MAC

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[2] It depends on which airtime control methods of EDCA is applied.

[3] The decision to create the TS and how to generate the TSPEC parameters are outside of the standard's scope.

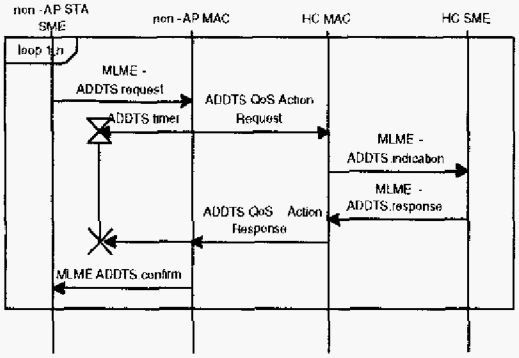

Fig. 9. Signaling and exchange of messages when a QoS traffic stream is added to an HC-coordinated 802.11 wireless LAN.

1 octets	1	1	4			1
Element ID	Length	QoS Info	Stream Parameters			Reserved
			AIFS	CWmin	TXOP	

Fig. 10. The modified EDCA parameter set element for supporting parameterized QoS in EDCA.

transmits the TSPEC in an ADDTS request in the corresponding QoS Action frame or the (re)association request frame to the HC and starts a response timer called ADDTS timer of duration *dot11ADDTSResponseTimout*. The HC MAC receives this management frame and generates an MLME-ADDTS.indication primitive to its SME containing the TSPEC. The SME in the HC decides whether to admit the TSPEC as specified, or refuse the TSPEC, or not admit but suggest an alternative TSPEC, and generates an MLME-ADDTS.response primitive containing the TSPEC and a ResultCode value by employing the admission-control algorithm. The HC MAC transmits an ADDTS response in the corresponding QoS Action frame or (re)association response containing this TSPEC and status.

Although the signaling is designed for HCCA to support parameterized QoS, we can use the same procedures for adding new QoS streams into a wireless LAN using EDCA. Here, the HC is replaced by the ACU since there is no HC in an EDCA-based wireless LAN. The most important task here is to transport the EDCA parameters (also decided by the ACU) to the station requesting for parameterized QoS. Fortunately, we can convey these parameters via the *EDCA Parameter Set Element* in the frame body of the MAC management frame.[4] We modify the EDCA parameter set element of 802.11e standard as shown in Figure V-B so that the ACU can signal the decision of admission and the corresponding EDCA parameters to the station.

If a wireless LAN operates in ad hoc mode, there will be no ACU for admission control and definitely no HC to allocate TXOPs to stations. In this case, stations can only use distributed admission control and the enhanced EDCA for parameterized QoS. Next, we outline how this can possibly be achieved in the ad hoc mode of 802.11e wireless LAN.

C. Admission Control in Ad Hoc Mode

For the purpose of admission control, each station has to monitor the channel and determine its current utilization. Here we do not consider the hidden terminal effects and assume that all stations hear each other and are not in the power saving mode. Otherwise, the QoS provisioning is almost impossible. Once the channel utilization is determined, each arriving stream's TSPEC element, when received at the SME, is passed onto the MAC for determining the guaranteed rate. Note that the signaling is similar to the one discussed earlier with the exception that there is no ADDTS frame sent physically on the medium.

Based on the guaranteed rate and the minimum PHY rate, the station can determine the value of r_i. If r_i is found to satisfy Eq. (7), the station transmits an RTS frame with the value of r_i to the destination station. Once the destination station responds to the RTS frame with a CTS frame, all stations assume that the new stream's QoS request has been accepted, and hence, update the system utilization (i.e., $\sum_i r_i$ in Eq. (7)) for later use. The station requesting admission, then, contends for the wireless medium with the enhanced EDCA parameters as explained before. In general, this admission-control algorithm is similar to that for parameterized QoS in EDCA, with the exception that the admission control is realized in a distributed manner. Because of this distributed nature and the fact that the minimum PHY transmission rates are determined by individual stations, some stations may over-occupy the wireless medium if they allow the streams to be transmitted at very low PHY transmission rates (and thus, a large r_i). Therefore, it is each individual station's responsibility to use the wireless medium "responsibly."

VI. EVALUATION

In this section, we compare the polling-based HCCA and the contention-based EDCA for their QoS support via simulation. We will stress the advantages of using the enhanced EDCA for QoS support as discussed in Section IV, and verify the effectiveness of the integrated airtime-based admission control and enhanced EDCA. We performed simulations in OPNET for four scenarios. In scenario 1, we compare the system efficiency, in terms of the number of streams admitted into a wireless LAN under EDCA and HCCA. In scenario 2, we compare the two controlling methods, namely, controlling TXOP limit and controlling medium accessing frequency, under EDCA. In scenarios 3 and 4, we compare the performance of HCCA and EDCA when some stations vary their physical transmission rates under the heavy- and light-load cases, respectively. We have modified the wireless LAN MAC of OPNET to include the admission-control algorithm and the signaling procedure as explained above.

A. Scenario 1: System Efficiency

We assume that each station carries a single traffic stream which requests a guaranteed rate of 5 Mbps.[5] We also assume that all stations are required to transmit at 54 Mbps for QoS

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[4] QoS Action frames are a MAC management frame.

[5] The average bit rate of a DVD-quality (MPEG-2) video is about 5Mbps.

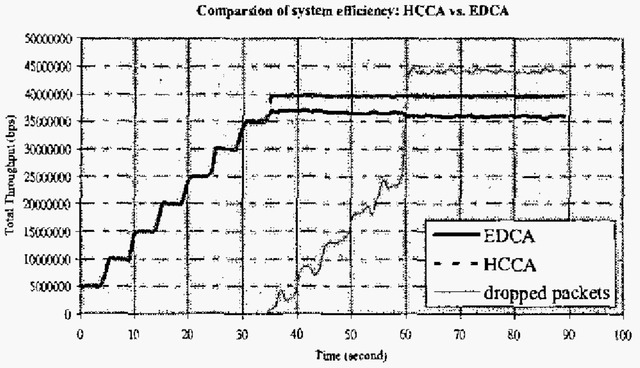

Fig. 11. Comparison of system efficiency, in terms of the total throughput, between HCCA and EDCA. *A new station carrying a single stream is added to the wireless LAN about every 5 seconds and transmits at 54 Mbps. The height of each "stair" in the figure is equal to a stream's guaranteed rate = 5 Mbps.

guarantees, and do not change their PHY rates. We increase the number of stations, starting from 1, until the wireless LAN cannot accommodate any more stations (or streams). For the EDCA case, we control the TXOP limit for airtime usage control. Since all streams have the same guaranteed rate (g_i =5 Mbps) and minimum PHY rate (R_i =54Mbps), each station uses the same TXOP limit in this scenario. For the HCCA case, we follow the procedures in Section II.

Figure 11 plots the total throughput under both HCCA and EDCA. Since all stations request the same guaranteed rate, one can easily convert the total throughput to the total number of stations (i.e., streams) admitted into the wireless LAN. We increment the number of stations every 5 seconds in order to explicitly show the throughput received by individual streams. Prior to $t = 35$ second, every admitted stream gets exactly the 5-Mbps guaranteed rate under both HCCA and EDCA. It shows that using the enhanced EDCA can achieve the same QoS guarantees as using the polling-based HCCA.

At $t = 35$ second, the number of stations is increased to 8. The figure shows that using EDCA cannot guarantee the streams' QoS any longer because it needs a total throughput of 40 Mbps to support 8 streams, but the wireless LAN can only provide about 37Mbps. However, under HCCA, all streams are still provided with the 5-Mbps guaranteed rate. This result is expected because HCCA uses the polling-based channel access (in contrast to the contention-based EDCA), hence resulting in a higher efficiency. After $t = 40$, more stations using EDCA are added to the wireless LAN and the total system throughput starts to drop gradually. At $t = 60$ second where there are 16 stations in the wireless LAN, the system throughput becomes 36 Mbps, compared to the maximum achievable throughput of 37 Mbps. Such decrease in the system throughput results in that more collisions occur when the number of stations increase. The amount of dropped frames under EDCA is also plotted which shows that frame dropping starts at $t = 35$ second. In contrast, the maximum achievable throughput under HCCA remain at 40 Mbps since the AP simply does not poll any additional streams/stations under HCCA. The efficiency of HCCA mainly depends on the frame size used by individual stations. If a larger frame size (we use 1500 bytes) is used, the maximum achievable throughput can be increased to 43 Mbps [25].

Based on the simulation results, one can also obtain the values of the effective airtime EA in Eq. (7). Because all streams are transmitted at the same PHY rate, the value of EA can be computed by

$$EA = \frac{\text{system total throughput}}{\text{PHY rate}}. \tag{18}$$

Therefore, we have $EA = 0.67$ under EDCA and $EA = 0.73$ under HCCA. Although the value of EA varies under EDCA (depending on the EDCA parameters used), it is always within the range between 0.65 and 0.68 in our simulation. We use $EA = 0.65$ in Eq. (7) for a more conservative admission control under EDCA.

Although using HCCA achieves a better efficiency, it only generates $0.06 = 0.73 - 0.67$ second more data-transmission time (within a one-second period) or about 3Mb more data frames when all stations transmit at 54Mbps (the maximal PHY rate in the 802.11a PHY specification). When stations use smaller PHY rates, the small difference between the EA values of EDCA and HCCA results in an even smaller throughput difference. Therefore, one can expect that using EDCA and HCCA will generate a similar performance, especially in terms of the total number of admissible streams.

B. Scenario 2: TXOP Limit vs. Medium Accessing Frequency

In this subsection, we compare the two controlling methods in EDCA, namely, controlling the stations' TXOP limits and medium accessing frequency. We still assume that each stream requires a 5-Mbps guaranteed rate. In order to emphasize the EDCA's quantitative control over stations' diverse airtime usage, we assume that stations 1 and 2 carry a single traffic stream but stations 3 and 4 carry 2 streams. That is, there are six traffic streams in total. We again assume that all stations transmitted at 54Mbps and do not change their PHY rate. Therefore, all streams are able to obtain their guaranteed rate based on the results in Scenario 1. In order to control the stations' medium accessing rate, we choose CW_{min} as the control parameter. Therefore, we choose $CW_{min,1} = CW_{min,2} = 15(2^4 - 1)$ and $CW_{win,3} = CW_{win,4} = 31(2^5 - 1)$ based on Eq. (17), and set $CW_{max} = 63(2^6 - 1)$ for all stations. The TXOP limits are chosen according to Eqs. (12) and (14).

Figure 12 plots the total throughput of using the two controlling methods. It shows that both methods generate identical results (in terms of throughput). One can observe that stations 1 and 2 both receive the 5-Mbps guaranteed rate after they join the wireless LAN at $t = 0$ and $t = 5$, while stations 3 and 4 both receive 10 Mbps (5 Mbps for each of their own two streams) after they join the wireless LAN at $t = 10$ and $t = 15$. The results show that both controlling methods can realize the distributed and quantitative control over stations' airtime usage. Here, the throughput is proportional to airtime usage since all stations transmit at the same PHY rate.

Figure 13 plots the delay under the two controlling methods. Once all 4 stations (all 6 streams) are admitted to the wireless

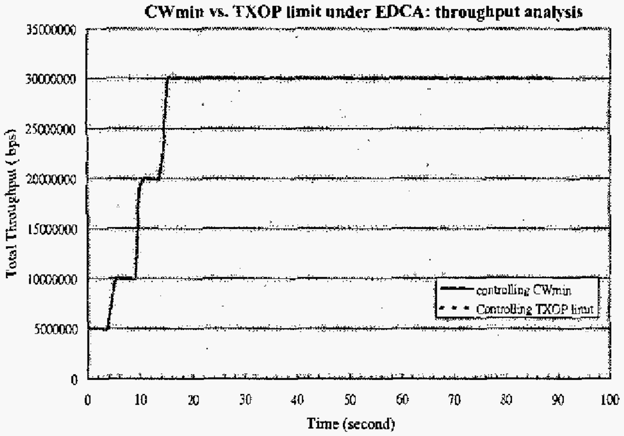

Fig. 12. Comparison of throughput between controlling stations' TXOP limits and CW_{min} values. *The figures shows that in EDCA, controlling stations' TXOP limits and controlling the CW_{min} values result in the same performance in terms of streams' throughput.

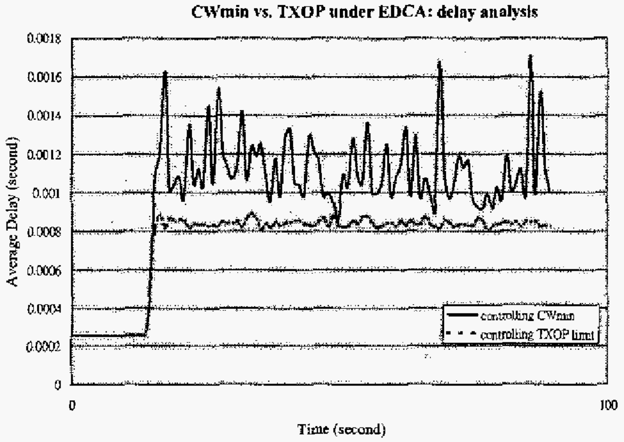

Fig. 13. Comparison of delay between controlling stations' TXOP limits and CW_{min} values. *The figures shows that in EDCA, controlling CW_{min} values may result in a large delay variance but still satisfy all stream's delay bound.

LAN, the delay remains around 0.8 msec if the TXOP Limit control is used, or fluctuates around 1.2 msecs if the CW_{min} control is used. The reason for the delay fluctuation in the latter is that if stations using a larger CW_{min} (i.e., 31) collide with other stations, they use $CW_{max} = 63$ as the contention window size due to the exponential random backoff. Thus, these stations may wait much longer than the case of controlling the TXOP Limit where stations (rarely) use $CW_{max} = 63$ only when 2 consecutive collisions occur. In any case, the delay under both methods are well below the streams' delay bound, which is 200 msecs in our simulation.

C. Scenario 3: Time-Varying Transmission Rates: a Heavy-Load Case

The main advantage of our airtime-based admission control over a rate-based counterpart is that, when some stations lower their PHY rates, they do not affect other stations' airtime allocation and QoS guarantees. Instead, only the QoS of the stations lowering their PHY rate below the negotiated minimum PHY rates are compromised. To simulate this scenario, we assume that there are 4 stations where station 1 carries a 5-Mbps stream and stations 2–4 each carry two 5-Mbps streams. All stations are required to transmit at 54Mbps to maintain their QoS. That is, the negotiated minimum PHY rate is 54 Mbps for all stations. Furthermore, we assume that station 1 lowers its PHY rate to 24 Mbps due to the link adaptation at $t = 15$ second.

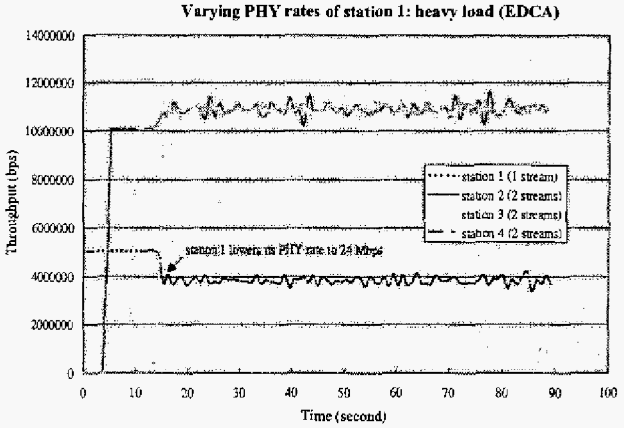

Fig. 14. Throughput of individual streams in EDCA: station 1 lowers its PHY rate to 18 Mbps at $t = 15$ second. *The wireless LAN has been heavily-loaded before station 1 lowers its PHY rate. Therefore, the wireless LAN cannot provide station 1 the guaranteed rate once station 1 lowers its rate. However, all other stations are not affected as in the HCCA case shown in Figure 15.

Figures 14 and 15 plot the throughput of individual stations under EDCA (controlling the TXOP limits) and HCCA, respectively. These figures show that stations 2–4 that maintain their PHY rate always receive at least 10-Mbps throughput (5 Mbps for each of their own 2 streams) after they join the wireless LAN at $t = 5$, 10, and 15 second, respectively. The only station that receives a throughput less than the guaranteed rate is station 1, which violates the agreement on maintaining the minimum PHY rate at 54 Mbps. The result verifies that our integrated scheme can effectively maintain the QoS for stations complying with the QoS negotiation and "isolates" the stations that violate the QoS negotiation from others in a distributed manner, which is in sharp contrast with the polling-based HCCA.

D. Scenario 4: Time-Varying Transmission Rates: a Light-Load Case

In Scenario 3, we conclude that stations lowering their PHY rates below the negotiated minimum PHY rates do not receive the QoS guarantees. However, we also mentioned in Section IV that when a wireless LAN has some unutilized resource (i.e., the airtime), the AP may temporarily allocate more resources to the stations lowering their PHY rates — without violating other stations' QoS — so as to support their QoS at lower PHY rates. This can be done via the HC of HCCA by computing a new service schedule. In Section IV, we claim that these adjustments can be completed without any centralized control if the enhanced EDCA is used, thanks to its autonomous distributed airtime control.

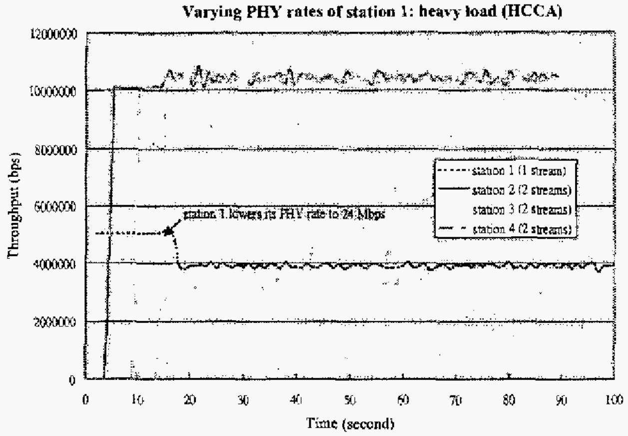

Fig. 15. Throughput of individual streams in HCCA: station 1 lowers its PHY rate to 24 Mbps at $t = 15$ second. *The wireless LAN has been heavily-loaded before station 1 lowers its PHY rate. Therefore, the HC cannot provide station 1 the guaranteed rate once station 1 lowers its rate.

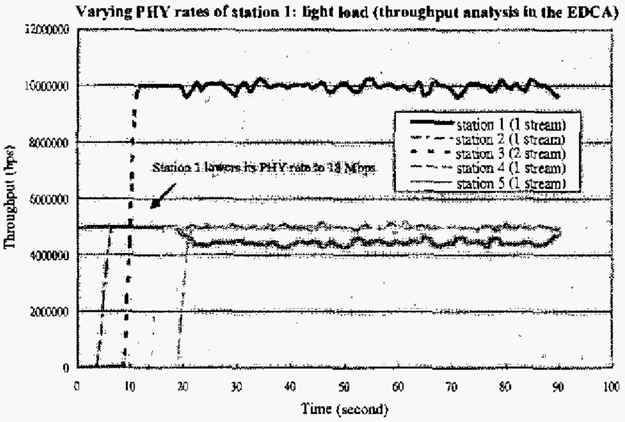

Fig. 16. Throughput of individual streams in EDCA: station 1 lowers its PHY rate to 18 Mbps at $t = 15$ second. *The wireless LAN is not heavily-loaded when station 1 lowers its PHY rate at $t = 15$ second. Therefore, station 1 can still receive the 5-Mbps guaranteed rate after $t = 15$. However, after $t = 20$ second, station 1 has to "relinquish" the extra airtime it is using so that station 5, which complies the minimum PHY rate of 54 Mbps receives the 5-Mbps guaranteed rate.

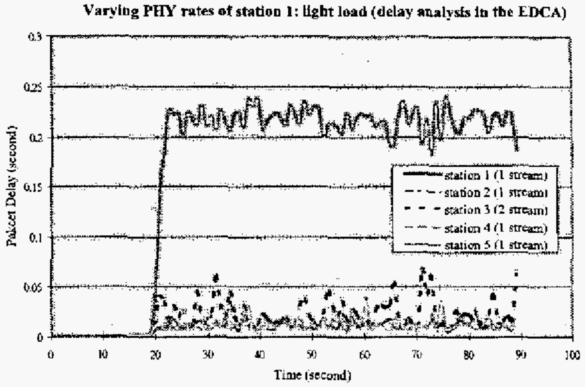

Fig. 17. Delay of individual streams in EDCA: station 1 lowers its PHY rate to 24 Mbps at $t = 15$ second. *The wireless LAN is not heavily-loaded when station 1 lowers its PHY rate at $t = 15$ second. Therefore, all streams' delay bound are still satisfied after $t = 15$. However, after $t = 20$ second, station 1 has to "relinquish" the extra airtime it is using so that station 5, which complies the minimum PHY rate can receive the QoS. As a result, station 1's stream experiences a delay greater than the required delay bound at $t = 20$ second.

To simulate this scenario, we assume that the wireless LAN only admits 4 stations before $t = 15$ second, and stations 1, 2 and 4 carry a single stream and station 3 carries 2 streams. We again assume that each stream requires a 5-Mbps guaranteed rate and that all stations are required to transmit at 54 Mbps to maintain their QoS. We assume that station 1 lowers its PHY rate to 18 Mbps at $t = 15$ second. Unlike Scenario 3, the wireless LAN is still able to (but not necessarily has to) provide the QoS to station 1 without affecting other stations' since there are only 5 streams asking for a total amount of airtime (before $t = 20$ second)

$$\frac{4*5}{54} + \frac{5}{18} = 0.64 < 0.65 = EA_{edca}. \tag{19}$$

We can observe in this figure that station 1 still obtains the required 5-Mbps guaranteed rate even though it violates the agreement upon using a 54-Mbps transmission rate. Here, we do not need to make any additional adjustments as required in HCCA. Instead, station 1 automatically adjusts its airtime usage by contending the wireless medium more frequently via the enhanced EDCA, due to the build-up MAC buffer queue.

After $t = 20$, we add station 5 which also carries a 5-Mbps stream into the wireless station. When station 5 requests for admission at $t = 20$ second, the AP should admit it based on Eq. (7)

$$\frac{6*5}{54} = 0.55 < 0.65 = EA_{edca}, \tag{20}$$

since all stations are required to transmit at R_i=54 Mbps. However, not all stations actually transmit at 54 Mbps. The total amount of airtime we really need to support QoS for all streams is

$$\frac{5*5}{54} + \frac{5}{18} = 0.73 > 0.65 = EA_{edca}, \tag{21}$$

where stations 2–5 have a total of 5 streams to transmit at 54 Mbps and stations has 1 stream to transmit at 18 Mbps. Obviously, station 1 should not receive the QoS (5-Mbps guaranteed rate). Figure 16 again shows this "expected" behavior and the most important fact is that such adjustment is again achieved automatically (via the EDCA parameters) without any adjustment which is required in HCCA. Figure 17 shows the delay of data frames from individual stations. Again, before $t = 20$ second, the delay bound of station 1 is satisfied even though station 1 violates the minimum PHY rate requirement. However, such QoS is not guaranteed any longer after $t = 20$ second, because station 5 joins the wireless LAN and complies with the minimum PHY rate requirement.

VII. CONCLUSIONS

In this paper, we provided a complete set of QoS solutions for the infrastructure-mode 802.11 wireless LAN (in both HCCA and EDCA) and the ad hoc-mode 802.11 wireless LAN. The QoS for a traffic stream is jointly determined by the wireless station and the admission-control unit, via the negotiation of traffic parameters in the TSPEC. Based on the negotiated results, a guaranteed rate is determined for the purpose of admission control. The admission control takes into account stations' varying PHY transmission rates (resulting from link adaptation), and effectively prevents the stations that violate their QoS negotiation from affecting other well-behaving stations' QoS guarantees.

In order to provide the parameterized QoS in EDCA, we also provided a new distributed, quantitative control of stations' airtime usage by controlling stations' TXOP limits or EDCA parameters. We then extended the current QoS signaling of HCCA defined in the IEEE 802.11e standard to perform admission control in our "parameterized QoS-capable" EDCA. Furthermore, we extended the airtime-based admission control (with the enhanced EDCA) for QoS provisioning in the ad hoc wireless LAN, and designed appropriate signaling procedures. We evaluated via simulation the effectiveness of this parameterized QoS-capable EDCA scheme, and demonstrated its advantages over the centralized, polling-based HCCA scheme.

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