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Enhanced QoS Mechanisms for IEEE 802.11e Wireless Networks

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Abstract—The quality-of-service (QoS) support for wireless LANs has been a hot research topic during the past few years. In this paper, two QoS provisioning mechanisms are proposed for the employment in 802.11e EDCA MAC scheme. First, the proposed call admission control mechanism can not only guarantee the QoS for the higher priority existing connections but also provide the minimum reserved bandwidth for traffic flows with lower priority. In addition, the adaptive contention window adjustment mechanism can adjust the maximum and minimum contention window size dynamically according to the existing connection number of each AC. The collision probability as well as the packet delay will thus be reduced effectively. Performance results via simulations have revealed the enhanced QoS property achieved by employing these two mechanisms.

***Keywords*—**802.11e, admission control, contention window, EDCA

I. Introduction

WITH the ever growth of the multimedia applications, the capability to support QoS has become an important issue in the wireless network environment. Since the DCF of the legacy IEEE 802.11 standard can only support best effort traffic, the IEEE 802.11 task group E thus proposes a new contention-based channel access scheme called Enhanced Distributed Channel Access (EDCA) mechanism in the IEEE 802.11e standard [1,2].

Based upon the DCF of IEEE 802.11 standard, the EDCA scheme of IEEE 802.11e provides prioritized services. In EDCA, four access categories (AC) are defined. (They are Background (AC_BK=AC[0]), Best-Effort (AC_BE=AC[1]), Video (AC_VI = AC[2]), and Voice (AC_VO=AC[3]), respectively). Each AC inherits the contention-based access method, with its own specific parameters, such as CWmin[AC], CWmax[AC], AIFS[AC], AIFSN[AC], and TXOPLimit[AC]. By choosing different values of these parameters properly, the AC with a higher level has a higher priority to access wireless channel than the AC with a lower level. Prioritized service can thus be achieved.

The MAC access operation in EDCA is described briefly as follows. Each AC contends for the channel access chance. Those ACs who want to start transmission must defer for an AIFS[AC] period, then start the backoff counter to delay a contention window (CW) for a random period. Once the backoff counter decreases to zero, the AC sends frames as many as possible within a TXOP[AC] time limit. The relation among all AIFSs and the contention procedure in EDCA scheme are depicted in Figure. 1.

However, the IEEE802.11e EDCA scheme alone cannot guarantee the strict QoS for real time applications under the heavily loaded situation due to its contention based property [3-5]. In this paper, an enhanced mechanism is proposed to be incorporated with EDCA scheme for satisfying the QoS demands. The proposed mechanism consists of both call admission control (CAC) part and adaptive contention window adjustment (ACA) part. By using the proposed CAC, the QoS access point (QAP) is able to calculate the proper amount of AC connections which could be established from all QoS stations (QSTA) without overloading the system. Furthermore, the ACA scheme adjusts the contention window size of each AC dynamically according to the number of its corresponding existing AC connections. The packet access delay and collision probability are thus reduced significantly.

The rest of the paper is organized as follows. The related works are described briefly in Section II. The proposed CAC algorithm is then presented in Section III, followed by the description of proposed ACA mechanism in Section IV. Simulation results and discussion are discussed in Section V. Finally, conclusions are drawn in Section VI.

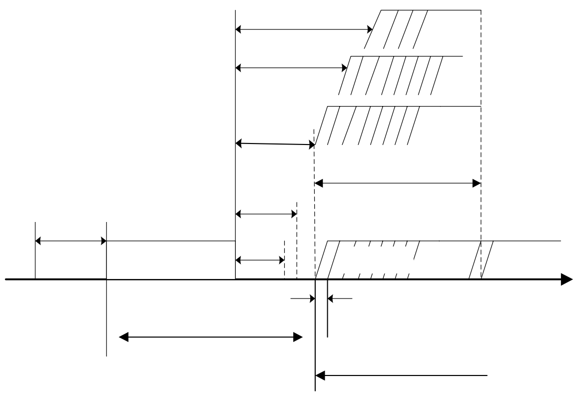

Fig. 1 Relationship among all AIFSs in 802.11e EDCA scheme

II. Related Works

The DAC mechanism proposed in [6] aims to protect the higher priority streams by incorporating the transmission

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budget for each AC. However, the mechanism functions poorly if the network is heavily loaded. Nor can it satisfy the QoS requirement for different applications. [7] and [8] use the virtual concept to simulate the network performance with virtual packets. They will then execute the admission control algorithm based upon obtained simulated collision probability. This method may reduce bandwidth wastage but may take excessive processing time for completing the call admission algorithm. [9] defines thresholds for transmission by simply estimating the real traffic experienced by the QSTA. However, the authors do not provide the exact criterions to define these thresholds. The mechanism in [10] aims to adjust the channel quality parameters dynamically in order to guarantee the minimum bandwidth of AC_BE without the detailed description. [11] uses a Markov Chain Model to predict the system performance if a new call is accepted. The QSTA then executes the call admission algorithm accordingly. However, the proposed mechanism does not take the virtual collision case into account.

III. Proposed Admission Control Mechanism

In the IEEE 802.11e EDCA MAC access scheme, the QSTA which wishes to activate a new AC call needs to transmit to QAP the ADDTS frame first. The ADDTS frame contains the necessary information to establish the new call as well as the TSPEC field, which contains the bandwidth requirements of this new traffic stream. However, it is not mandatory for QAP to implement the call admission control (CAC) mechanism in the IEEE 802.11e EDCA standard. In the following, an effective CAC algorithm which could be incorporated into the EDCA scheme is proposed to enhance the QoS performance for this network. Our key idea is that the acceptance of a new AC call must not reduce the QoS experienced by the existing AC calls to a certain extent which varies for different prioritized ACs. More specifically, the QAP will accept a new AC call only if both of the following criteria are met: (1) The average bandwidth requirements of all existing AC calls with higher or equal priority to the new AC call could be guaranteed. (2) The minimum reserved bandwidth of all existing AC calls with lower priority than the new AC call is satisfied. The proposed CAC algorithm is shown as follows.

```
For a new requested AC[i] flow, 0 ≤ i ≤ 3
if (i == 0) {
  w = 0;
}else{
  w = 1;
}
if ( Σ_{j=i}^{3} AC[j]_total_average + w × Σ_{j=0}^{max(i-1,0)} AC[j]_reserved_min + AC[i]_new < R × α ){
  Accept the requested AC[i] flow;
}else{
  Reject the requested AC[i] flow;
}
```

The parameter R is the physical data rate. α, a system parameter with the value between (0,1), represents the effective proportion of system capacity that could be used for call admission control. This value reflects the fact that for a contention based access algorithm such as EDCA in 802.11e networks, the whole system capacity cannot be fully utilized due to the inherent bandwidth wastage resulting from packet collision and backoff algorithm. $AC[i]_{new}$ is the mean data rate specified in TSPEC, which represents the mean bandwidth requirement of the new AC[i] call. $AC[j]_{total\_average}$ is the sum of the average bandwidth requirements of all existing AC[j] traffic streams. $AC[j]_{reserved\_\min}$ is the minimum bandwidth of existing AC[j] which should be reserved by QAP.

Finally, when connection ends, the QSTA transmits DELTS frame to QAP to release the call. The QAP then recycles the connection resources.

IV. Proposed Adaptive Contention Window Adjustment Algorithm

With the proposed admission control mechanism, the system performance is effectively improved. However, to reduce channel collisions as the system load increases, in this paper, the Adaptive Contention Window Adjustment (ACA) algorithm is proposed. The mechanism enables QAP to dynamically calculate and adjust both $CW_{\min}$ and $CW_{\max}$ according to the equivalent number of existing AC connections. The QAP will then broadcast the updated $CW_{\min}$ and $CW_{\max}$ in the beacons to QSTAs. QSTAs reset their CWs accordingly. Hence, the system efficiency improves. It is noted that for the legacy IEEE 802.11 system, the authors in [12] propose the following formula to adjust the value of $CW_{\min}$ dynamically based on the existing number of STAs, n:

$$CW_{min} = (n-1)\sqrt{\frac{T_{physical} + T_{SIFS} + T_{ACK} + T_{DIFS}}{T_{slot}}}$$

The time parameter $T_{physical}$ is the packet transmission time. T_{SIFS} is the duration of SIFS; T_{ACK} is the duration of ACK frame. The adjusted $CW_{\min}$ (depending on the number of STA) in [12] is shown to reflect the congestion status of the system and reduce the collision probability significantly. Extending this concept to take into account the four prioritized ACs in the IEEE 802.11e network, we define four Adjustment Factors (AFs), each corresponding to one prioritized ACs, respectively.

$$AF[i] = \sqrt{\frac{T_{physical} + T_{SIFS} + T_{ACK} + T_{AIFS[i]}}{T_{slot}}}$$

Where $T_{AIFS[i]}$ is the duration of AIFS for AC[i] , $0 \le i \le 3$. The proposed ACA algorithm is shown below.

```
int connection_weight = 0;
for(int i = 3; i ≥ 0; i--)
{
   connection_weight += connection[i];
   if((connection_weight - 1) × AF[i] > CW[i]_min_default){
      CW[i]_min = (connection_weight - 1) × AF[i];
      CW[i]_max = CW[i]_min × ratio[i];
   }else{
      CW[i]_min = CW[i]_min_default;
      CW[i]_max = CW[i]_max_default;
   }
}
```

The connection[i] represents the number of instantaneous existing AC[i] connections. The parameter connection_weight represents the equivalent number of existing AC connections which will compete for the channel access, viewed by a specific AC. This value is different for ACs with different priorities. The reason is that a given AC will be likely to experience the competition for channel access only from those existing AC connections with higher or equal priority to itself. Therefore, the higher priority of the AC, the smaller number of equivalent AC connections it will witness. Its $CW[i]_{\min}$ should be adjusted accordingly. Besides, the parameter $ratio[i]$ defines the ratio between $CW[i]_{\min}$ and $CW[i]_{\max}$ according to rule set by IEEE 802.11e standard, shown in Table I. Two parameters $CW[i]_{\min\_default}$ and $CW[i]_{\max\_default}$ represent the well defined default values of $CW[i]_{\min}$ and $CW[i]_{\max}$ in IEEE 802.11e standard.

If the number of equivalent AC connections is large enough such that (connection_weight-1)$\times AF[i] > CW[i]_{\min\_default}$, the new $CW[i]_{\min}$ to set to be (connection_weight-1)$\times AF[i]$ for reducing collision probability. Otherwise the system uses the default $CW[i]_{\min}$ value.

V. Simulation Results

The traffic generated by each AC of each QSTA is assumed to be the exponential ON-OFF fashion, shown in Fig. 2. That is, the duration for both the ON and the OFF state follows the exponential distribution. The ON state, with mean duration of 5sec, represents the active duration for each AC connection. The packets during ON period follow the constant bit rate (CBR) fashion. Before the ON state, each AC has to transmit ADDTS to QAP through the CSMA/CA contention scheme, thus the contention delay may be induced for each call. The OFF state represents the idle time from the end of a service flow to the beginning of the next service flow with the mean duration of $1/\lambda$seconds. The larger λ, the more frequent service or offered load. Table II, III, and IV show all the parameters in simulation.

Three simulation parameters are used to evaluate the system performance: the connection delay, the call blocking probability, and the packet delay. The connection delay represents the delay time of the new call from being generated to being accepted by QAP. The call blocking probability computed by QAP is the rejection probability of a new call. The packet delay contains both the queueing delay and the channel access delay. The connection delays of AC_VO and AC_BK are revealed in Figs, 3 and 4, while those of AC_VI and AC_BE are omitted since they show the similar trends. The connection delay increases as the offered load or λ increases because there are more flows contending for setting connections in QAP. This may cause significant collisions. On the other hand, the smaller α causes the longer connection delay since the total permitted bandwidth is lowered such that it is more difficult for the new flow being accepted by QAP. Fig. 5 and 6 show call blocking probability for AC_BE and AC_BK, respectively. Note that the call blocking probability increases as the offered load or λ increases. It also shows that the smaller α, the higher call blocking probability. No noticeable blocking probability is experienced by AC_VO and AC_VI. Fig. 7 and 8 show the packet delay of AC_VO and AC_BK again without those of AC_VI and AC_BE. The packet delay increases as λ increases. On the other hand, α limits the permitted proportion of system capacity for the proposed call admission control algorithm under the given physical data rate. A smaller α allows fewer admitted connection flows inside QAP and therefore the channel contention is reduced. Fig. 9 and 10 reveal the merits of ACA schemes. We consider the packet delay for the following three cases: (1) neither CAC nor ACA is equipped. (2) CAC equipped only. (3) CAC+ACA equipped. The packet delay of each AC is reduced with the ACA algorithm adapted dynamically to the existing number of connections, especially for AC_VO (and AC_VI). However, it is not significant to AC_BK (and AC_BE) because the default CW value is already large enough for this simulation scenario.

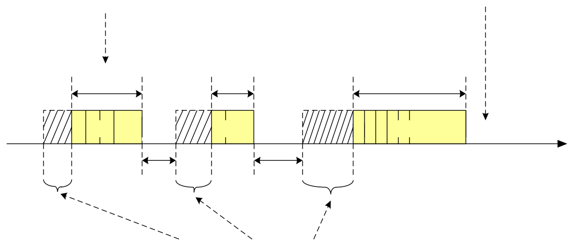

Fig. 2 Traffic Generation Pattern

TABLE I
AC's in IEEE 802.11e EDCA

AC	CW $_{min}$	CW $_{max}$
AC_BK	**aCWmin**	**aCWmax**
AC_BE	**aCWmin**	**aCWmax**
AC_VI	(aCWmin+1)/2 – 1	aCWmin
AC_VO	(aCWmin+1)/4 – 1	(aCWmin+1)/2 – 1

TABLE II
CSMA/CA PARAMETERS IN 802.11A

Physical Rate	36*Mbps*
Unit SlotTime	9*us*
SIFS	16*us*
DIFS	34*us*
ACK frame Size	14*bytes*
Beacon Interval	100*ms*

TABLE III
DEFAULT EDCA PARAMETRERS

	Voice	**Video**	**Best Effort**	**Background**
AC	AC_VO	AC_VI	AC_BE	AC_BK
AIFSN	2	2	3	7
CWmin	7	15	31	31
CWmax	15	31	1023	1023
Packet Size	160 *bytes*	660 bytes	1280 bytes	1600 *bytes*
Packet Interval	20 *ms*	18 *ms*	16 *ms*	12.5 *ms*
Mean Data Rate	8 *KB/s*	36 *KB/s*	80 *KB/s*	128 *KB/s*

TABLE IV
DEFAULT PARAMETERS IN ACA ALGORITHM

	Voice	**Video**	**Best Effort**	**Background**
reserved_min	4 *KB/s*	24 *KB/s*	50 *KB/s*	80 *KB/s*

VI. CONCLUSION

In this paper, the CAC algorithm is first proposed as a solution to the contention-based admission control scheme. The ACA algorithm is then proposed for the adaptive contention window adjustment scheme. In the simulation, though the higher α can lower both the connection delay and the call blocking probability, however, it simultaneously increases the packet delay. The proposed ACA algorithm can successfully decrease both the connection delay and call blocking probability. The combination of the CAC+ACA algorithm can reduce the packet delay caused by a larger α significantly.

ACKNOWLEDGMENT

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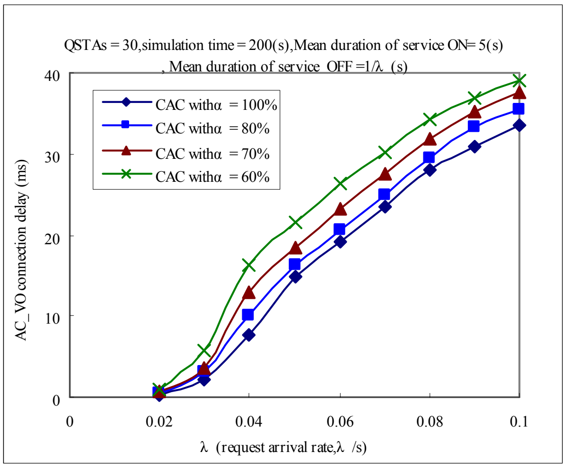

Fig. 3 Connection delay of Voice call with CAC

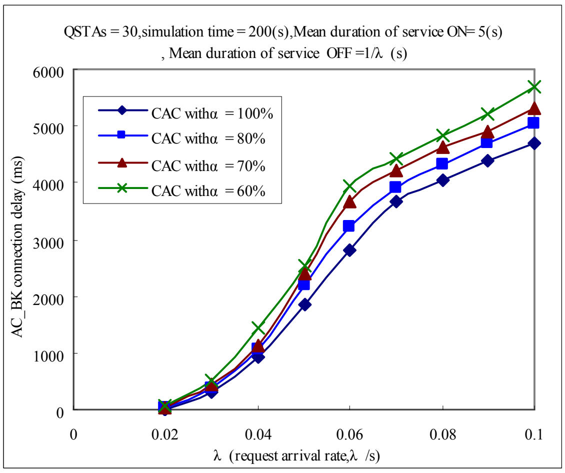

Fig. 4 Connection delay of Background call with CAC

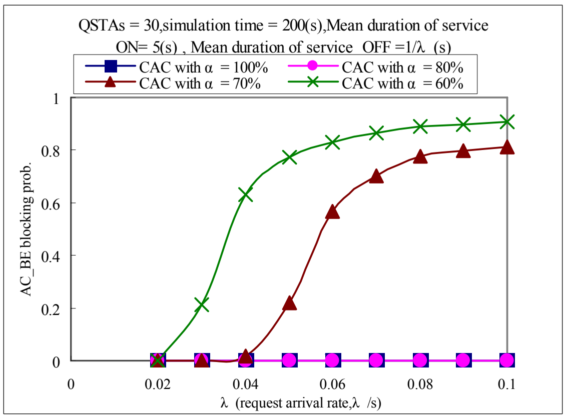

Fig. 5 Blocking Probability of Best Effort call with CAC

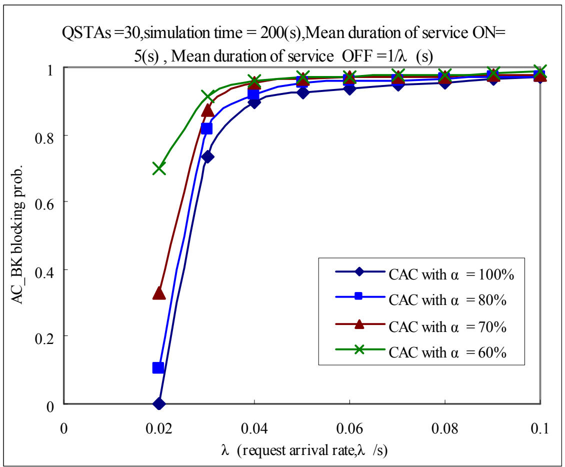

Fig. 6 Blocking Probability of Background call with CAC

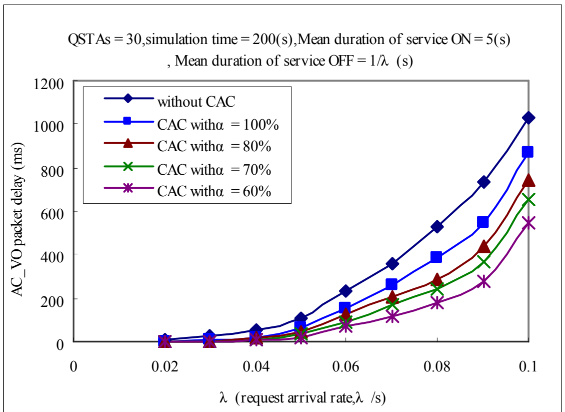

Fig. 7 Voice packet delay with CAC and without CAC

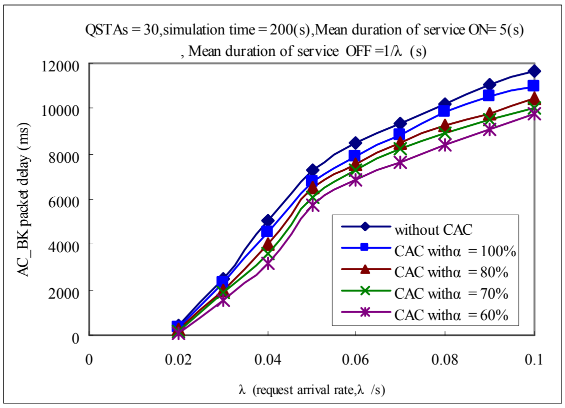

Fig. 8 Background packet delay with CAC and without CAC

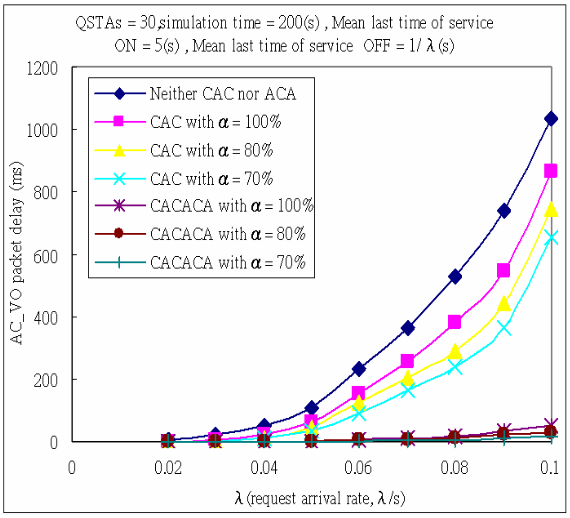

Fig. 9 Comparison of packet delay of Voice between CAC and CACACA

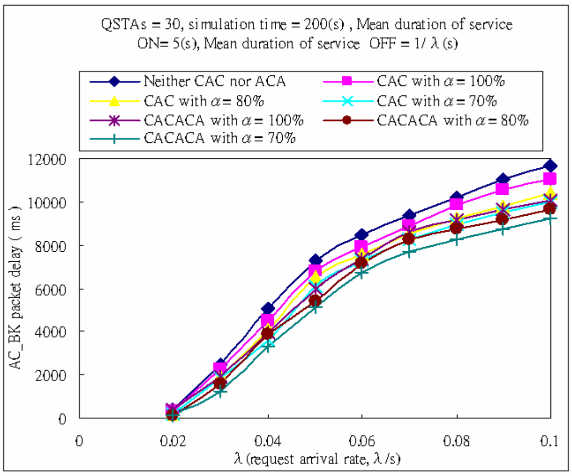

Fig. 10 Comparison of packet delay of Background between CAC and CACACA