Interclass Collision Protection (ICP) Model for IEEE 802.11e Wireless LANs (WLANs)

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Abstract

Distributed Coordination Function (DCF) in IEEE 802.11 and Enhanced Distributed Channel Access (EDCA) in IEEE 802.11e are contention-based access mechanism in Wireless LAN. Both DCF and EDCA reduce collisions based on inter-frame space (IFS) and backoff mechanisms. However, collisions are unavoidable even with the two mechanisms. Especially, in the EDCA model, the collision can be classified into interclass and intraclass collision. To eliminate interclass collision in Wireless LAN, we propose an interclass collision protection (ICP) scheme by employing contention protection period (CPP) after backoff. Analysis is performed for one dimensional EDCA model and for the proposed ICP based EDCA model.

I. INTRODUCTION

Wireless local area network (WLAN) is rapidly growing due to the technology development to support mobility. Last few years have seen growth in the installation of access points (APs) based on IEEE 802.11 WLAN [1] to support data communications. It has advantages of the low cost and simple deployment. With the increasing expectation of voice over Internet Protocol (VoIP) services, WLAN is expected to provide a reliable service to voice packets in addition to best-effort data packets. However, IEEE 802.11 WLAN cannot satisfy quality of service (QoS) requirements of real time services. To support QoS requirements in medium access control (MAC) level the standardization committee proposed IEEE 802.11e [2]. The IEEE 802.11e MAC protocol employs a hybrid coordination function (HCF) that includes enhanced distributed channel access (EDCA). The EDCA provides class priority by differentiating the interframe space and contention window size. However, collision is still an impediment because EDCA is contention based mechanism analogous to DCF. Thus, we propose a scheme to improve performance of WLAN by avoiding interclass collision.

In the literature, several papers have examined the performance of DCF and EDCF using analytical model. Bianchi [3] proposed an analytical model of DCF to calculate saturation throughput by using two dimensional Markov chain. Ziouva and Antonakopoulos [4] improved Bianchi's model to derive a saturation delay. Bianchi and Tinnerello [5] improved this model by using elementary conditional probability rather than two dimensional Markov chain. Most of analytical studies of IEEE 802.11e EDCA analyze performance based on the analysis in IEEE 802.11 DCF model. Especially, Xiao [6] provides an analytical model based on backoff scheme calculated by two dimensional Markov Chain. However, he doesn't consider the priority based on interframe space.

In this paper, we propose and analyze interclass collision protection (ICP) model. ICP model is used to reduce collision by eliminating interclass collision. For eliminating interclass collision, we adopt a guard period named contention protection period (CPP) after backoff period.

Proposed model assumes that stations transmit in ideal conditions with no errors in the channel and no hidden stations. Another basic assumption is that every station is in saturation condition. Also, we assume that the collision probability of a transmitted packet is constant and independent of the retransmissions.

The remainder of this paper is organized as follows. Section II introduces IEEE 802.11e EDCA and the ICP model. Throughput and delay analysis is presented in Section III. Section IV discussed numerical results. Finally, Section V concludes the paper.

II. INTERCLASS COLLISION PROTECTION MODEL

A. Enhanced Distributed Channel Access (EDCA)

EDCA is designed to enhance the DCF mechanism by supporting service differentiation among categories and distributing these categories in the channel access. EDCA consists of four access categories (ACs). Each AC has different priority with different contention window (CW) and arbitration interframe space (AIFS). CW plays a role of giving higher AC more statistical opportunities to access channel. The CW size, $CW_{i,j}$ for the priority class i in backoff stage j is determined follows [6].

$$CW_{i,j} = \begin{cases} \sigma_i^j CW_{i,0} = CW_{i,\min}, & \\ \quad \text{for } j = 0,1,\cdots,m_i - 1, & \text{if } \mathrm{R}_i > m_i \\ \sigma_i^m CW_{i,0} = CW_{i,\max}, & \\ \quad \text{for } j = 0,1,\cdots,\mathrm{R}_i, & \text{if } \mathrm{R}_i > m_i \\ \sigma_i^j CW_{i,0}, & \\ \quad \text{for } j = 0,1,\cdots,\mathrm{R}_i, & \text{if } \mathrm{R}_i \le m_i \end{cases} \quad (1)$$

where σ_i is increasing factor of class i (for example increasing factor of DCF is 2), $CW_{i,min}$ and $CW_{i,max}$ are minimum and maximum CW size of class i, and $L_{i,retry}$ is retry limit of class i. Backoff period is randomly chosen in range of [0, $CW_{i,j}$]. The AIFS is applied to achieve differentiation of each class. The AIFS for a given AC is determined by the following equation.

$$AIFS_i = SIFS + AIFSN_i \times \delta \quad (2)$$

where $AIFSN_i$ is AIFS Number of ith AC (AC_i) determined by the AC and physical setting of EDCA standardization [2]. δ is the duration of a time slot. The AC with the smallest AIFS has the highest priority.

Although collision can be reduced in higher AC with higher transmission opportunity by differentiation of CW and AIFS, it still exists in a saturated traffic condition.

B. Interclass Collision Protection (ICP) Model

ICP model eliminates interclass collision by using contention protection period (CPP). Same transmission procedure is employed as in EDCA except the CPP. When the wireless channel is idle and station i needs to transmit, the station transmits after waiting AIFS and backoff period determined by the AC. The CPP is inserted after the existing backoff period. By using the CPP, only the highest class station transmits even if the backoff periods of different class stations are finished simultaneously. Thus the ICP model can eliminate delay by interclass collision. That is, in this situation the highest class station transmits the data and other station waits until the channel is idle. After cycle we need to set new backoff period to the lower class stations. If the stations don't reset backoff period, collision can be occurred in next period because the remaining backoff period of lower stations is zero. To protect this case we make the lower class station gets the backoff period from previous own backoff stage.

CPP consists of two elements. That is backoff timeslot and orthogonal timeslot. Backoff timeslots proceed as timeslots of backoff period. Each backoff timeslot checks whether the channel is busy or not. If the channel is idle, a station transmits in the next timeslot. Otherwise, a station freezes until next free period. Orthogonal timeslot transmits busy signal, named orthogonal backoff signal during one timeslot. The orthogonal backoff signal guarantees orthogonality to other signals. That is, any station or AP can translate its data signal even in the transmission of the orthogonal signal. An orthogonal backoff signal transmitted by a station blocks transmission of the lower priority stations and makes the highest AC station transmits its data.

Figure 1 illustrates transmission of first class station in the four-class model. There are existed period of four stations finishes simultaneously. After the backoff period station 1 is transmitted and four stations. Station 1 is AC_0, station 2 and 3 are AC_1, and station 4 is AC_3. In this figure backoff others wait during the transmission. In the next cycle station 1 sets new backoff period from initial backoff stage because the transmission of station 1 is successful and other stations get backoff period from previous backoff stage. If lower stations don't reset backoff period, station 2, 3, and 4 have zero backoff period and station 2 and 3 make collision in the next cycle.

III. ANALATICAL MODEL

A. Analytical Model

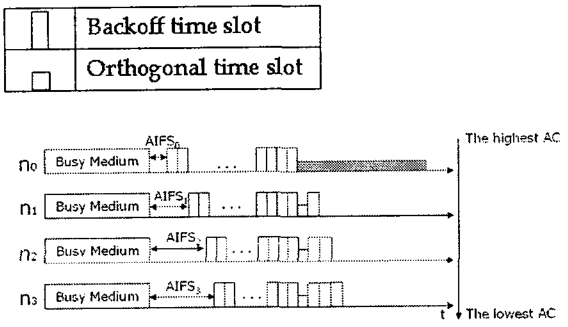

Figure 1. Basic ICP model

To analyze ICP model, we examine IEEE 802.11e EDCA model based on [5]. In the literature EDCA model with two dimensional Markov chains is considered to analyze throughput and delay. Two stochastic processes, backoff stage and backoff counter are investigated in the two dimensional Markov chain In this paper we propose one dimensional Markov chain by decoupling the backoff stage updating process from the backoff counter.

Let TX_i is the event that a station of ith Access Category (AC_i) is transmitting a frame into a timeslot. Also, let $s_i=j$ be the event that a station of AC_i is in backoff stage j, $j \in (0,\cdots,R_i)$. Then, $P(s_i=j)$ can be obtained as follows from the Bayes' Theorem.

$$P(s_i = j) = P(TX_i)\frac{P(s_i = j \mid TX_i)}{P(TX_i \mid s_i = j)} \qquad (3)$$

Note that station of AC_i can be in any stage j, when it transmits a data frame. Thus, we have

$$\tau_i = P(TX_i) = \frac{1}{\sum_{j=0}^{R_i} \frac{P(s_i = j \mid TX_i)}{P(TX_i \mid s_i = j)}} \qquad (4)$$

$P(s_i=j|TX_i)$ represents the probability that a station of AC_i is in stage j. This probability is obtained stochastic process ($s_i=j$). That is, it is followed by the steady-state distribution of a discrete-time Markov chain $s_i(k)$, describing the backoff stage during the station's transmission instant k, whose non-null one-step transition probability is given as follows.

$$\begin{cases} P(s_i(k+1)=j \mid s_i(k)=j-1)=p_i & j=0,\cdots,R_i \\ P(s_i(k+1)=0 \mid s_i(k)=j)=1-p_i & j=0,\cdots,R_i-1 \\ P(s_i(k+1)=0 \mid s_i(k)=R_i)=1 & j=R_i \\ P(s_i(k+1)=j \mid s_i(k)=j)=q_i & j=0,\cdots,R_i \end{cases} \qquad (5)$$

p_i is the collision probability of a frame in AC_i. q_i is the recycling probability which represents any station of higher class seen by a frame of AC_i being transmitted on the channel. From (5) we can get $P(s_i=j|TX_i)$.

$$P(s_i = j \mid TX_i) = \frac{\left(1-\frac{p_i}{1-q_i}\right)\left(\frac{p_i}{1-q_i}\right)^j}{1-\left(\frac{p_i}{1-q_i}\right)^{R_i+1}} \qquad (6)$$

$$, \; i \in (0,\cdots,N-1), j \in (0,\cdots,R_i)$$

Now, $P(TX_i|s_i=j)$ in equation (4) is the probability that a station of AC_i transmits a frame in backoff stage j. From [5], given backoff stage j, $P(TX_i|s_i=j)$ is obtained by dividing the average number of slots spent by the station during one cycle.

$$P(TX_i \mid s_i = j) = \frac{1}{1+\alpha_i + E[b_{ij}]} \qquad (7)$$

$$, \; i \in (0,\cdots,N-1), j \in (0,\cdots,R_i)$$

$E[b_{ij}]$ is the average value of the backoff counter equal to $CW_{ij}/2$, and α_i is difference between AIFS$_0$ and AIFS$_i$. CW_{ij} is CW size obtained by equation (1). In IEEE 802.11e model, high AC station transmits early with the difference of AIFS; we can think low AC station stay in backoff cycle during α_i. From equation (5) and equation (6) into (3) can be written as.

$$\tau_i = P(TX_i) = \frac{1}{\sum_{j=0}^{R_i} \frac{P(s_i = j \mid TX_i)}{P(TX_i \mid s_i = j)}}$$

$$= \frac{1}{1+\alpha_i + \frac{1-\left(\frac{p_i}{1-q_i}\right)}{1-\left(\frac{p_i}{1-q_i}\right)^{R_i+1}} \sum_{j=0}^{R_i}\left(\frac{p_i}{1-q_i}\right)^j E[b_{ij}]} , \qquad (8)$$

$$i \in (0,\cdots,N-1), j \in (0,\cdots,R_i)$$

Collision occurs in AC$_i$ when two more stations of AC$_i$ transmit and any station of higher than AC$_i$ doesn't transmits a data. Therefore, the collision probability is calculated as.

$$p_i = \left(1-(1-\tau_i)^{n_i-1}\right)\prod_{h}^{i-1}(1-\tau_h)^{n_h} \quad . \quad (9)$$
$$,i \in (0,\cdots,N-1)$$

The recycling probability is calculated by the transmitting probability of stations of AC$_i$ and higher AC than AC$_i$ simultaneously.

$$q_0 = 0,$$
$$q_i = \left(1-(1-\tau_i)^{n_i}\right)\left(1-\prod_{h}^{i-1}(1-\tau_h)^{n_h}\right) \quad (10)$$
$$,i \in (0,\cdots,N-1)$$

Equation (8), (9), and (10) form a nonlinear system with same number of variables and equations. This system can be solved by utilizing a numerical method and has a unique solution in the range of γ_i, p_i, q_i.

B. Throughput analysis

Let the probability $p_{S,i}$ (or $p_{C,i}$) be the probability that a successful transmission (or collision) at AC_i. Then, we have in a slot time. Also, let p_b be the probability that the channel is busy.

$$p_{S,i} = n_i\tau_i(1-\tau_i)^{n_i-1}\prod_{h=0}^{i-1}(1-\tau_h)^{n_h} \quad (11)$$
$$,i \in (0,\cdots,N-1)$$

$$p_{C,i} = \frac{n_i(n_i-1)}{2}\tau_i^{\,2}(1-\tau_i)^{n_i-2}\prod_{h=0}^{i-1}(1-\tau_h)^{n_h} \quad (12)$$
$$,i \in (0,\cdots,N-1)$$

$$p_b = \sum_{i=1}^{N-1}(p_{S,i}+p_{C,i}), i \in (0,\cdots,N-1) \quad (13)$$

Let S_i (i=0,…,N-1) denote the normalized throughput of AC_i. The throughput S_i is given as follows.

$$S_i = \frac{\text{E(payload transmission time in a slot time for the I class)}}{\text{E(lengh of a slot time)}}$$
$$= \frac{p_{S,i}T_{E(L)}}{(1-p_b)\delta + \sum_{i=0}^{N-1}\left(p_{s,i}T_{S,i}+p_{C,i}T_{C,i}\right)} \quad (14)$$

δ, $T_{E(L)}$, $T_{S,i}$, and $T_{C,i}$ in the above equation denote the duration of empty timeslot, the time to transmit an average payload, the average transmission time of AC$_i$, and the average collision time of AC$_i$, respectively. $T_{S,i}$ and $T_{C,i}$ are calculated like that.

$$\begin{cases} T_{S,0} = H + T_{E[L]} + SIFS + ACK + AIFS_i \\ T_{S,i} = H + T_{E[L]} + SIFS + ACK + AIFS_i + (i+1)\delta \end{cases} \quad (15)$$

$$\begin{cases} T_{C,0} = H + T_{E[L^*]} + E(IFS) \\ T_{C,i} = H + T_{E[L^*]} + E(IFS) + E(N_{i,retry})\delta \end{cases} \quad (16)$$

If transmission succeeds (or collides), $T_{S,i}$ (or $T_{C,i}$) needs more time to process CPP. To get average collision time, we need to know average number of retries, $E(N_{i,retry})$, which is given as.

$$E[N_{i,retry}] = \sum_{j=0}^{R_i}\frac{j(p_i+q_i)^j(1-p_i-q_i)}{1-(p_i+q_i)^{R_i+1}},$$
$$i \in (0,\cdots,N-1) \quad (17)$$

IV. NUMERICAL RESULT

The computational result is based on ICP model for IEEE 802.11e EDCA Physical layer parameters are based on IEEE 802.11a and IEEE 802.11e standardization [2]. It is summarized in Table 1. Figure 2 compares throughput by IEEE 802.11e EDCA and ICP model for different of stations. In the figure, the throughput of ICP model is improved by approximately 10% except in AC_3 compared to the IEEE 802.11e EDCA.

The improvement of total throughput is due to

Table 1. Simulation parameters

Parameter	Value
Packet payload, $T_{E(L)}$	8184 bits
Slot time	20 us
MAC header	224 bits
PHY header	192 bits
ACK packets	112 bits + PHY header
SIFS	10 us
Minimum CW	{16, 32, 64, 64}
Maximum CW	{32, 64, 512, 512}
Retry limits	{4, 7, 10, 14}
AIFSN	{2, 2, 3, 7}

the elimination of interclass collision in EDCA model. As the channel is congested, the throughput improvement by the first AC is vivid. It is because the station of highest class is transmitted in the situation of interclass collision. The improvement by the second AC is larger than that the other ACs, when the number of stations is small. It is because that the collision is occurred in highest AC stations when backoff period of interclass stations finishes simultaneously. That is, in this situation stations which are in same and lower AC are not regarded as collision.

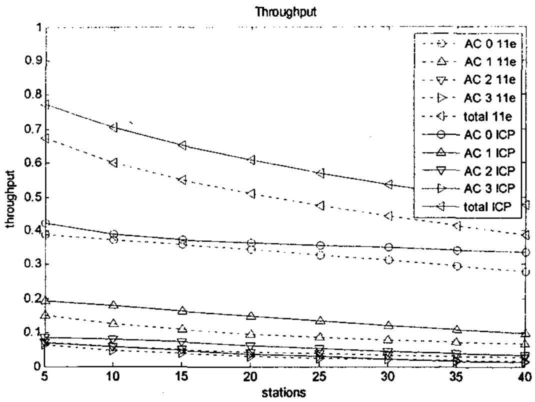

Figure 2. Normalized throughput

V. CONCLUSION

In this paper we propose an interclass collision protection model to increase throughput in wireless LAN. To eliminate interclass collision we propose the contention protection period. When backoff period of interclass stations finish simultaneously the highest station transmit and the others waits next idle period. We make analytical model of ICP and compare IEEE 802.11e EDCA. The numerical results show that ICP model can provide better performance to compare existing EDCA model.

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