COLLISION-AWARE ADAPTION OF CONTENTION WINDOW IN 802.11E WIRELESS LAN

Shih-Wei Pan, Jung-Shyr Wu and Ming-Wei You

Department of Communication Engineering, National Central University, JhungLi City, Taiwan

ABSTRACT

One of the key challenges in designing a quality of service (QOS) scheme for IEEE 802.11 wireless LANs (WLANS) is reducing collisions and improving throughput. Existed Adaptive contention windows mechanisms can reduce collisions of all traffic. However, adaptive contention window algorithms cannot guarantee the absolute priority of the high-priority traffic. Especially in the heavy loading, low-priority traffics will introduce unnecessary collisions and cause unsuccessful transmission. Our scheme aims to share the transmission channel efficiently and to provide the absolute differentiated traffic scheme. Relative priorities are provisioned by adjusting the range of the back-off timer of low-priority traffic class taking into account both applications requirements and network conditions. We demonstrate the effectiveness of our solution by comparing with existing approaches through extensive simulations. Results show that our scheme reduces frame delay as well when traffic load is heavy. Furthermore, our scheme is simple and easy to implement.

KEYWORDS

802.11e, Collision-aware, Contention Window Sizes, Back-off

1. INTRODUCTION

Over the recent decade, the wireless local area network (WLAN) has been a promising technology providing high-speed and low-cost wireless communication. The IEEE 802.11 is the popular technology to implement WLANs. The 802.11 WLAN is one single channel shared by several geographically distributed nodes. Without central control, the IEEE 802.11 Medium Access Control (MAC) exploits CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance) to resolve access collision [1]. In the CSMA/CA access scheme, the distribution coordination function (DCF) of IEEE 802.11 performs binary exponential back-off (BEB) to reduce frame collision probability.

In order to improve the performance of contention-based, many researchers have attempted to optimize the size of the contention window. Bianchi analyzed the saturated throughput by using the Markov chain model and study revealed that the saturated throughput of IEEE 802.11 DCF decrease as the number of nodes increases [2]. Consequently, the BEB analysis has been adequate excellent discussions on the issues on DCF [3]-[6]. The BEB analysis indicated that the collision can be reduced as extending the size of the contention windows. However, extending the size of the contention window has no benefit to improve the quality of service (QoS).

Consequently, the IEEE 802.11 Task Group E has specifies the contention-based access mechanisms from prioritized QoS Enhanced Distributed Channel Access (EDCA) in order to achieve QoS requirements in IEEE 802.11 WLANs [7]. The EDCA aims to enhance the DCF derived from the original 802.11 MAC. Service stream are classified into different Access Categories (ACs) with different parameters. Parameters of ACs include differentiated

Arbitration Inter Frame Spaces (AIFSs), and differentiated CWs. ACs take advantage the difference of parameters to guarantee the transmission opportunity of the high-priority traffic. By setting proper parameters, high-priority traffic will occupy more transmission opportunities than lower-priority traffic. EDCA can be compatible with existing 802.11 standards.

The main contribution of EDCA is to ensure better services to high-priority class while offering a minimum service for the low-priority traffic. Although EDCA can provide the differentiated quality of service, the performance is not optimal since EDCA parameters cannot be adapted to the network conditions. Actually, each AC is implemented as a virtual station, the collision rate increases very fast in the short time while multi-media services are transmitting simultaneously. High-priority traffic such as video or voice usually generates large amount of packet. The large amount packets of high-priority traffic occupy frequently the transmission channel and cause the saturation network loading in the short time. While the network loading is suddenly heavy, EDCA will suffer from intensive contentions. The fundamental problem comes from the improper back-off parameters set and the ignorant loading back-off algorithm.

In order to solve the back-off fundamental problem, we propose a proper choice of the CW parameter set which is based on network loading status and has a great influence on overall network performance. The remainder of this paper is organized as follows. In Section II, we brief the IEEE 802.11e EDCA and describe the collision problem. Then, the differentiated adaptive back-off scheme is described in detail in Section III. Simulation methodology and performance evaluation of our proposal are details in Section IV. Section VI concludes the paper by summarizing results and outlining future works.

2. RELATED WORK

2.1. Protocol Description of DCF and EDCA

A legacy DCF is the basic MAC mechanism for IEEE 802.11. It performs carrier sense multiple access with CSMA/CA with (BEB) procedures to access wireless medium [1][7]. In DCF, a station with a data frame to transmit supervises the channel activities until a DIFS. After sensing an idle DIFS, the station still waits for a random back-off interval before each transmitting. The back-off time counter is decremented in terms of slot time as long as the channel is sensed idle. If the channel is sensed busy during back-off time, the station to suspend back-off countdown. Until the channel is idle for DIFS, the remained back-off time counter is decremented again. As the remained back-off time is zero, a station transits immediately data frames. As each new transmission attempt, the back-off time is randomly picked from [0, CW-1] in terms of time slots, where CW is the current back-off windows size. The initial CW is CWmin. After each collision occurred, CW is doubled until a maximum back-off window size value is CWmax. An optional mechanism named RTC/CTS is also defined in the DCF. It is used to prevent the data frame transmission failure. Before transmitting a data frame, a station preliminary transmits a special short frame called request to send (RTS). The receiving station responds a clear to send (CTS) frame if the receiving station allows the data transmission. The transmitting station is allowed to transmit its packet only if the CTS frame is correctly received. Collisions occur only on the RTS frame, and it is early detected by the transmitting stations by the lack of CTS responses.

The EDCA works on four ACs, which are virtual DCFs, and each AC accomplishes a differentiated channel access. Differentiated AC[i] (i=0,…,3) are achieved by the initial back-off window size CWmin[i], the maximum back-off window size CWmax[i], and the AIFS[i]. AIFS for a given AC is determined by the following equations:

$$\mathrm{AIFS[i]} = \mathrm{SIFS} + \mathrm{AIFSN[i]} \times \mathrm{aSlotTime},$$

where AIFSN[i] is AIFS number dictated by the AC and aSlotTime is the duration of a time slot. The AC of the highest priority has the smallest AIFS. In other words, the EDCA takes advantage of AIFS[i], CWmin[i] and CWmax[i] instead of DIFS, CWmin and CWmax, shown in Figure 1. In the EDCA, both the physical carrier sensing and the virtual sensing methods are similar to those in the DCF.

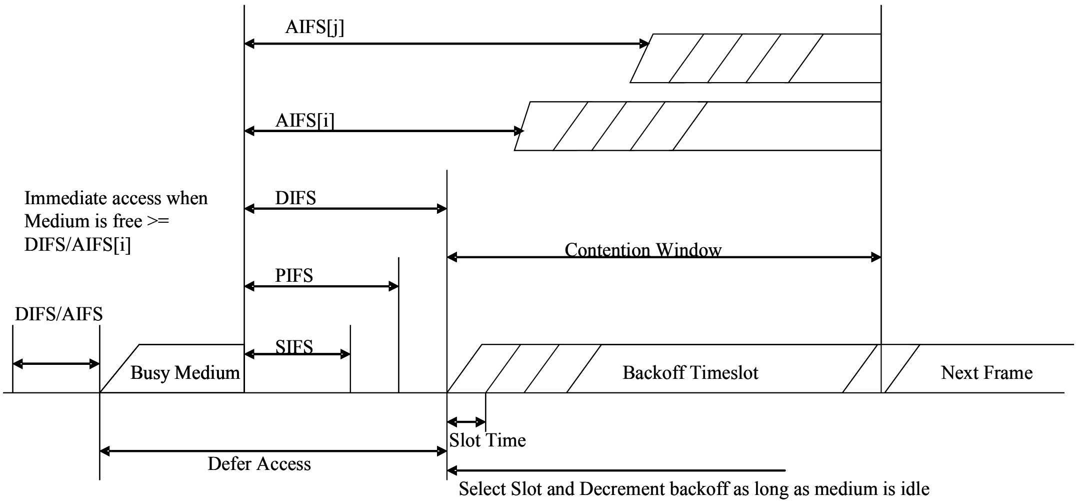

Figure 1 Inter-frame Space Relations

2.2. Problem Description

The ECDA scheme has a different slot decrement method unlike legacy DCF scheme. AIFS and CW affect the number of transmission opportunities. The traffic with the shorter AIFS can occupy more transmission opportunities. Yang analyzed the differentiated CWs and the maximum regardless of differentiated AIFS [13]. Yang validated that the initial window size, the window-increasing factor and the maximum back-off stage can reduce the collision probability [13]. The lower-priority traffic with the larger AIFS affects slightly the performance of the higher-priority traffic [9]. Hwang analyzed the effect of AIFS with the default parameters set of IEEE 802.11 EDCA and the larger AIFS has slightly lower channel access probability in the coexistence EDCA network with different AIFS [9]. Hui took advantage of the unified model to estimate the saturation throughput ratio of different ACs with the same AIFS and different CWs [8]. Observe the analysis on of EDCA, the high-priority traffic with the shorter AIFS has much better performance over the lower-priority with the longer AIFS especially at high-traffic load [8][9]. Although in the literatures there have been adequate excellent discussion on the issues on DCF and EDCF [8]-[12], none of the above studies proposed a mechanism to force the ACs to adopt differentiated CWs that maximum the channel capacity for current channel status.

In order to improve the efficiency of the IEEE 802.11e EDCA, Chen proposed to incorporate contention adaption into EDCA and significantly reduce the energy consumption [10]. Chen's scheme used the collision probability to decide whether the lower-priority traffics are allowed to transmit. The collision probability measured the collision of the whole network including the high-priority traffics and the low-priority traffics. The adaptive CW of the legacy DCF took advantage of the collision probability to adapt the CW and the size of CW is based on the measurement of collisions [11]-[14]. Comparing to the previous performance evaluations [10]-

[14], the collision probability of the shorter AIFS can influence the longer AIFS one. Hence, the adaptive CW only takes into account the collision probability with the same AIFS and the shorter AIFS. However, the low-priority traffic with the longer AIFS and CW still influences the high-priority traffic with the shorter AIFS and CW by the observation of the simulation. For example, Figure 2 shows the difference of AIFS back-off decrease method between AIFS = 2 and AIFS = 3. When all the stations have the same CW = 3, the EDCA STA1 decreases the back-off value at T1, the end of AIFS. On the other hand, the STA2 and the STA3 decreases the back-off counter at T2. The STA1 starts the transmission of packet at T4 after the backoff counter is already 0 and the STA3 transmits a packet after the backoff counter changes from 1 to 0. Hence, in this example, the STA1 and the STA3 send packets at the same time. The earliest transmission time for the STA1 or the STA3 is T1 when it chooses 0 as back-off counter. The STA2 can transmit at T2 in case of 0 back-off counter. So, effectively any EDCA stations with AIFSN=3 will have to wait 1 more slot to get access to the medium compared with AIFSN=2 stations. The collision only occurs among stations with the same AIFSN and the smaller AIFSN. Hence, the station with AIFSN=2 has a priority to access channel over the station with AIFSN=3. However, there is a variation in case that there are receptions during back-off as shown in Figure 3. When the STA1 with AIFSN=2 and the STA2 with AIFSN=3 have 2 as back-off counter. The STA1 can decrease the back-off counter at T1 and transmit a packet at T4. But the STA2 also has back-off counter=0 at T4. The collision between the STA1 and the SAT2 occurs at T4. Hence, the collision between the high-priority traffic and the low-priority traffic will occur if the difference of AIFSNs is equal to the difference of CWs. By observation, the extend size of CWs can reduce efficiently collisions among traffic with the same AIFS. However, none of the above studies proposed a mechanism to prevent collisions between the high-priority traffic and the low-priority traffic.

According the IEEE 802.11e, the default parameters sets of AC_VO and AC_VK are the same AIFS, as shown as Table 1 [7]. The traffic of the lower-priority traffics of AV_BK and AC_BE are the larger AIFS. The adaptive CW of IEEE 802.11e shall adapt the CW to the collision probability with the same AIFS and the shorter AIFS while the network is on the light load. In the heavy load, the lower-priority traffic shall use the long CW for the transmission opportunity and reduce the collision probability. Hence, we propose the novel adaptive CW mechanism depended on the difference AIFS.

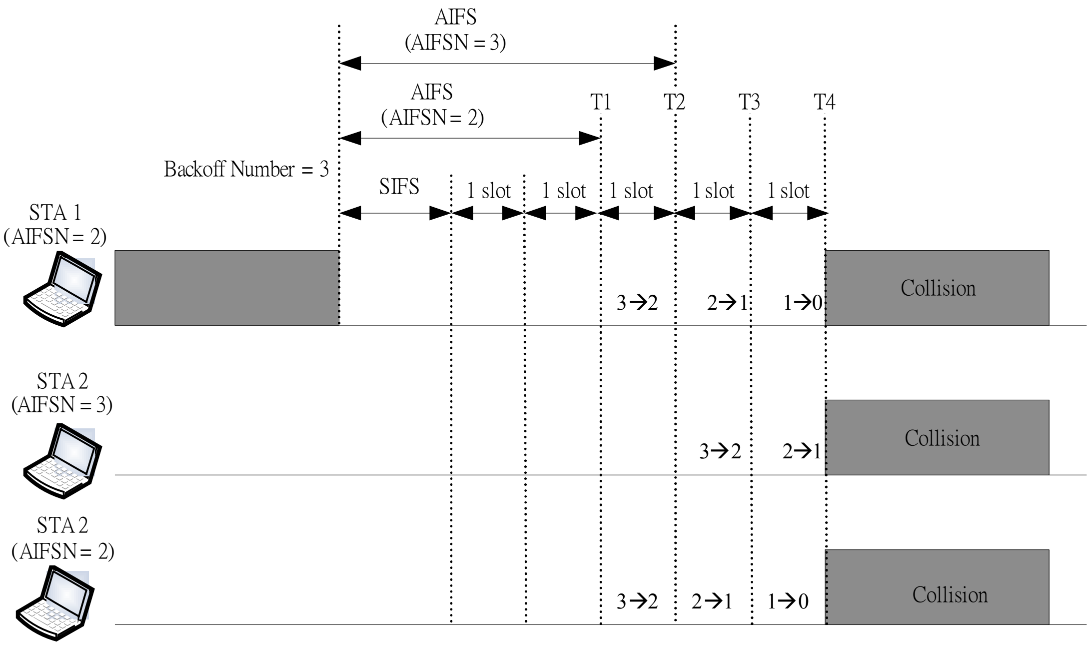

Figure 1 The collision occurs among stations with the same AIFSN or the same back-off counter

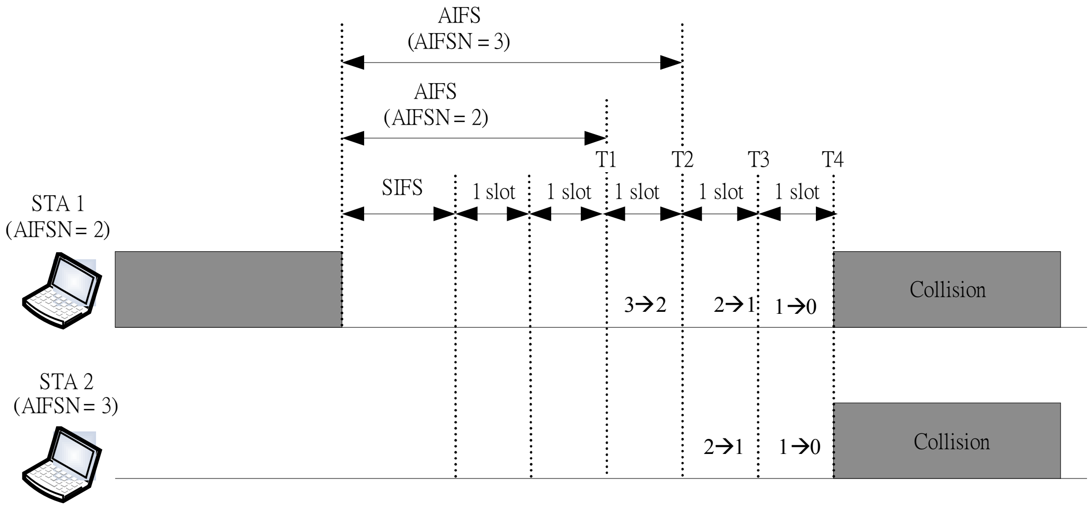

Figure 2 The collision occurs among stations with different AIFSNs

3. THE ADAPTIVE BACK-OFF MECHANISM

In order to efficiently support time-bounded multimedia applications, we use a dynamic procedure to change the range of the back-off timer after collisions. We believe that this adaptation will increase the total goodput of the traffic and assure the superior of the high-priority traffic.

In the basic EDCA, the CWmin[i] and CWmax[i] values are statically set for each priority level. The proposal takes account the average collision rate in the short time and the difference of CWs. The highest priority traffic has the smallest AIFS and the smallest contention window value so that it has the highest priority to access the media. The proposal scheme reset the CW[i] value more slowly to adaptive values. The adaptive value depends on the current CW[i] sizes and the average collision rate while maintaining the priority-based discrimination. The adaptive slow CW decrease is a tradeoff between waiting some back-off time and risking a collision followed by the whole transmission contention.

For this purpose, the proposal is concerned with the back-off timer range of the low-priority traffic, regardless of the high-priority traffic. The proposal divides two phases. The first phase is working on the light loading. The first phase takes advantage of EDCA. All stations content the transmission opportunity according by the EDCA scheme [7]. As the network loading growing, the second phase is working on the heavy loading. The second phase takes advantage of the collision situation to adopt the CW. In the next sub-sections, the second phase is explained how the contention window of each priority level is set after consecutive successful transmissions or collisions.

3.1 Discriminating the Network loading

By observation of previous studies, more collisions occur while the network loading is heavy. Collision probability can be easily measured and precisely reflect the network loading level. Each station simply keeps tracking the number of channel accesses and records the number of collisions. The collision probability $P^{j}_{collision}$ then can be derived as follows:

$$P^{j}{}_{collision} = \frac{N_{collision}}{N_{access}} \qquad (1)$$

where N_{access} is the number of channel accesses, and $N_{collision}$ is the number of collisions among N_{access} , refers to j^{th} the update period. The station works in normal EDCA operation initially. After each channel access, the station updates $P^{j}{}_{collision}$. Only previous accesses are included for the calculation. To predict the bias against transient collisions, we use an estimator of Exponentially Weighted Moving Average (EWMA) to smoothen the estimated values. Let be the average collision rate for each update period computed according to the following iterative relationship:

$$P_{collision\_average} = (1-\alpha)\times P^{j-1}_{collision\_average} + \alpha \times P^{j}_{collision} \qquad (2)$$

where α and $(1-\alpha)$ is the weight (as known as the smoothing factor) and effectively determines the memory size used in the averaging process. If $P_{collision\_average}$ is larger than a predefined threshold, $P^{threshold}_{collision}$, the proposal will consider that the network loading is the heavy loading. In the heavy loading, the low-priority traffic used the second phase to content the transmission opportunity. On the other hand, $P_{collision\_average}$ is smaller than a predefined threshold, $P^{threshold}_{collision}$. The low-priority traffic used the original 802.11e EDCA to content the transmission opportunity.

3.2 The adaptive CW of the low-priority traffic as the heavy loading

The objective of the second phase is to ensure that the high-priority traffic has the absolute priority to occupy the transmission opportunity especially in the network loading is heavy. The second phase of the low-priority traffic access scheme adopts the CW size and the back-off time cannot equal to the amount of the $AIFS$ and the CW of the high-priority. Hence, the back-off timer of the low-priority traffic in the second phase is randomly pickup from

$$[CW[AC], CW[AC]\times 2] \ . \qquad (3)$$

$CW[AC]$ is the current contention window size. After each transmission of packet of the low priority, all stations update the $P_{collision\_average}$ and exam whether the network loading is heavy. Hence, the update period of $P^{j}{}_{collision}$ is the key parameter to sense the network loading condition. In order to prevent a surge of the network loading, all stations record the number of consecutive successful transmissions N_{trans} . The network loading degrades the light level if the

N_{trans} is greater than the predefined successful transmissions threshold $N_{trans\_threshold}$. The second phase mechanism simply sets the contention window of the corresponding class according by (3) after each unsuccessful transmission. The second phase is operating while $P_{collision\_average} \geq P_{collision}^{threshold}$ or $N_{trans} \leq N_{trans\_threshold}$.Picked the back-off timer of the second phase is depicted in Figure 4.

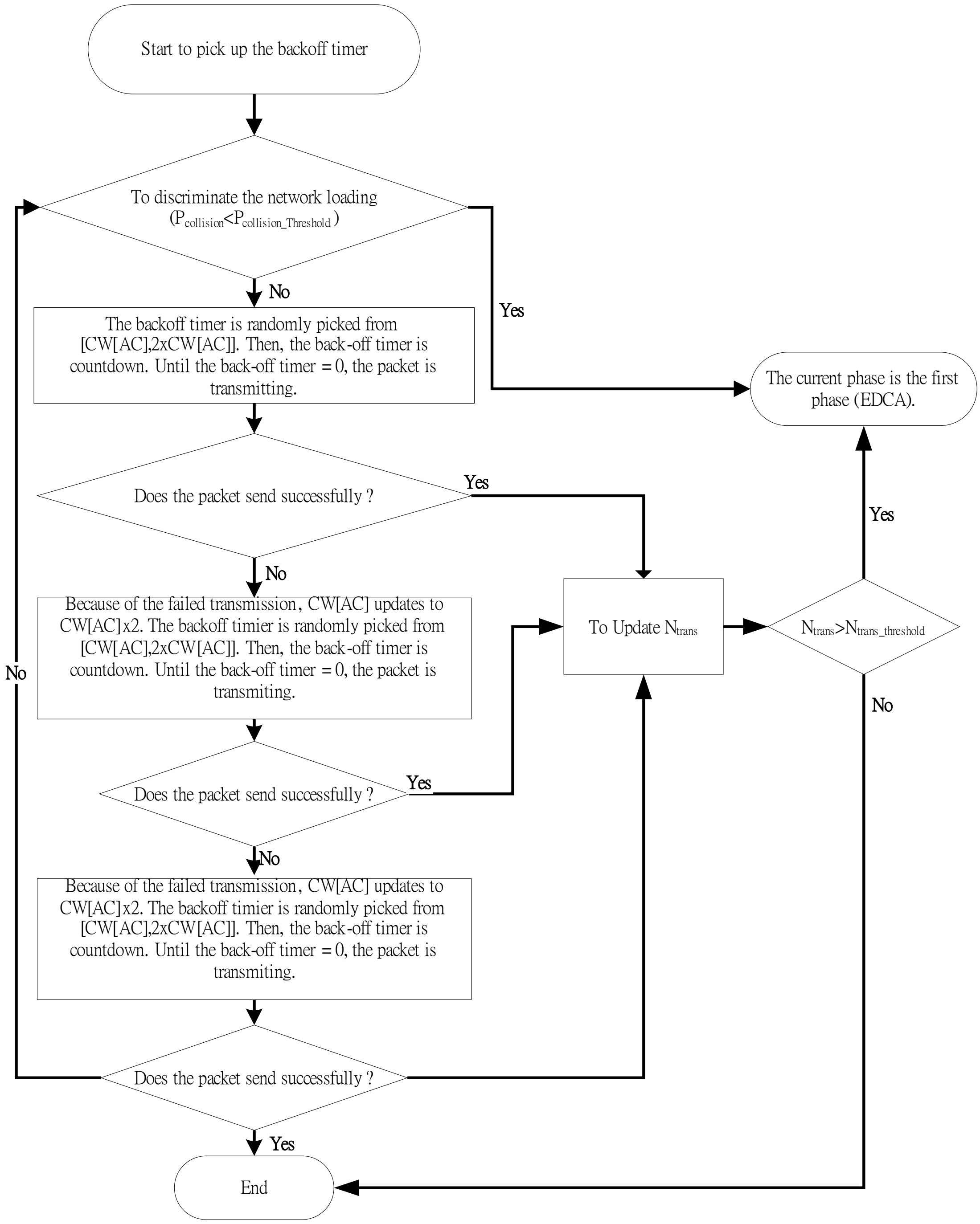

Figure 3 The flow chart of the second phase

4. SIMULATIONS AND RESULTS

We have implemented our proposal in the ns-2 simulator [15]. We report in this section part of simulations we have done with different network topologies and source characteristics. In order to show advantages of the new CW of our proposal, we also present the comparison of the original EDCA and Lamia's AEDCF [14].

As mentioned in Section 3, our scheme uses the collision rate to decimate network loading. We have done several set of simulations to observe the relation between throughput and collision rate. The simulation constructs one 802.11e Access Point (AP) and twenty stations. Each station is fed three active ACs traffic with the highest priority of AC_VO, a middle priority of AC_VI and the lowest priority of AC_BE, respectively. RTS/CTS mechanism is employed. The parameters of 802.11e MAC and PHY deployed in the simulation, as well the comparative EDCA, are shown in Table 1. The simulation architecture is depicted as Figure 5. The payload of all type of traffics is list in Table 2.

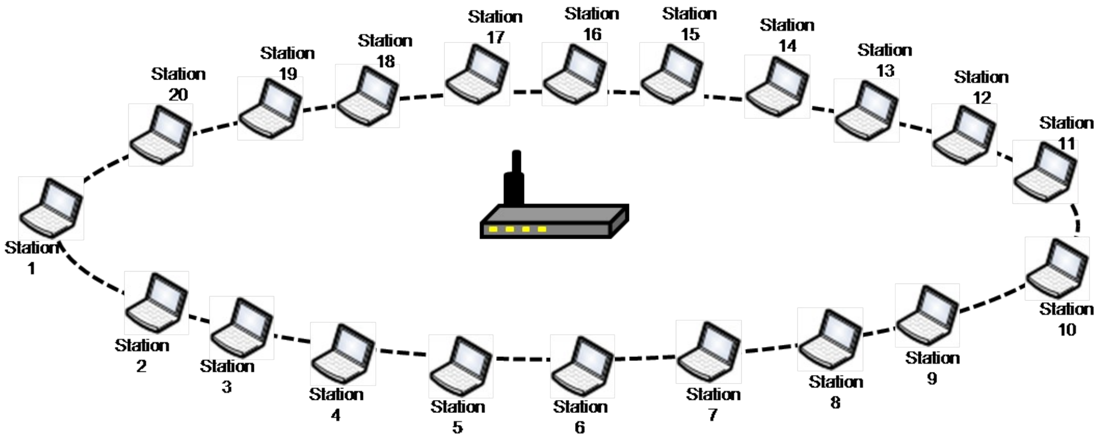

Figure 5 The simulation architecture

Table 1 The simulation parameters set

Phy Header	192 bits
Mac Header	272 bits
RTS Frame	Phy Header + 160bits
CTS Frame	Phy Header + 112bits
CTS TimeOut	Phy Header + 112bits
ACK Timeout	DIFS+ACK
Data Rate	11 Mbps
Time Slot	20µs
SIFS	10µs
AIFS[AC_VO]	2 Time Slots
AIFS[AC_VI]	2 Time Slots
AIFS[AC_BE]	3 Time Slots
CW[AC_VO]	{7, 15}
CW[AC_VI]	{15, 31}
CW[AC_BE]	{31, 1023}
α	0.5

Table 2 Payloads of all traffics

	AC_VO (Voice)	AC_VI (Video)	AC_BE (Best_effort)
Packet Size	160 k bytes	1280 k bytes	1500 k bytes
Mean Arrival Time	20 ms	10 ms	12.5 ms
Sending Rate	64 k bits per second	1024 k bits per second	1200k bits per second

4.1. The effect of collision rate and the number of consecutive successful transmissions

As aforementioned as equation (2), the proposal measures collision rate and consecutive successful transmissions to discriminate the network loading. We have done several sets of simulations to observe the effect of collision rate and consecutive successful transmissions. First, we set that the $N_{trans\_threshold}$ is 0 and $P_{collision}^{threshold}$ is 0.1, 0.2, 0.3, 0.4, and 0.5, respectively. The relation of collision rate and throughput is shown as Figure 5. The network throughput achieves the peak of the network throughput when the amount of stations is between 12 and 14. The performance is poor in a few of stations when the collision rate $P_{collision}^{threshold}$ is set as 0.1 and 0.2. The $P_{collision}^{threshold}$ is so small that the network loading condition is easy to be the heavy loading. In the heavy loading, the contention window size will extend and increase the waiting time for all transmission attempts. However, the performance is getting worse while the collision rate is set as 0.4 and 0.5. The reason is the $P_{collision}^{threshold}$ is too high and the network loading condition is hard to be the heavy loading. As the observation of Figure 5, the proposal define the $P_{collision}^{threshold}$ is 0.3.

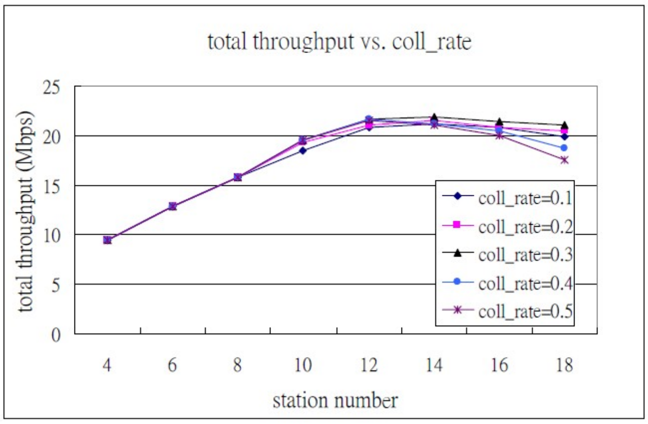

Figure 5 The relation between throughput and collision rate

In order to find out the optimization $N_{trans\_threshold}$, the collision rate threshold $P_{collision}^{threshold}$ is set as 0.3. The simulation set $N_{trans\_threshold}$ as 3, 4, 5 and 6, respectively. As the observation of Figure 6, the throughput is the worst while $N_{trans\_threshold}$ is 3 or 4. While $N_{trans\_threshold}$ is 6, the performance is worse than $N_{trans\_threshold}$ is 5.Hence, the proposal set $N_{trans\_threshold}$ as 5.

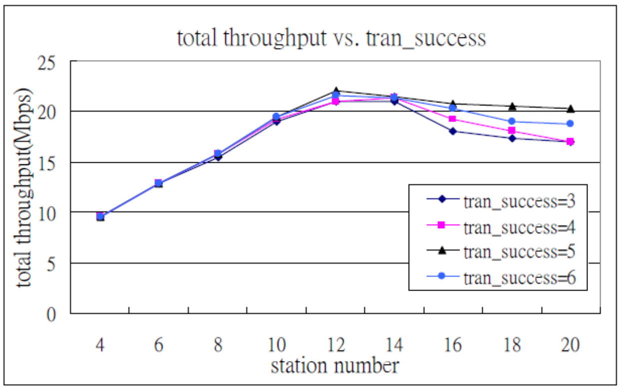

Figure 6 The relation between throughput and the number of concessive successful transmission

4.2. Throughput

Figure 7, 8 and 9 illustrate the throughput of AC_VO (Voice), AC_VI (Video) and AC_BE (Best effort), respectively. The throughput drop slightly as the number of nodes increases, since some stations works as competing stations and more collisions occur as the number of stations increases. The throughput of the proposal is the best.

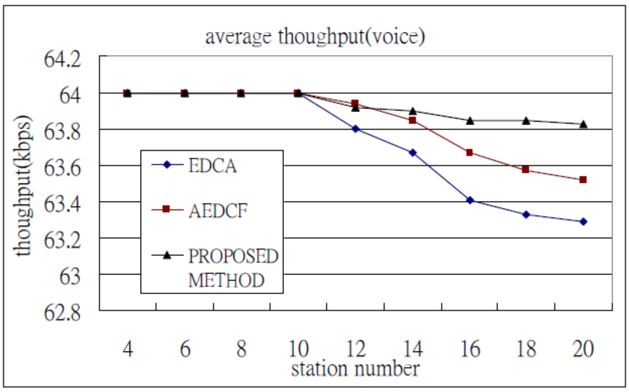

Figure 7 The throughput of Voice

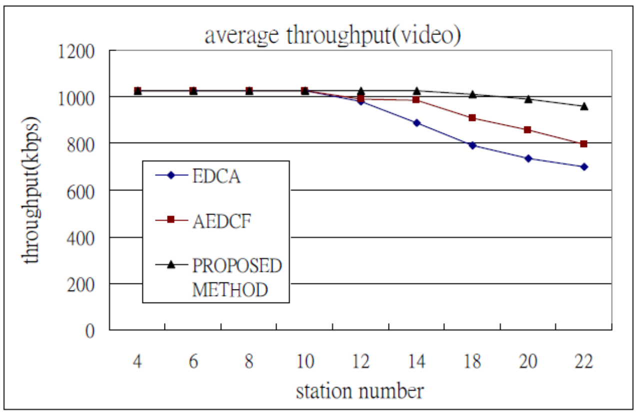

Figure 8 The throughput of Video

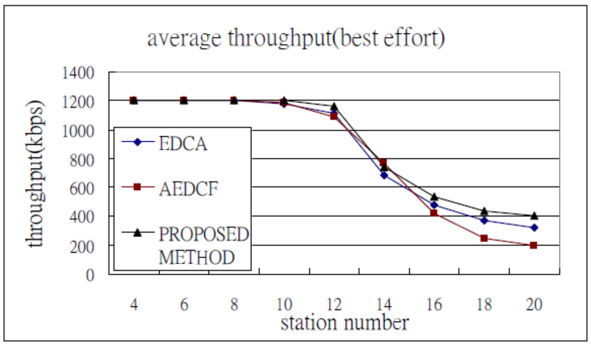

Figure 9 The throughput of Best Effort

4.3. Mean Delay

Figure 10, 11 and 12 show the mean delay performance of all traffic versus the number of stations for EDCA, AEDCF and the proposed method, respectively. When comparing and contrasting these figures, the proposed method is able to keep the delay low even when the traffic load is very heavy, i.e., with a large number of stations.

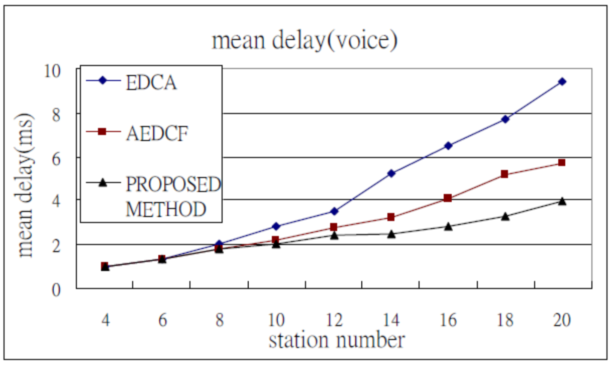

Figure 10 The mean delay of Voice

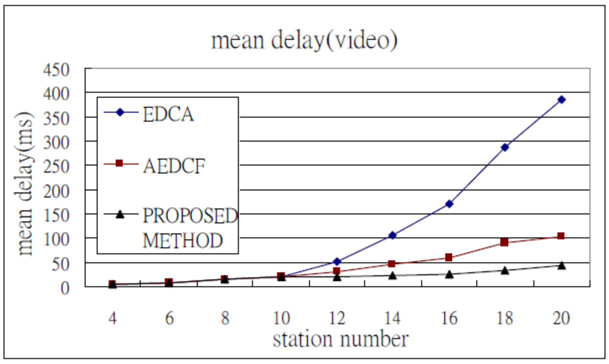

Figure 11 The mean delay of Video

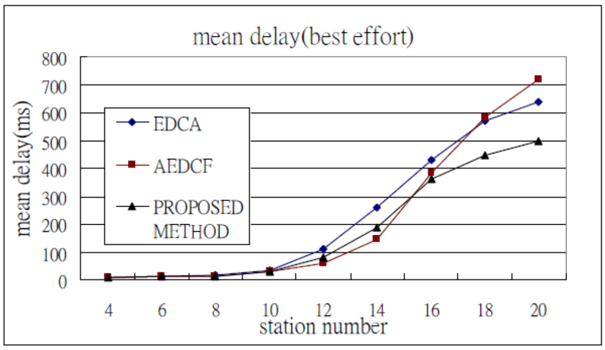

Figure 12 The mean delay of Best Effort

4.4. Medium Utilization

Due to the scarcity of wireless bandwidth, we also study the medium utilization (M_u) of the different schemes by computing the percentage of time used for transmission of data frames:

$$M_u = \frac{TotalTime - CollisionTime - IdleTime}{TotalTme} \times 100\%$$

Figure 13 shows the medium utilization as a function of the traffic load. The medium utilization is going worse while the number of station is increasing. We can see the medium utilization of the proposed method is 8% greater than the basic EDCA when the number of stations is 16. Moreover, the number of stations increases and the medium utilization is almost static. The proposed method achieves better medium utilization than the basic schemes whatever the network loading.

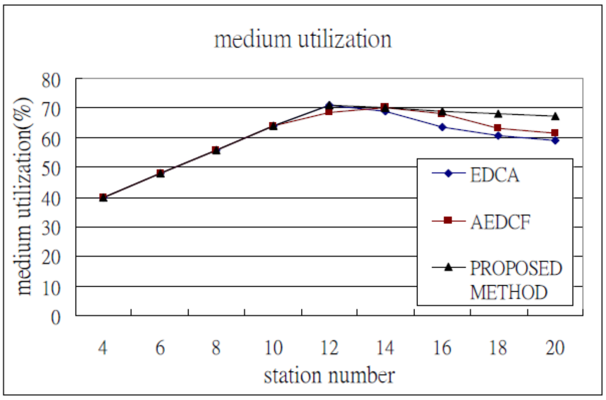

Figure 13 The medium utilization

5. Conclusions

Our main contribution in this paper is the design of a new adaptive scheme for Quality of Service enhancement for IEEE 802.11 WLANs. We extend the basic 802.11e EDCF scheme by dynamically varying the back-off time range of low-priority traffic. Simulation results demonstrated that our scheme achieves better performance of throughput, delay and the medium utilization. We validate our results by simulating the impact of sources and network dynamics on the performance metrics and compare the results obtained with the basic EDCF and the AEDCF. Although the proposal is intended to improve performance of wireless infrastructure networks, the same idea can be used in the ad-hoc mode with some changes. Future works could include adapting other parameters such as AIFS, the maximum number of retransmissions and the packet burst length according to the network load rate.

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