# A Sustained QoS Solution by Contention Adaptation in IEEE 802.11e Wireless LANs

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*Abstract:* - The most significant issue in 802.11 contention based networks is to prevent collisions and to ensure connection quality. Researchers have shown an increased interest in collision aware back-off algorithms. However, collision aware back-off algorithms are still failed to ensure strict priority for the high priority traffic. Especially in the heavy loading network, a large number of unsuccessful collisions of low priority traffic are the leading cause of the performance degradation of high priority traffic. Our scheme aims to share the transmission channel efficiently and to provide the strict priority contention scheme. Our approach is derived from the Enhanced Distributed Channel Access (EDCA) induced in the IEEE 802.11e standard. Relative priorities adjust the average size of the CW of each traffic class according to 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 improves the throughput of higher priority traffic as well when traffic load is heavy. Furthermore, our scheme is simple and easy to implement.

*Key-Words: 802.11e, Back-off, EDCF, Contention Window, Collision, QoS*

## 1 Introduction

Over the recent decades, 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 window. However, extending the size of the contention window delays the packet transmission.

Consequently, the IEEE 802.11 Task Group E has specified the contention-based access mechanisms from prioritized QoS (Quality of Service) Enhanced Distributed Channel Access (EDCA) in order to achieve QoS requirements [7]. The objective of EDCA enhances 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 contention windows (CWs). ACs can provide the differentiated priority to share the single channel. By setting proper parameters, high priority traffic will get more transmission opportunities than low 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 a large amount of packets. 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.

In order to solve the back-off fundamental problem, we propose the proper choice of CW parameter sets 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 window 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.

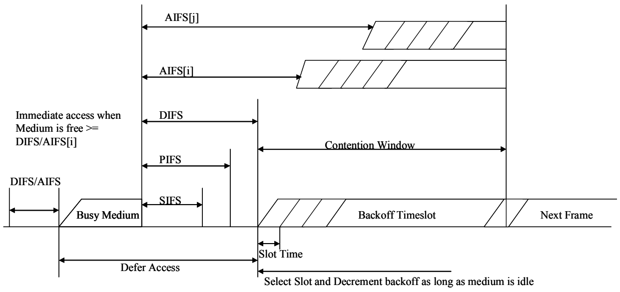

Fig. 1 Inter-frame Space

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:

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

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 Fig. 1. In the EDCA, both the physical carrier sensing and the virtual sensing methods are similar to those in the DCF.

### 2.2 Problem Description

The ECDA scheme has a different slot decrement method unlike legacy DCF scheme. The EDCA uses AIFS and CW to affect the number of transmission opportunities. In order to study the effect of CW, 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]-[8]. The BEB analysis indicated that the collision can be reduced as extending the size of the contention window. However, extending the size of the contention window delays the packet transmission.

The traffic with the shorter AIFS can occupy more transmission opportunities. The queue-based

802.11e offers some improvements. But the evolution of 802.11e with different QoS requirements under different scenarios is still an open issue. In order to standardize 802.11e simulation models and tools, Yang analyzed the differentiated CWs and the maximum regardless of differentiated AIFS [15]. Yang validated that the initial CW size, the window-increasing factor and the maximum back-off stage can reduce the collision probability [15]. The lower-priority traffic with the larger AIFS affects slightly the performance of the higher-priority traffic [11]. Qiang attempted to decrease CW slowly after each successful transmission. The slow decrease CW scheme without RTS/CTS is helpful for the throughput [6]. 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 [11]. Hui took advantage of the unified model to estimate the saturation throughput ratio of different ACs with the same AIFS and different CWs [10]. To 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. The lower-priority traffic with the same AIFS influences the higher-priority with the same AIFS especially at high traffic load. Although in the literatures there have been adequate excellent discussion on the issues on DCF and EDCF [10]-[14], 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. Many researches attempted to optimize the trade-off between channel efficiency, priority and fairness [7].

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 [12]. 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 [13]-[17].

To observe the previous performance evaluations [3]-[17], the collision probability and the throughput are influenced by CW and AIFS. The smaller $CW_{min}$ values lead to smaller aggregate throughput. This is an obvious drawback of $CW_{min}$ differentiation: the performance differentiation is paid for in terms of aggregate performance [16][17]. This phenomenon is easily explained by considering that the reduction of the $CW_{min}$ value may significantly increase the probability of collision on the channel, thus reducing the overall effectiveness of the random access mechanism [6]-[15]. In contrary to $CW_{min}$ differentiation, the AIFS mechanism is beneficial in terms of throughput performance.

On the question of the strictly priority assurance, the random access mechanism [6]-[15] show that high frame cannot be transmitted before the lower priority ones. The strictly priority cannot be assured. In other words, the AIFS values of the lower priority must be larger than that of the high priority plus its maximum contention window, i.e.,

$$AIFS[j] \geq AIFS[i] + CW_{\max}[i], \ \ if \quad j < i. \quad (1)$$

According to Eq. 1, the value of CWmax should be set to a small eligible value so as not to severely degrade the throughput performance of lower priority traffic. In the following, we introduce the novel adaptive CW mechanism depended on the difference AIFS.

## 3 The Adaptive CW Mechanism

In order to efficiently support time-bounded multimedia applications, we use a dynamic procedure to adjust the CW size after collisions. In this adaptation, the total goodput of the traffic will increase and the transmission delay time is close the IEEE 802.11e.

In the basic EDCA, the CWmin[i] and CWmax[i] values are statically set for each priority level. The proposal takes account of 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. Mobile stations with the proposal scheme use the observation of collision and to calculate the network loading. 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.

The proposal divides two phases. The first phase is working on the light loading. The first phase is the original EDCA. All stations content transmission opportunities according by the EDCA scheme. As the network loading growing, the second phase is working on the heavy loading. The second phase adapts the CW to the collision situation. In the next sub-sections, the discrimination of the network loading and the second phase is explained how the CW of each priority level is set after collisions.

(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 then can be derived as follows:

$$P^{j}_{collision} = \frac{N_{collision}}{N_{access}} \qquad (2)$$

where $N_{access}$ is the number of channel accesses, and $N_{collision}$ is the number of collisions among $N_{access}$, $j$ refers to the $j^{th}$ update period. The station works in normal EDCA operation initially. After each channel access, the station updates $P^{j}_{collision}$. Only previous $n$ 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 $P_{collision\_average}$ be the average collision rate for each update period computed according to the following iterative relationship:

$$P_{collision\_average} = (1-\alpha)\times P^{j-1}_{collision\_average} + \alpha \times P^{j}_{collisio} \qquad (3)$$

where $\alpha$ 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, $P^{threshold}_{collision}$, Mobile stations with the proposal scheme 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 transmission opportunities.

(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 $AIFS$ and $CW$ of the high priority. Therefore, the back-off timer range of the second phase is not between 0 and CW. The back-off timer of the low-priority traffic is randomly pickup from

$$\left[CW_{new}(AC), CW_{new}(AC)\times 2\right]. \qquad (4)$$

$CW_{new}[AC]$ is the low bound of the new contention window. To assure the superior of the high-priority traffic,

$$CW_{new}[AC] = CW_{\max}[AC_{high}] - Diff(AIFS_{low} - AIFS_{high}) \qquad (5)$$

where $CW_{\max}[AC_{high}]$ is the maximum contention window size of the high-priority traffic and

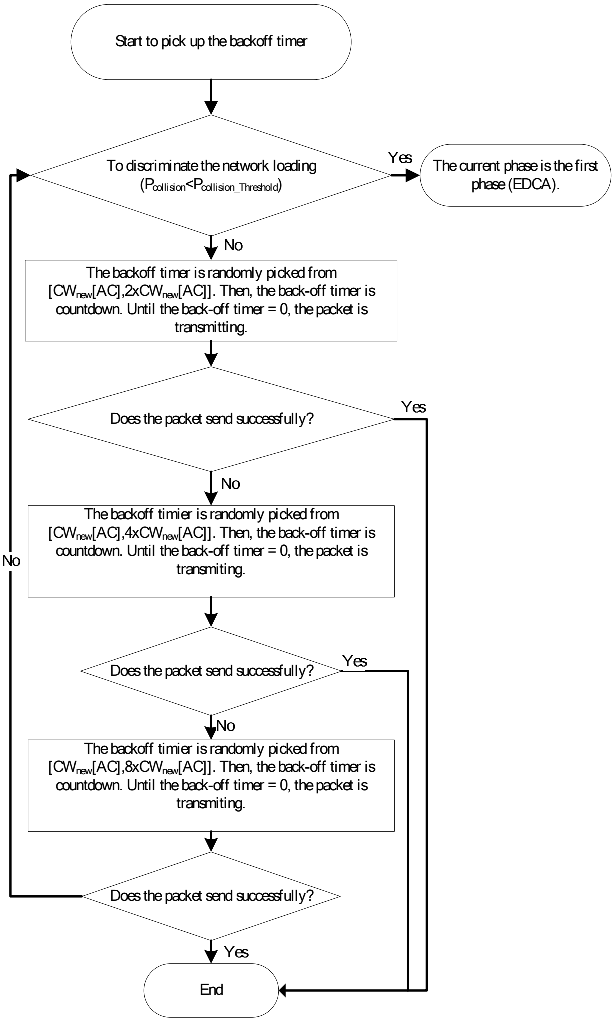

Fig. 2 The flow chart of the second phase

$Diff\ (AIFS_{low} - AIFS_{high})$ is the difference of the AIFS of the low-priority traffic and the AIFS of thehigh-priority traffic. The operation of CW sizes is similar as the BEB procedure. After each unsuccessful transmission of packet of the low priority, the contention window of the low priority is doubled, while remaining less than the maximum contention window of the low-priority $CW_{\max}[AC_{low}]$. However, the second phase mechanism simply sets the contention window of the corresponding class according by (4) after each successful transmission. $P_{collision}$ is updated after each transmission attempt. In order to discriminate the network loading, the proposal check whether $P_{collision}$ is larger than a pre-defined threshold, $P_{collision}^{threshold}$. In the same time, the high-priority traffic of the second phase still contents against other stations according the EDCA scheme. Picked the back-off timer of the second phase is depicted in Fig. 2.

## 4 Simulation and Results

We have implemented our proposal in the ns-2 simulator [19]. 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.

As mentioned in Section 3, our scheme uses the collision rate to decimate network loading and the smooth factor is 0.5. The AC_VO is the higher priority traffic and implements the basic 802.11e EDCF. AC_VI, AC_BK and AC_BE are lower priority traffic and implement the proposal scheme. The simulation uses the topology shown in Fig. 3, which consists of 15 stations indexed from 1 to 15. Each station is fed three active ACs traffic. RTS/CTS mechanism is employed. The parameters of 802.11e MAC and PHY deployed in the simulation, as well the comparative EDCA.

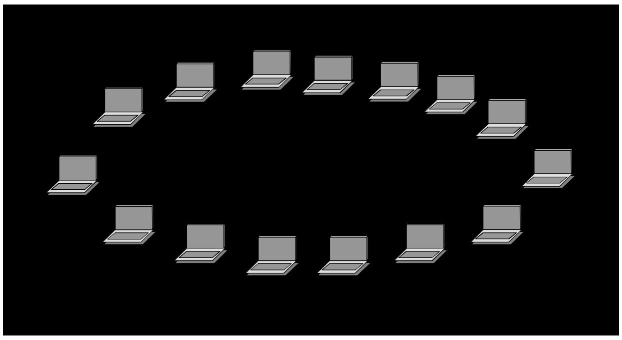

Fig. 3 The simulation architecture

The EDCA parameter sets of the four experiments are listed in Table I. The payload applications are listed in Table II and the traffic model implements the passion distribution. The network model is set up the infrastructure mode. Each station is resident. In order to simulate heterogenic traffics, each station deploys one as follows.

- Experiment 1: Including AC_VO, AC_VI and AC_BE.
- Experiment 2: Including AC_VO, AC_BE and AC_BK.
- Experiment 3: Including AC_VO, AC_VI and AC_BK.
- Experiment 4: Including AC_VI, AC_BE and AC_BK.

Table I The 802.11e EDCA of simulation parameters set

| | |
|---|---|
| Payload Size | 1000 bytes |
| 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 |
| AIFS[AC_BK] | 7 Time Slots |
| CW[AC_VO] | {7, 15} |
| CW[AC_VI] | {15, 31} |
| CW[AC_BE] | {31, 1023} |
| CW[AC_BK] | {31, 1023} |
| $CW_{new}$[AC] | 27 |

Table II Applications in the simulation

| | AC_VO | AC_VI | AC_BK | AC_BE |
|---|---|---|---|---|
| Packet Size | 160 k bytes | 1280 k bytes | 200 k bytes | 200 k bytes |
| Mean Arrival Time | 20 ms | 10 ms | 12.5 ms | 12.5 ms |
| Sending | 64 k bits | 1024 k | 128k | 128k |

| | | | | |
|---|---|---|---|---|
| Rate | per second | bits per second | bits per second | bits per second |

In each experiment, we simulate fifteen scenarios for this WLAN; progressively, from scenario 1 to scenario 15, we add WS1 to WS15 to the system one at a time.

### 5.1 Results of Experiment 1

The results of the experiment 1 are presented Fig. 4, Fig. 5, and Fig. 6, respectively. Fig. 4 shows the throughput of AC_VO corresponding to the high-priority traffic. The throughput of the proposal scheme is able to keep the higher throughput while the number of station is increasing from 11 to 15.

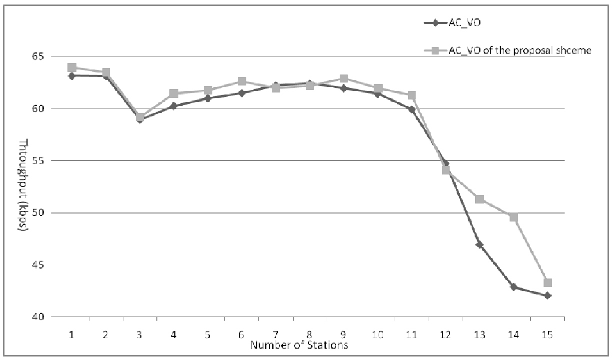

Fig. 4 Throughput Comparison of the AC_VO in the experiment 1

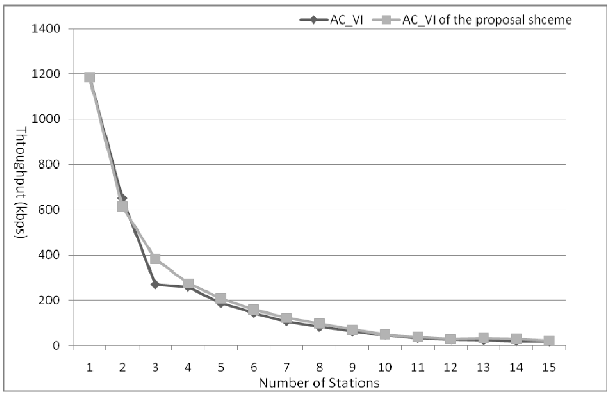

Fig. 5 Throughput Comparison of the AC_VI in the experiment 1

Fig. 5 shows the throughput of the AC_VI corresponding to the high-priority traffic. We observe that the proposal scheme does not affect the throughput of the AC_VI. Lines of the throughput of the basic 802.11e and the proposal scheme are closer.

Fig. 6 shows the throughput of the AC_BK corresponding to the low-priority traffic. The second phase leads that the throughput of the basic 802.11e is better than the proposal scheme.

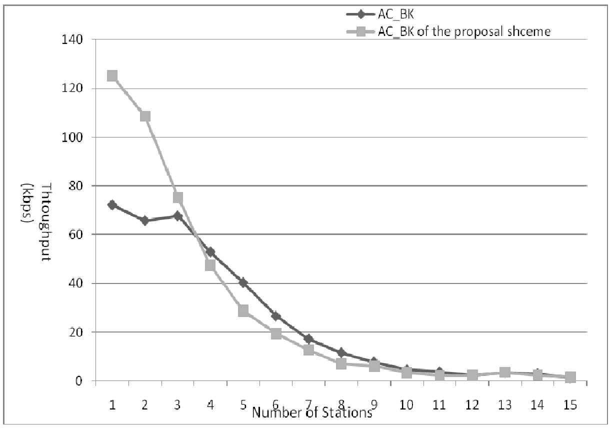

Fig. 6 Throughput Comparison of the AC_BK in the experiment 1

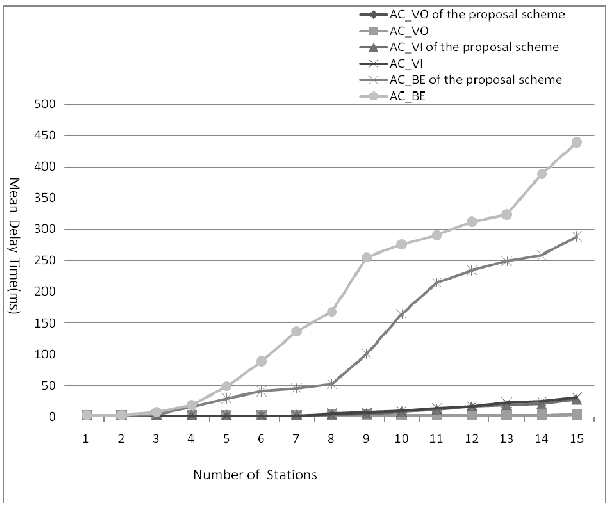

Fig. 7 Delay Time Comparison in the experiment 1

Fig. 7 shows the delay time in the experiment 1, the mean delay time of AC_VI and AC_VO is very close. However, the delay time of AC_BK is distinct. The proposal of AC_BK is better than the 802.11e after 5 stations.

### 5.2 Results of Experiment 2

The results of the experiment 2 are presented Fig. 8, Fig. 9 and Fig. 10, respectively. Fig. 8 shows the throughput of AC_VI corresponding to the high-priority traffic. The throughput of the proposal scheme is able to keep the higher throughput while the number of station is increasing from 11 to 15. Fig. 9 shows the throughput of the AC_VI corresponding to the high-priority traffic. We observe that the proposal scheme does not affect the throughput of the AC_VI. Lines of the throughput of the basic 802.11e and the proposal scheme are closer.

Fig. 10 shows the throughput of the AC_BE corresponding to the low-priority traffic. The second phase leads that the throughput of the basic 802.11e is better than the proposal scheme.

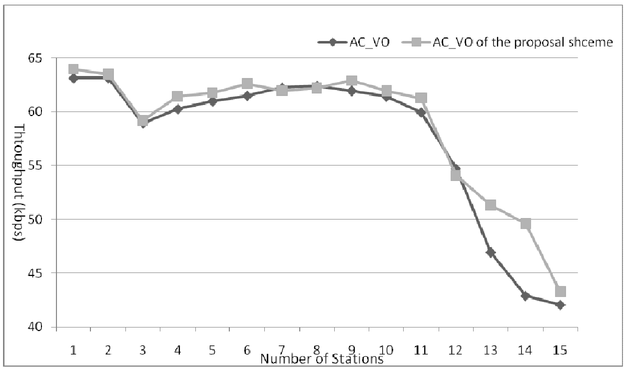

Fig. 8 Throughput Comparison of the AC_VO in the experiment 2

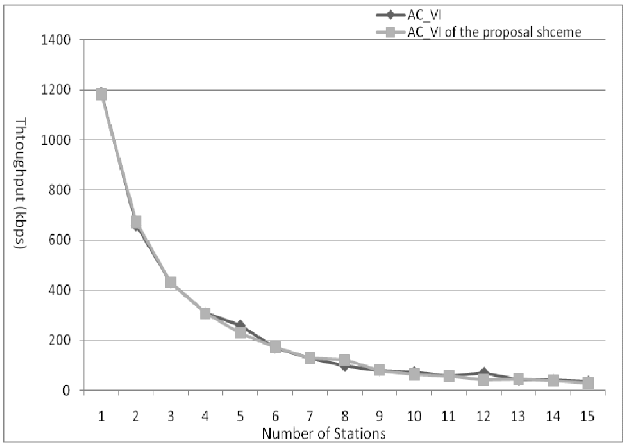

Fig. 9 Throughput Comparison of the AC_VI in the experiment 2

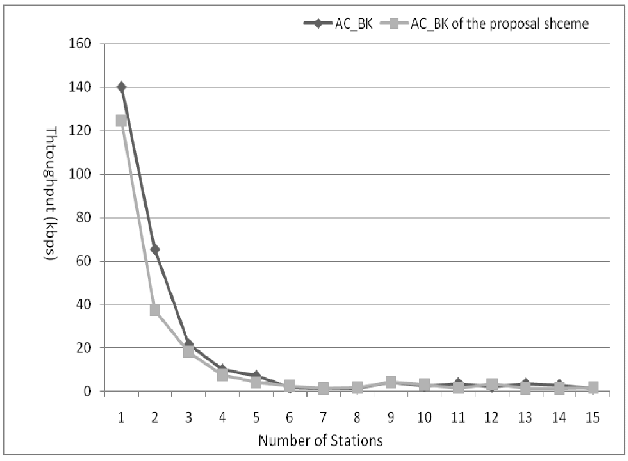

Fig. 10 Throughput Comparison of the AC_BK in the experiment 2

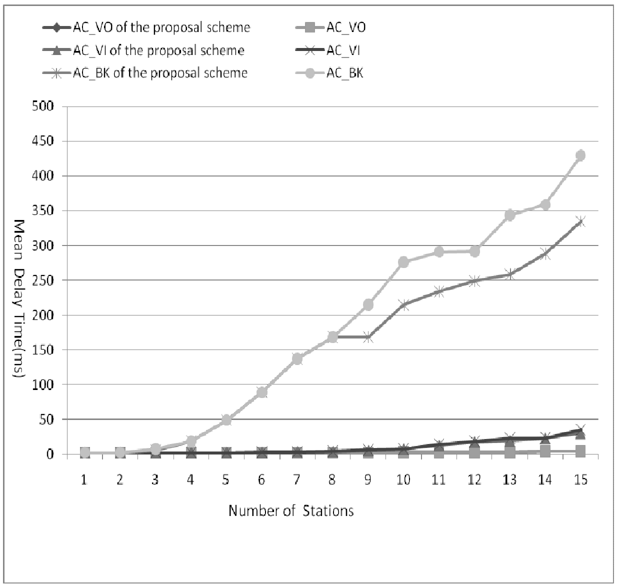

Fig. 11 Delay Time Comparison in the experiment 2

Fig. 11 shows the delay time in the experiment 2, the mean delay time of AC_VI and AC_VO is very close. However, the delay time of AC_BK is distinct between 802.11e and the proposal. The proposal of AC_BK is better than the 802.11e after 9 stations.

### 5.3 Results of Experiment 3

The results of the experiment 3 are presented Fig. 12, Fig. 13 and Fig. 14, respectively. Fig. 12 shows the throughput of AC_VO corresponding to the high-priority traffic. The throughput of the proposal scheme is able to keep the higher throughput. Fig. 13 and Fig. 14 show the throughput of the AC_BK and the AC_BE corresponding to the low-priority traffics. Because of the shorter AIFS, the throughput of AC_BK has the better performance than the AC_BE.

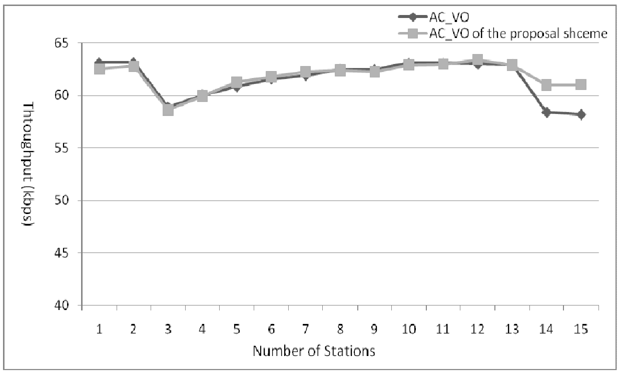

Fig. 12 Throughput Comparison of the AC_VO in the experiment 3

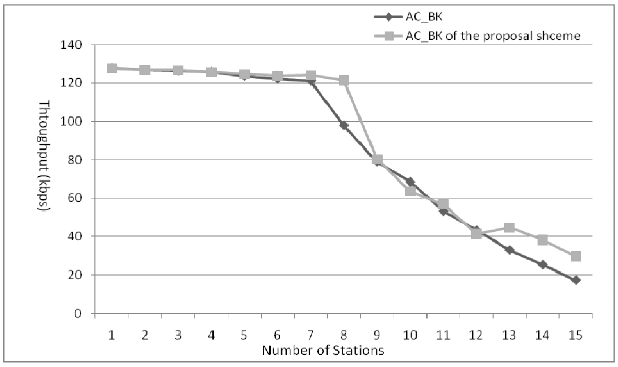

Fig. 13 Throughput Comparison of the AC_BK in the experiment 3

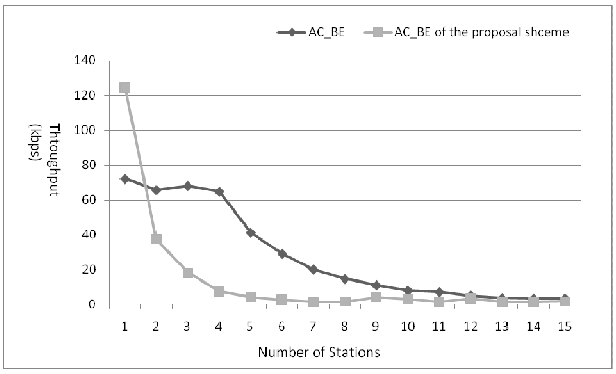

Fig. 14 Throughput Comparison of the AC_BE in the experiment 3

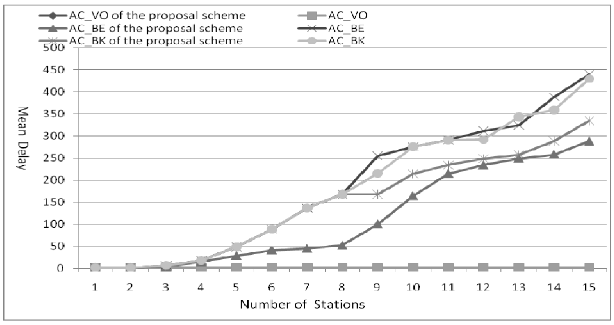

Fig. 15 Delay Time Comparison in the experiment 3

Fig. 15 shows the delay time in the experiment 3. The lower priority traffic of AC_BE cannot influence the mean delay time of the higher priority because of the superior AIFS.

## 5.4 Results of Experiment 4

The results of the experiment 4 are presented Fig. 16, Fig. 17 and Fig. 18, respectively. Fig. 16 shows the throughput of AC_VI corresponding to the high-priority traffic. While the number of stations is 5, the network loading is overloading. The throughput of the basic 802.11e is almost 0 after the network overloading. However, the proposal scheme is able to prevent collisions and provide more transmission opportunities for the whole network. Fig. 17 shows the throughput of the AC_BK corresponding to the low-priority traffic. We observe that the performance of the basic 802.11e is better than the proposal scheme while the number of stations is less than 4. However, the performance of the proposal is better than the basic 802.11e after 5 stations. Fig. 18 shows the throughput of the AC_BE corresponding to the low- priority traffic. The throughput of the AC_BE is worse while the network loading is becoming the heavy loading. The AC_BK and the AC_BE are the same low-priority traffic and implement the second phase. The AC_BK has the smaller AIFS and easily occupies more transmission

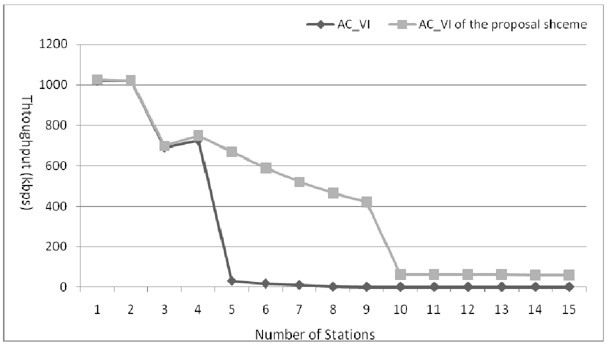

Fig. 16 Throughput Comparison of the AC_VI in the experiment 4

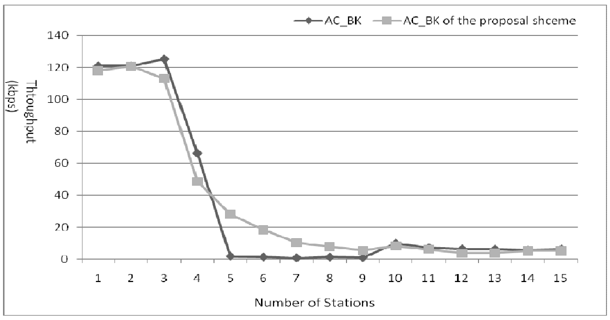

Fig. 17 Throughput Comparison of the AC_BK in the experiment 4

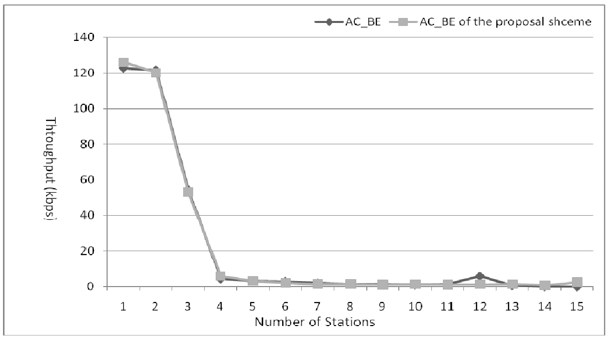

Fig. 18 Throughput Comparison of the AC_BE in the experiment 4

opportunities. In the same AC_BE, the proposal scheme has the better performance than the basic 802.11e.

Fig. 19 shows the delay time in the experiment 4. The lower priority traffic of AC_BE cannot influence the mean delay time of the higher priority because of the superior AIFS.

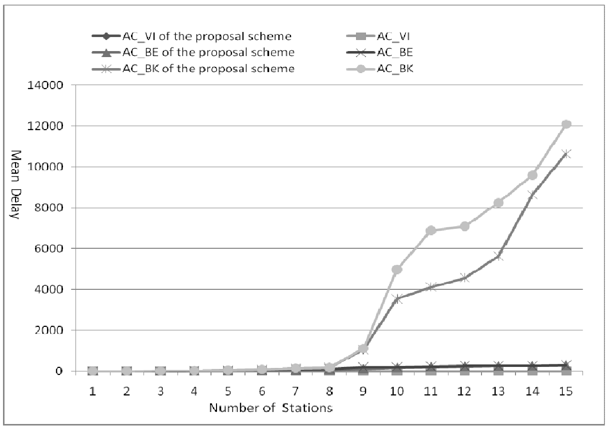

Fig. 19 Delay Time Comparison of the AC_BK in the experiment 4

## 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 contention window of each active class of service. Simulation results demonstrated that our scheme achieves better performance of throughput. We validate our results by compare the results obtained with the basic EDCF. Although our proposed intended to improve performance of wireless infrastructure networks, the same idea can be used in the ad-hoc mode with some changes. However the discriminating network load is not exactly, the adaptive CW scheme needs to distinguish the network load accurately. The numerical model and analysis is the further work to verify the adaptive CW scheme.

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