Performance Enhancement of IEEE 802.11e WLAN by Dynamic Adaptive Contention Window

Rathnakar Achary[*], V. Vaithiyanathan*, Pethur Raj**, Nagarajan S[***]

[*]School of Computing SASTRA University, India

[**]Infrastructure Architect IBM Global Cloud Center of Excellence IBM India, Bangalore

[***]Department of Computer Science and Engineering SASTRA University, India

a.rathnakar@gmail.com, vvn@it.sastra.edu. peterindia@gmail.com, nagarajan@cse.sastra.edu

Abstract: **The service differentiation and adaptation are the important mechanisms for enhancing the performance of IEEE 802.11wireless local area networks (WLANs). However, all these mechanisms will have limitations for dealing high bandwidth streaming applications. The service differentiation technique proposed in IEEE 802.11e [4] mainly considers the signal with higher priority values to access the wireless channel. Signals with lower priority values have to wait in the queue for a longer time to get an access to the channel. Also as the number of high priority frames in the access categories (ACs) increases, results internal collisions. This degrades the performance of 802.11 WLAN. In this research paper we developed an approach to improve the quality of service (QoS) of WLAN by maximizing the channel throughput and minimizing the internal collision, by adaptively changing the contention window (CW) size based on their priority values and the service requirements of the signals in the queue. The proposed algorithm enables the ACs to share the channel and maximize the channel performance and minimize the collision.**

Keywords **- Service differentiation, Contention window, EDCA, HCCA, ADDTS, TSPEC**

I. INTRODUCTION

Wireless networks are having different characteristics compared to its wired counterpart. To provide the required performance guarantee of a wireless channel the behavior of its media access control (MAC) layer is considered. Due to the time varying nature of the wireless channel the throughput, transmission delay and latency cannot be guaranteed. To address these issues IEEE Task Group E has proposed the standard 802.11e, it compare the capabilities provided by original MAC layer. These enhancements will differentiate the quality of service in QoS stations (QSTAs) and QoS access points (QAPs) form non-QSTAs and non-QAPs respectively.

The QoS mechanism introduced in IEEE 802.11 can be defined into two function blocks as; medium access functions and traffic specification (TSPEC) management functions. IEEE 802.11e a new media access control layer access mechanism HCF (Hybrid Coordination Function) to maintain the QoS requirements of IEEE 802.11 is proposed [11]. It provides both enhanced distributed channel access (EDCA), a contention based channel access mechanism and hybrid coordination function controlled channel access (HCCA), which is by controlled channel access mechanism. EDCA has been intended to provide prioritized service, analogous to Diffserv, whereas HCCA is developed to support parameterized service, like Intserv. The fundamental approach of this medium access mechanism is the transmission opportunity (TXOP); it is a time bounded interval in which a QSTA is permitted to send a series of packets. The EDCA-TXOP is the TXOP obtained using contention based channel access and HCCA (Polled) TXOP is that by HCCA, controlled channel access. The EDCA mechanism ensures that the STAs with higher priority value can access wireless channel at first than the stations with lower priority values. It allows the traffic by setting the values for different contention window parameters, which is used for back-off mechanism and the interframe space values. This provides the service differentiation for accessing the channel, but we cannot expect a complete QoS for streaming applications. In IEEE 802.11e, EDCA offers channel access [4] by contention based techniques. It allows only the high priority traffic to access the medium. Traffic with lower priority values will starve. Two or more high priority signal with the same priority value contending to access the channel at the same time results in collision. This degrade the performance of the WLAN. In this paper we focus on the QoS guarantee for real-time traffic under the EDCA channel access, by adaptively selecting the CW size based on the queue lengths in different access categories (ACs) [16]. This minimizing the internal collisions and maximize the throughout.

The CW size of real-time traffic, with high priority value is smaller than that of best-effort (BE) traffic. This helps real-time traffics to get better channel access. When large number of QSTAs with real-time traffics contending to access the channel, the traffic with lower priority values have to wait in the queue for a longer time. The performance impairment of the channel is due to the smaller size of the CW for real-time traffic. This small CW usually generate a short back-off time for them compared to the BE traffic. It results more internal collisions among the real-time traffics in the ACs. Adaptively changing the CW size is the only solution to minimize this problem [1].

To mitigate the performance deprivation problem, numerous solutions and algorithms are proposed. These solutions are mainly applicable to IEEE 802.11MAC layer. G. Bianchi [6] compared the performance and the likelihood of frame transmission in 802.11 DCF systems by Markov chain method. In this work the performance of the channel is enhanced by adapting an analytical model under ideal channel conditions [7]. In the other algorithms the throughput of IEEE 802.11 wireless local area network, is enhanced by dynamically adjusting the CW size. Bianchi et.al using Kelman filter the estimation of the active station is proposed in [5]. The CW size for the number of STAs is adaptively selected to access the channel. I. Aad, Q. Ni et.al proposed a simple CW size minimizing function in [2]. The CW size is minimized to half as a substitute for its original value instead of resetting it after accessing the channel and successfully transmitting the packets.

In this paper we propose an algorithm to dynamically change the CW size based on the priority values and service requirements of the traffic in the ACs. This streamlines the channel access process by minimizing the collision among the high priority signals and improves the QoS. The main objective of the proposed algorithm is that, each QSTA has to choose a suitable CW value. All the QSTAs equally share the resources to maximize the throughput. The analytical expressions developed give the relationship between the CW size and the throughput. Performance of the proposed algorithm is analyzed by comparative study. Result obtained from this indicates that, the developed algorithm enables the ACs to share the channels among the high priority STAs and improved the channel performance [7] significantly, and minimized the internal collision. Rest of this paper is organized as follows: Section 2 describes the overview of EDCA and CW. In section 3 we described the analysis of throughput variation by changing the CW size, and section 4 the performance analysis of the proposed system by simulation followed with conclusion in section 5.

II. EDCA AND CONTENTION WINDOW (CW)

IEEE 802.11e standard, EDCA is one of the ideal methods for accessing the channel [3]. It uses service differentiation. This distributed channel access process defines four access categories (ACs) to provide priority based services with the key parameters viz; CW size, arbitration interframe spacing (AIFS) value and transmission opportunity (TXOP) for a specific AC to provide the required QoS. Each access category AC[i], (i=0,1,2,3) has its own priority value are; 0-BE(AC_0), 1-BG(AC_1), 2-VI(AC_2) and 3-VO(AC_3).

The priority level of an AC is determined based on arbitration interframe spacing (AIFS) and CW values as in figure1. Smaller the AIFS and $CW_{\min}$ values, larger will be the TXOP for an AC. This represents that, it has a higher priority value than the other ACs. i.e an AC with higher priority value has smaller CW ($CW_{\min}$) size. Generally the CW value ranges from $CW_{\min}$ to $CW_{\max}$. EDCA runs a back-off mechanism for the frame transmission [3]. Using the back-off process for frame transmission, a STAs has to wait for a period of AIFS[AC] and then execute a back-off procedure by setting the back-off counter to a random number determined from CW value range (1, CW+1). The CW is initially set to $CW_{\min}$. The back-off counter value is reduced in every slotTime. When it reaches to minimum value, the STA can transmit the packet [1]. If two or more STAs attain the $CW_{\min}$ value at the same time slot a collision occurs, and the CW value increases exponentially. This increases the delay in transmission, and degrades the performance of the 802.11 WLAN [7][10].

III. THROUGHPUT ANALYSIS AND CW

To enhance the throughput of IEEE802.11 WLAN, IEEE 802.11e working group has proposed an admission control mechanism. Two entities considered here for the implementation of the admission control process are; the QSTA and QAP, which support the QoS. In admission control process a QSTA requests the preferred QoS to the QAP, which process it to decide, whether the requested service can be granted or not. In reply to this, the QAP sends a message to the QSTA including information of acceptance or rejection. Those STAs which are accepted, allowed to send the packet. Admission control is an efficient technique to provide QoS by managing the available resources in the wireless network. The $CW_{\min}$ value is one of the significant QoS factors that greatly affect throughput and transmission delay, for the packets of smaller CW size. In this segment we analyze the QoS parameters like bandwidth and transmission delay of IEEE 802.11e WLAN, by changing the CW value [10].

A. *Throughput Analysis*

Consider a WLAN with ‘n’ number of QSTA contending to access the wireless channel. The QAP calculate the $CW_{\min}$ parameter for each accepted QSTA and also for the newly requesting QSTA; which satisfy the transmission delay and throughput requirements. Assume that if $QSTA_i$ with a CW, CW_i has to access the wireless channel. The probability that the $QSTA_i$ transmitting the frame is;

$$\tau_i = \frac{2}{CW_i + 1} \quad ....(1)$$ Where $i = 1,2,......n$

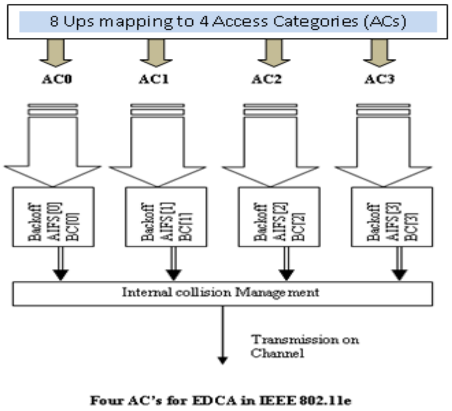

Figure1. Four ACs in EDCA

And the probability of the frames, which are transmitted successfully from a $QSTA_i$ is;

$$P_{s,i} = \tau_i \prod_{j \neq i} (1 - \tau_j) \quad ....(2)$$

If $\omega_i = \frac{\tau_i}{\tau_1} \quad \tau_i = \omega_i \, \tau_1 \quad ....(3)$

Then the probability of successful frame transmission P_s from eqn. (2) and (3) is;

$$P_s = \sum_i \omega_i \tau_1 \prod_{j \neq i} (1 - \omega_j \tau_1) \quad ....(4)$$

P_e - the availability of the empty time slot for a given channel,

$$P_e = \prod_i (1 - \tau_i) \ = \prod_i (1 - \omega_i \tau_1) \quad ......(5)$$

The collective performance is computed by (2)

$$r_{Total} = \frac{P_s . L}{P_s . T_s + P_e . T_e + P_c T_c} \quad ....(6)$$

Where,

L - the normal load duration

Ts and Tc – the average duration of a successful transmission and collision

Te – the time duration of the unoccupied time slot

Using equation (4) and (5) the probability for packet collision is obtained as $P_c = 1 - P_s - P_e \quad ....(7)$

Substituting eqn. (7) in (6) we can write eqn. (6) as

$$r_{Total} = \frac{L}{T_s - T_c + \frac{P_e (T_e - T_c) + T_c}{P_s}} \quad ......(8)$$

To find the number of accepted QSTAs, consider the relation between the throughput of QSTAs, $QSTA_i$, and $QSTA_j$ as;

$$\frac{r_i}{r_j} = \frac{\tau_i . \prod_{k \neq i} (1 - \tau_k)}{\tau_j \prod_{k \neq i} (1 - \tau_k)} = \frac{\tau_i (1 - \tau_j)}{\tau_j (1 - \tau_i .)} \quad ....(9)$$

$$\frac{r_i}{r_j} = \frac{\tau_i .}{\tau_j} \quad ....(10) \quad (where \ \ \tau_i \ \ is \, very \ small)$$

If the number of $QSTAs$ are very large this ratio in eqn. (10) is more accurate. When the number of QSTAs almost saturates the channel, the QAP starts rejecting the STAs.

From eqn. (10),

$$\frac{r_i}{r_j} = \frac{\omega_i}{\omega_j} \Rightarrow r_i = \frac{\omega_i}{\sum_i \omega_i} . r_{total} \quad ....(11)$$

Throughput of $QSTA_i$ is;

$$r_i = \frac{\omega_i}{\sum_i \omega_i} . \frac{L}{T_s - T_c + \frac{P_e (T_e - T_c) + T_c}{P_s}} \quad .....(12)$$

B. Throughput Analysis Based on CW

Let the throughput used by the $QSTA_i$ is r_i as in eqn. (12), the actual throughput requirements of the station is, Ri.

The throughput requirement of the entire CW set $\{CW_1, CW_2, ..., CW_n\}$ for 'n' QSTAs is

$\forall \, i \in \{1,2,3,..........., n\} \ r_i \geq R_i$.

The QAP compute the $CW_{\min}$ values ranging from $\{CW_1, CW_2, ..., CW_n\}$ for the accepted $QSTA_i$ and also for the contending $QSTAs$, it satisfy the performance requirement set $\{R_1, R_2, ..., R_n\}$ and delay bound. This range is considered as critical range. To improve the QoS of IEEE 802.11e WLAN, the admission control algorithm implemented in the QAP should accept as many $QSTAs$ as possible to optimize this critical range with $\frac{r_j}{R_j}$ ratio minimum.

$$i.e, \ \frac{r_i}{r_j} = \frac{R_i}{R_j} \quad ....(13)$$

Using eqn. (10) and (13)

$$\omega_i = \frac{R_i}{R_j} \quad ....(14) \cdot$$

In eqn. (12),

$$r_i = \frac{\omega_i}{\sum_i \omega_i} . \frac{L}{T_s - T_c + \frac{P_e (T_e - T_c) + T_c}{P_s}} \quad ......(15)$$

If L, Ts, and Te are constants, the resulting equation will be

$$\hat{r} = \frac{P_s}{P_e (T_e - T_c) + T_c} \quad ....(16)$$

Maximizing eqn. (16) will maximizes all r_i's

$$\hat{r} = \frac{\sum_i \omega_i \tau_1 \prod_{j \neq i} (1-\omega_j \tau_1)}{\prod_i (1-\omega_i \tau_1)(T_e - T_c) + T_c} \quad ....(17)$$

When ‘n’ is very large $\tau_1 << 1$

$$\hat{r} = \frac{a\tau_1 - b\tau_1^2}{c\tau_1 + T_e} \quad ....(18)$$

Where, $a = \sum_i \omega_i$, $b = \sum_i \sum_{j \neq i} \omega_i \omega_j$ and

$$c = \sum_i \omega_i \ (T_c - T_e) \quad ....(19)$$

Optimization of the τ_1, τ_1^* values, for maximizing $\hat{r}$ is by

$$\frac{d\hat{r}}{d\tau_1}\Big|_{\tau_1 = \tau_1^*} = 0; = bc.(\tau_1^*)^2 + 2bT_e.\tau_1^* - a.T_e = 0$$

$$\tau_1^* = \frac{\sqrt{(bT_e)^2 + abcT_e}_{\ 1} - bT_e}{bc} \quad ....(20)$$

The optimal CW set that maximizes all r_i's is $\forall_{\, i},\ CW_i^* = \frac{2}{\tau_i^*} - 1$, $CW_i^* = \frac{2}{\omega_i \tau_i^*} - 1$ ....(21)

From the above expression we can infer the relationship between CW_i and the throughput as; the contention window CW_i is inversely proportional to the throughput.

C. Dynamic Adaptive CW

The dynamic CW adaption mechanism is provided in two stages. In both stages we assume that, for a STA n_i with access categories AC2 and AC3 (where i=2 or 3) the number of flows with higher priority frames in the queue is greater than zero. The algorithm in the first stage is considered before the transmission of beacon signals. This algorithm evaluates the queue size in AC3 and decides to increase or reduce the CW size of AC3. When AC3 is changed the CW size, its size for the other ACs are also changed by increasing or decreasing their values to maintain the service differentiation [16]. The CW size is updated based on the two important parameters viz; the number of QSTAs intend to send the streaming applications (i.e, the total real-time traffic of stations n_3 and n_2) and the CW size of the AC3. In this stage the algorithm compares the total CW of the STAs n_3 and n_2 with the half of $CW_{\min}(3)$, accordingly it also updates as in the first stage of the algorithm. Once the CW size is decided it is communicated to the QSTAs through beacon frames. In stage one of the algorithm the CW size in AC2 are not updated. It is considered in stage two of the algorithm; and updated by increasing or decreasing the CW size. In the algorithm we considered the number of STAs which are contending for channel access with high bandwidth traffic and half of $CW_{\min}(2)$ value. For updating the contention window size of AC2, half of $CW_{\min}(2)$ value is mapped to the number of stations with real-time traffic (i.e, total traffic in STAs n_3 and n_2). Based on this compression the CW size is decided by the algorithm. Before starting the real-time traffic with a priority i (i= 2or 3), the QSTA forwards ADDTS request to the QAP. This ADDTS contains the priority value and TSPEC. The TSPEC represents the minimum and maximum QoS needed in terms of the priority values of the associated traffic in the ACs. The ADDTS request received by QAP is verified to decide, whether the available network resources could accommodate theses real-time traffic. The QAP first verifies for maximum QoS for the high priority traffic from queue in AC3, and evaluate the resource requirements. If sufficient resources are available, it is accepted; otherwise the proposed algorithm in the QAP updates the CW size by minimizing [1] or increasing its value. Then it checks for the queue in AC2 and considers it only if the needed resources are available to fulfill the minimum QoS requirements. If it is not available then the QAP will increase the CW size by doubling its value. When the CW size in AC3 and AC2 are modified dynamically, the $CW_{\min}(1)$ and $CW_{\min}(0)$, for the other ACs AC1 and AC0 are also updated accordingly. The algorithm in the QAP accepts the frames to access the channel or keeps in hold based on the priority value of the queue and the updated CW size.

IV. PERFORMANCE ANALYSIS

The performance related to throughout and collision in the IEEE 802.11e WLAN using the proposed algorithm is evaluated in this section. It is done by a comparative analysis with other algorithms which are widely used, such as; (i). IEEE 802.11 with DCF back-off mechanism, (ii).The relative fair throughput allotment mechanism, and (iii) Time fairness algorithm. The pseudo-code for both the algorithms are in figure (2) and figure (3), we simulated these algorithms using NS-2. The proposed algorithm is implemented in the QAP of the basic service set (BSS) in an infrastructure mode as in figure (4). MAC and PHY parameters are considered from 802.11 standards as default values. The packet size is maintained as 1.5Kbytes. The performances of four algorithms are compared on, IEEE 802.11g and IEEE802.11e standards. Each cases of analysis two different scenarios are considered. In the first case we considered the AC3 and AC2 carrying high priority frames, compete to access the channel and in the second case by considering the traffic queue in all ACs. The number of stations in both the cases are same with different priority scenarios. The results are analyzed in terms of throughput and internal collision ratio. The simulation is run for a period of 20secs.

```
Algorithm : Dynamic Threshold Based
            Admission Control
Input :  ADDTS,  TSPEC
Output : True/False
If $(CW\min[3]+1)/2 < (n_3 \text{ and } n_4)$
Else If $(CW\min[2]+1)/2 > (CW\min[3]+1)$ then
    $CW\min[3]=2*((w_{\min}+1)/4-1)$
    $CW\max[3]=2*((w_{\min}+1)/2-1)$
        Else
        $CW\min[3]=2*((w_{\min}+1)/4-1)$
        $CW\max[3]=2*((w_{\min}+1)/2-1)$
        $CW\min[2]=2*((w_{\min}+1)/2-1)$
        $CW\max[2]=2*w_{\max}$
        $CW\min[1]=2*w_{\min}$
        $CW\min[0]=2*w_{\min}$
    Else If
$(CW\min[3]+1)/2*2 < (n_3+n_2)$ then
AnyCW size are not changed
ElseIf
$n_2=0$
    $CW\min[3]=((w_{\min}+1)/4-1)/2$
        $CW\max[3]=((w_{\min}+1)/2-1)/2$
        $CW\min[2]=((w_{\min}+1)/2-1)/2$
        $CW\max[2]=w_{\max}/2$
        $CW\min[1]=w_{\min}/2$
        $CW\min[0]=w_{\min}/2$
    $CW\min[3]=((w_{\min}+1)/4-1)/2$
  $CW\max[3]=((w_{\min}+1)/2-1)/2$
    endIf
  endIf
```

Figure 2. Algorithm for updating $CW_{\min}[3]$ and $CW_{\min}[2]$

A. *Throughput*

In this section of simulation the throughput of all the traffic streams are considered for evaluation. Our objective is to enhance the WLAN throughput by increasing the number of flows. Figure 5(a) (b) and (c) shows the measured highest throughput by increasing the network load. The network throughput, using proposed algorithm significantly outperforms the other mechanisms. When compared to the other schemes the average throughput improvement is 13.48%. This high throughput is achieved by providing the fair channel access for all the high priority frames.

B. *Collision*

The collision is measured by comparing the collisions experienced and the packets dropped by 802.11 DCF mechanisms to the other algorithms. This can be evaluated as collision ratio. The number of total collision experienced by each station is obtained by summing all the collisions in each station. By using the proposed algorithm the number of collisions and packet drop decreases, as the number of STAs contending to access the channel increases. The collision results more packet drop and the retransmissions of the packets. This increases the end-to-end delay. As in Figure 6 (a), (b) and (c), using the proposed algorithm, the highest value of one way end-to-end delay of 20msec. It is very small compared to the maximum one way end-to-end delay of 150msec (ITU-2001).

```
Algorithm : Dynamic Threshold Based
            Admission Control
Input :  ADDTS,  TSPEC
Output : True/False
If $(CW\min[2]+1)/2 < (n_2+n_3)$ then
    $CW\min[2]=2*((w_{\min}+1)/2-1)$
      $CW\max[2]=2*w_{\max}$
        $CW\min[1]=2*w_{\min}$
        $CW\min[0]=2*w_{\min}$
Else If $(CW\min[2]+1)/2*2 < (n_3+n_2)$ then
Any CW size are not changed
Else If
$((CW\min[2]+1)/2 > (CW\min[3]+1)$ then
$CW\min[2]=((w_{\min}+1)/2-1)/2$
$CW\max[2]=w_{\max}/2$
$CW\min[1]=w_{\min}/2$
$CW\min[0]=w_{\min}/2$
Else
Any CW size are not changed
    endIf
endIf
```

Figure 3. Algorithm for updating $CW_{\min}[1]$ and $CW_{\min}[0]$

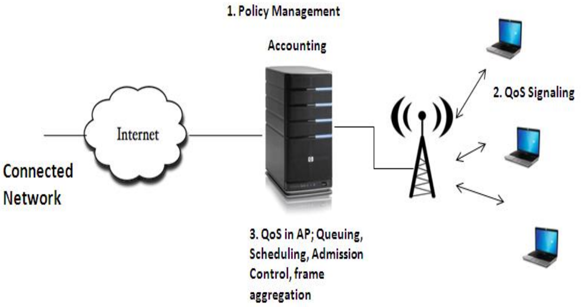

Figure 4. BSS architecture considered for testing

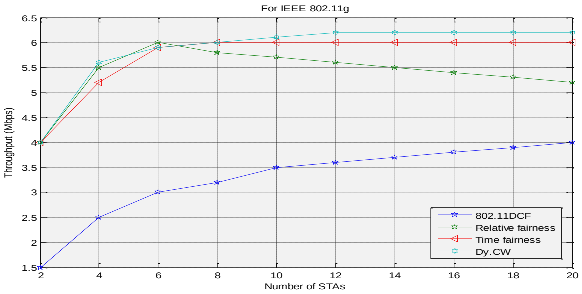

Figure 5 (a). For IEEE 802.11g

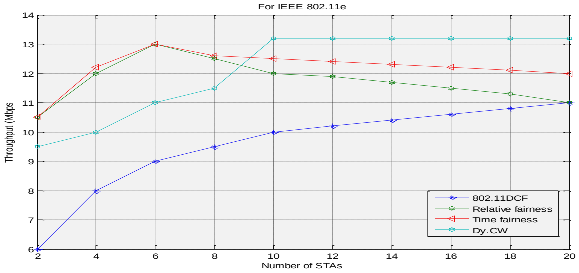

Figure 5 (b). For IEEE 802.11e

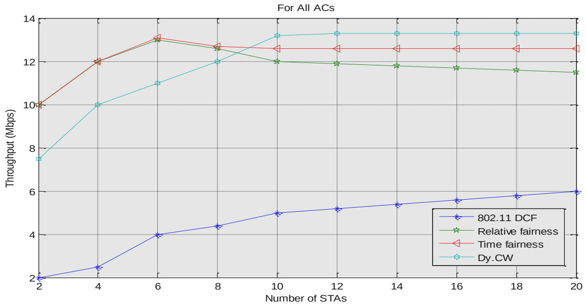

Figure 5 (c). For All ACs

The performance evaluation by simulation demonstrates that the proposed algorithm performs better than the other conventional algorithms by maximizing the throughput and minimizing the collision rate. As a result the wireless channel is equally shared by all the QSTAs contending to access the channel.

V. CONCLUSION

A novel MAC algorithm for IEEE 802.11e WLAN to enhance the throughput and minimize the collision rate is proposed in this paper. The proposed algorithm achieves this by considering the high priority frames in the ACs of each QSATs contending to access the wireless channel, by providing appropriate CW size. The performance of the algorithm is analyzed by comparing it with the other prominent algorithms. The evaluation result demonstrates that the proposed algorithm performs better than other algorithms referred for comparison. As a part of the future enhancement we planned to realize the performance of our algorithm in high performance WLAN standard like IEEE 802.11n multiple input multiple output (MIMO) to improve its QoS.

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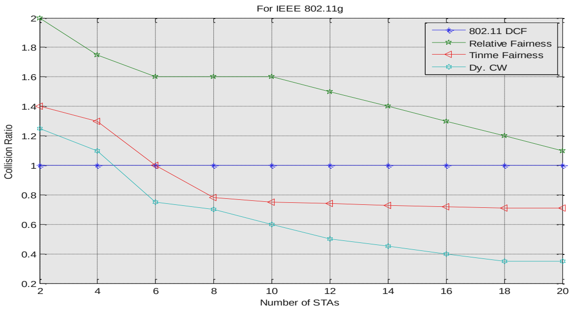

Figure 6 (a). For IEEE 802.11g

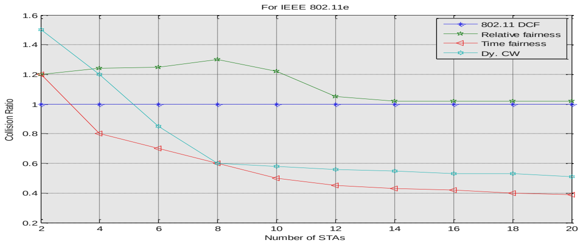

Figure 6 (b). For IEEE802.11e

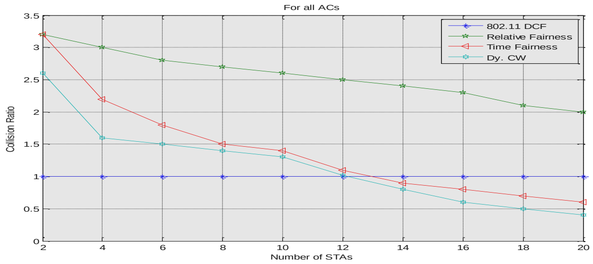

Figure 6 (c). For All ACs

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