Novel Mechanisms for Quality of Service Improvements in Wireless Ad Hoc Networks

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Abstract: - This paper proposes two mechanisms for improving the IEEE 802.11 DCF protocol performance and for enhancing QoS in IEEE 802.11 wireless LANs. These are Ratio based and Collision Rate Variation (CRV) schemes. The Ratio based scheme uses the collision rate value of the current and the past history of the network conditions to adaptively adjust the Contention Window (CW) size for each individual station. The CRV scheme also employs the collision rate and collision rate variation values to adjust the CW value locally for each individual station based on the current and previous network conditions. The aim of developing these approaches is to reduce the probability of collisions among the contending stations in a heavily loaded network in an attempt to improve QoS in IEEE 802.11 DCF protocol. The proposed schemes are evaluated and compared with the conventional IEEE 802.11 DCF and the Exponential Increase Exponential Decrease (EIED) schemes. The evaluation is carried out for different scenarios (i.e. different traffic load and different network size) using the ns-2 simulator. The metrics used in the evaluation are delay, jitter, throughput, packet loss, protocol efficiency, and collision rate. The results indicate that the best performance is achieved by using the proposed schemes with superiority for the CRV scheme in most cases.

Keywords: - Quality of Service (QoS), IEEE 802.11 MAC protocol, Network Simulator, Contention Window (CW), Distributed Coordination Function (DCF), and Wireless Networks.

1. Introduction

Wireless communications is a technology that is becoming an important feature of many aspects of our daily life. Not only are computer networks becoming mobile, many devices will have one or several wireless interfaces such as laptops, cameras, and phones [1]. In some cases these devices and even fixed stations wish to communicate with each other without requiring an infrastructure. In these cases, there is a need for ad-hoc wireless networks to provide an effective network communication between different wireless devices. This type of network has a number of applications such as conferences, emergency operations, and military operations [2] and [3].

Usually every device in ad-hoc wireless network is able to communicate with every other device when all devices are spread around a relatively small geographic range. The devices need to be within the transmission range of each other in order to be able to establish a direct communication and to compete with each other to access the wireless medium. If the devices are out of the transmission range of each other due to lack of transmission power, long distance between the wireless devices, interference, noise or due to mobility, it becomes essential to have an intermediary node between them [3]. This node results in a multi-hop ad-hoc network. In this type of network a routing protocol is required and the Medium Access Control (MAC) protocol has to share the media with fairness between different devices for different applications [4] and [3].

The function of the MAC protocol is to provide efficient and fair sharing of medium among all stations in the network. In wireless networks, MAC protocols can be categorized either as distributed or centralized protocols [5]. Distributed wireless networks, also called ad-hoc networks, are wireless stations communicating with one another without any need for central administration. Centralized wireless networks, are extensions to wired networks and have Access Points (*AP*) that act as the interface between wireless and wired networks. The *AP* polls the stations before assigning access rights in turn and a station is only permitted to send when it is allocated the right to do so. An example of a centralized protocol is the IEEE 802.11 Point Coordination Function (PCF) [6]. Distributed protocols are contention algorithms that permit stations in ad-hoc networks to be able to communicate according to the Carrier Sense Multiple Access with Collision Avoidance (*CSMA/CA*) mechanism. The IEEE 802.11 Distributed Coordination Function (DCF) is one example of a distributed protocol. Other examples include, *HIPERLAN* [35] and *MACAW* [36].

The main area of concern in this paper is to propose two mechanisms for improving the IEEE 802.11 DCF protocol performance and for enhancing QoS in IEEE 802.11 DCF scheme [7]. These are Ratio based and Collision Rate Variation (*CRV*) schemes.

In this paper, a number of related studies are described in the next section. Section 3 introduces a detailed description of the Ratio based and *CRV* schemes. The simulation model is presented in section 4. The results obtained are analyzed and discussed in section 5. Conclusions are given in last section 6.

2. Related Work

Several algorithms that dynamically change the value of *CW* to improve the performance of the IEEE 802.11 DCF protocol have been proposed and are described in [7-18]. For instance, in [17], the Linear/Multiplicative Increase and Linear Decrease (*LMILD*) backoff algorithm is presented. In *LMILD* scheme, colliding stations increase their Contention Window multiplicatively, while other stations overhearing the collisions increase their contention Window linearly. After successful transmission, all stations decrease their *CW* linearly. An adaptive DCF scheme was proposed in [18]. The proposed approach is based on adjusting the backoff procedure based on the knowledge of collision and the freezes time the backoff timer of the station experiences. The study showed that, the proposed scheme outperformed the IEEE 802.11 DCF scheme in term of throughput.

Several recent studies have improved the performance of IEEE 802.11 DCF by either modifying the *CW* or adjusting the value of Inter Frame Space (*IFS*). For instance the variation of the Arbitrary Inter Frame Space (*AIFS*) between stations leads to a lower probability of collisions and a faster progressing of backoff counter as reported in [19]. The author in [20] presented the *AIFS* as a technique for providing service differentiation between different classes in the IEEE 802.11e protocol. In [21], the length of *DIFS* was adopted as a differentiation mechanism. In their scheme, the *DIFS* length was calculated based on the ratio of estimated transmission rate to the total transmission rate. Their scheme imposed major modifications to the IEEE 802.11 DCF scheme in which the single queue was split into two queues. Their results showed that using variable length of *IFS*, service differentiation can be achieved. In [22], the adjusted *IFS* parameter with other parameters such as quantum rate and deficit counter was used to provide QoS mechanism. Their results showed that using an adjusted *IFS* length, QoS could be supported. In [23], the authors proposed a method for optimizing MAC parameters in the EDCF protocol, such as *CW* and *DIFS*. The proposed method improved throughput and delay as compared with the IEEE 802.11e. However, this method was based on storing several network configurations using database which imposed high computations.

Most of the discussed schemes require exchange of information between stations. Moreover, they require a sophisticated computation as the case in [24-26] and [23]. Other schemes impose major modifications to the structure of the IEEE 802.11 DCF as the case in [27-30]. Furthermore, most studies only consider one or two of the QoS parameters. Moreover, they only depend on the current conditions of the network without considering the past history. In this chapter, a Ratio based and *CRV* schemes are proposed to overcome these shortcomings aforementioned. They are as simple as the BEB to implement while significantly outperformed the IEEE 802.11 DCF and the *EIED* schemes.

The term Quality of Service (QoS) has been mentioned several times in this paper. This term is widely used but with a variety of meanings and perspectives. For instance, RFC 2386 defines QoS as a set of service requirements to be met while transmitting data packets from the source to the destination [37]. Another definition is that QoS refers to the ability to provide a level of assurance of data delivery and to provide a set of measurable service attributes in terms of delay, jitter, throughput, and packet loss over the network. QoS can also be defined as the ability of network components, such as a host and application to provide some consistent level of ensuring data delivery over the network with different levels for different classes of traffic [38]. In this paper, QoS refers to the ability of the network of providing the desired QoS requirements in terms of delay, jitter, throughput, and packet loss for the transmitted applications.

3. Approach Description

The basic IEEE 802.11 DCF protocol adjusts its *CW* value based on the current state of transmission, i.e. it doubles the *CW* value upon unsuccessful transmission and resets to the CW_{min} upon successful transmission [4]. The DCF scheme does not consider the past history of the network or the readily available information. For the *EIED* scheme, *EIED* (ri, rd) is used to denote the amount of increase and decrease in the *CW* size after successful and unsuccessful transmission. If collision occurred, the new *CW* is increased by the multiplication factor (ri) and after successful transmission, the new *CW* is decreased by the multiplication factor (rd). In this chapter, the value of 2 is chosen for each (ri) and (rd) as one of the possible cases of the *EIED* scheme [31]. The *EIED* scheme is used in the performance comparison, because it is not as aggressive as the basic IEEE 802.11 DCF when the *CW* is reset to CW_{min} after successful transmission.

In order to make the protocol behave correctly, the *CW* value should be dynamically adjusted to adapt to the dynamic changes in the number of contending stations and in the amount of traffic over time. This can be carried out by tuning the *CW* value after each successful and unsuccessful transmission. This adjustment is carried out locally for each station at runtime. A detailed explanation of how the *CW* value is adjusted is given in the following sections.

3.1 Radio Based Scheme (Case of Successful Transmission)

After each successful transmission, the DCF mechanism resets the *CW* of the station to its CW_{min} (i.e. $CW_{new} = CW_{min}$) ignoring the network conditions. This action by the successful station causes frequent collisions especially when the network is very large and heavily loaded because of small value of *CW*. This agrees with the fact that when a collision occurs, a new one is likely to take place in the near future since the collided packet requires retransmission which causes extra overhead. For this reason the Ratio based and the *CRV* schemes are proposed in order to mitigate bursty collisions. In the Ratio based scheme, the *CW* size is adaptively adjusted based on computing the current collision ratio for each station, since collision can provide a good indication about the level of contention in the network. The current collision ratio is computed using the number of collisions and the number of successfully acknowledged transmissions extracted from the history window (wi) as shown in Equation 1. The history window (wi) is a sliding array that contains number of sent packets including part of the history.

$$R^{wi}_{current}[N] = \frac{Num(collisions_{wi}[N])}{Num(collision_{wi}[N]) + Num(successful_{wi}[N])} \quad (1)$$

Where, $(Num(collisions_{wi}[N]))$ is the number of collisions for a station (N) that is extracted from the history window (wi), $(Num(successful_{wi}[N]))$ represents the number of packets that has been successfully acknowledged for a station (N) that is extracted from the same history window (wi), $(R^{wi}_{current}[N])$ is the current collision ratio of a station (N). The $(R^{wi}_{current}[N])$ value is computed based on the number of collided packets and the number of successfully received packets that are extracted from the history window (wi). The $(R^{wi}_{current}[N])$ value is always in the range of [0, 1].

In order to maintain a continuous knowledge about the past history of the transmission the sliding window (wi) is adopted. Furthermore, to reduce or to alleviate the random fluctuations in the computed $(R^{wi}_{current}[N])$ an Exponentially Weighted Moving Average (EWMA) is used to smooth the series of collision ratios (i.e. $R^{wi}_{current}[N]$ value) as given in Equation 2 [32].

$$R^{wi}_{average} = (1-\lambda) * R^{wi}_{current} + \lambda * R^{wi-1}_{average} \quad (2)$$

Where the $(R^{wi}_{current})$ denotes the current or instantaneous collision ratio for a station (N), (λ) stands for a weighting factor which determines the memory size used in the average process, $(R^{wi-1}_{average})$ represents the previous average collision ratio that is computed form the previous history window $(wi-1)$, while $(R^{wi}_{average})$ is the average collision ratio at the current history window (wi).

The instantaneous collision ratio $(R^{wi}_{current})$ and the average collision ratio $(R^{wi}_{current})$ are calculated based on the size of the total number of packets sent in (wi). The size of (wi) is selected not to be large in order to get a reasonable estimation about the network status. However, it should not be too small in order to get sufficient knowledge about the readily available information of each individual station. Moreover, using a sliding window ensures that the system always keeps a continuous tracking for the history of the total number of packets sent. However, the size of (wi) and the weighting factor (λ) are selected according to an extensive set of simulations carried out with several network topologies and different traffic loads. In order to achieve a tradeoff value between throughput and delay and in order to provide a good balance between removing short term fluctuations impact and capturing long term trends. Upon obtaining the value of ($R^{wi}_{average}$) described in Equation 2, the new CW size for a station (N) after successful transmission is computed based on Equation 3:

$$CW_{new}[N] = CW_{new-1}[N]\left(1 - \frac{R^{wi}_{average}}{f}\right) \quad (3)$$

Where ($CW_{new}[N]$) is the new computed contention window for a station (N), ($CW_{new-1}[N]$) stands for the previous computed CW for a station (N), and the notation (f) stands for a scaling factor (the impact of this factor is discussed later in this paper). Hence, the selected CW size by a station (N) is obtained using Equation.4. Equation 4 also guarantees that the ($CW_{new}[N]$) size does not go below the minimum contention window of a station (N) (i.e. $CW_{\min}[N]$).

$$CW[N] = Max(CW_{\min}[N], CW_{new}[N]) \quad (4)$$

3.2 Ratio Based Scheme (Case of Collision)

In the legacy IEEE 802.11 DCF [4], after each collision, the CW is doubled. If the maximum limit known as maximum Contention Window (CW_{max}) is reached, the collided station remains at CW_{max}. In the Ratio based scheme, after each collision, the new CW of the collided station is computed as depicted in Equation 5:

$$CW_{new}[N] = CW_{new-1}[N]\left(1 + f * R^{wi}_{average}\right) \quad (5)$$

Where ($CW_{new}[N]$), (f), ($CW_{new-1}[N]$) and ($R^{wi}_{average}$) are as discussed in the successful transmission case. The selected CW value by a station (N) is obtained using Equation 6. Note that ($CW_{\max}[N]$) is the maximum contention window for a station (N).Equation 6 also ensures that the ($CW_{new}[N]$) size does not exceed the maximum contention window (i.e. $CW_{\max}[N]$).

$$CW[N] = Min(CW_{\max}[N], CW_{new}) \quad (6)$$

3.3 Collision Rate Variation Scheme

The Collision Rate Variation (*CRV*) scheme is based on the variation in the collision ratio that was discussed in the Ratio based scheme. Therefore, this scheme is introduced in order to obtain further knowledge about the changes in the network conditions by monitoring the variations in the current and previous values of collision ratio. In the *CRV* scheme, the *CRV* value of each station is calculated based on Equation 7

$$CRV[N] = R_{current\_average}[N] - R_{previous\_average}[N] \quad (7)$$

Where, ($CRV[N]$) is the collision ratio variation for a station (N), ($R_{current\_average}[N]$) and ($R_{previous\_average}[N]$) stand for the current and the previous average collision ratio for a station (N), respectively.

According to Equation 7, the *CRV* values are varied between -1 to 1. The variation of *CRV* values is used to adjust the *CW* size and the *DIFS* for each station. This was discussed for each individual parameter in the following two sections.

Contention Window Adjustment Using Collision Rate Variation Scheme.

In this section the operation of *CRV* scheme to adjust the *CW* size for each individual station based on the variation in the *CRV* value is explained. Using the *CRV* scheme, the new *CW* size (i.e. $CW_{new}[N]$) is updated using Equation 8.

$$CW_{new}[N] = CW_{new-1}[N] + \left(f * CW_{new-1}[N] * CRV[N]\right) \quad (8)$$

Where, (f) refers to a scaling factor (discussed later for more details), ($CW_{new}[N]$) is the computed CW for a station (N), ($CW_{new-1}[N]$) stands for the previous CW size for a station (N), and ($CRV[N]$) is the computed collision ratio variation for a station (N).

If the computed value of CRV using Equation 7 is negative, this implies that the current number of collisions is less than previous number of collisions, therefore, the new CW size (i.e. $CW_{new}[N]$) is used by a station (N) after each successful transmission and called as $CW_{success}[N]$. To ensure that the new CW for a station (N) (i.e. $CW_{new}[N]$) does not go below the minimum contention window of a station (N) (i.e. $CW_{\min}[N]$), the CW size of the successful station (N) is limited by Equation 9.

$$CW[N] = Max(CW_{new}[N]\,,\, CW_{\min}[N]) \quad (9)$$

If the computed CRV value is positive, this implies that the current number of collisions for a station (N) is more than the previous number of collisions for the same station. As a result, the new CW size (i.e. $CW_{new}[N]$) is used by a station (N) after each collision and called as $CW_{collision}[N]$. To ensure that the CW for a station (N) (i.e. $CW_{new}[N]$) does not exceed the maximum contention window size of a station (N) (i.e. $CW_{\max}[N]$), the CW size for a collided station (N) is limited by using Equation 10.

$$CW[N] = Min(CW_{new}[N]\,,\, CW_{\max}[N]) \quad (10)$$

In the Ratio based and CRV schemes, the CW value does not reset to CW_{min} after successful transmission except in the following cases: (1) at the beginning of the transmission where the station starts with its initial CW_{min}. (2) When the station experiences a large CW size (i.e., $CW[N] > (f+1) * CW_{\min}[N]$), in order to avoid starvation. (3) When the number of retransmission attempts of the collided packets reaches the maximum limit (i.e. station experiences high value of CW).

In CRV scheme, the CW value is adjusted according to the variations in the collision ratio. A negative CRV value determines that the station experiences less collision, indicating a more successful transmission takes place while a positive value determines that the station experiences more collisions. Therefore, the use of the CRV scheme provides a good guide for selecting the CW value (i.e. $CW_{success}$ *or* $CW_{collision}$). The appendix contains:

- Ratio based scheme when collision occurs (figure 1).
- Ratio based scheme when successful transmission occurs (figure 2).
- Collision Rate Variation (CRV) scheme for adjusting CW size (figure 3).

4. Simulation Model

To evaluate the validity of the Ratio based and CRV schemes and compare their performance with the basic IEEE 802.11 DCF and *EIED* schemes in terms of QoS parameters, the NS-2 simulation package was used [33]. The network model used employs the topology shown in Figure 4 for different scenarios. The parameters used in these simulations were based on the IEEE 802.11 network configurations [34] and they are summarised in Table 1.

Table 1. IEEE 802.11 simulation settings [33] and [4].

Parameter	Value
DIFS	50 µsec
SIFS	10 µsec
CW_{min}	31slots
CW_{max}	1023 slots
Slot Time	20 µsec
UDP header	8 bytes
IP header	20 bytes
MAC header	28 bytes
PHY header	24 bytes
Data Rate	2.0 Mbps
Routing Protocol	AODV
IFQ Size	50

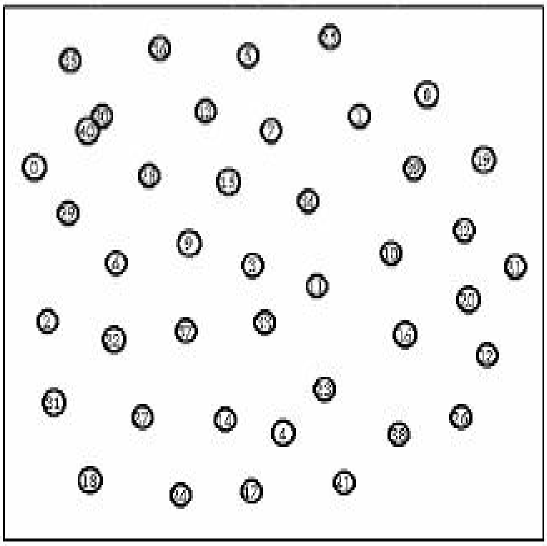


Fig. 4. Single hop topology.

In all simulations, a Constant Bt Rate (*CBR*) traffic sources were employed. The packet sizes used for *CBR* traffic were 512, 160 and 200 bytes. The packet generation rates were 384 Kbps, 64 Kbps and 128 Kbps.

The simulations were performed for several scenarios in order to critically evaluate the performance of the proposed schemes by means of comparison with the IEEE 802.11 DCF and the Exponential Increase Exponential Decrease (*EIED*) schemes. These scenarios include varying the network size (small, medium, and large network sizes), traffic load (light, medium, and heavy load), and the variation of the number of active station over time.

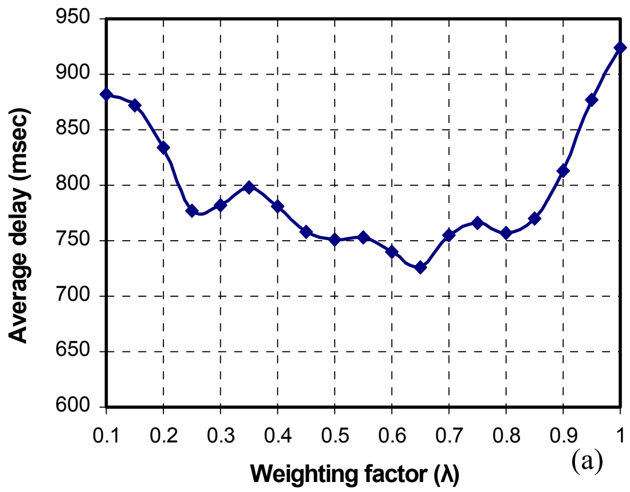
5. Results and Discussions

This section provides the simulation results for the proposed methods and compares them with both, the Exponential Increase Exponential Decrease (*EIED*) with *ri* and *rd* factors equal 2 and the original IEEE 802.11 DCF schemes.

5.1 Parameter Tuning

In this section, the influence of history window size (wi), scaling factor (f) and weighting factor (λ) is investigated. The results showed that the right set of these parameters can lead to better performance. In order to ensure that these parameters were appropriately selected, several simulations were carried out with different topologies and different traffic loads. In this discussion, a network with 10 stations transmitted *CBR* traffic to 10 destinations in heavy and medium load cases. Average throughput and average delay were considered as the main metrics.

The weighting factor (λ) was varied in the range of 0 to 1. Figures 5a and 5b depict the average delay and average throughput as a function of weighting factor (λ), respectively. Every single point of the results obtained represented an average of 10 simulations in order to avoid the bias of random number generation. It can be observed from Figure 5a that the lowest average delay corresponded to λ = 0.65. Figure 5b shows that the highest average throughput corresponded to λ = 0.7. Consequently, the value of λ equal 0.6 was selected since it achieved a tradeoff between average throughput and average delay.



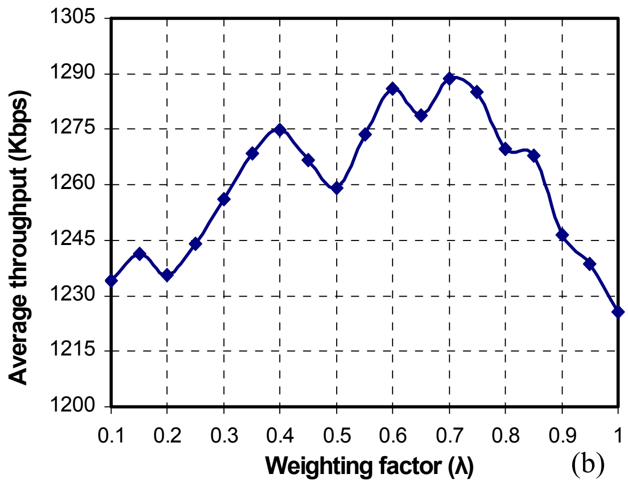
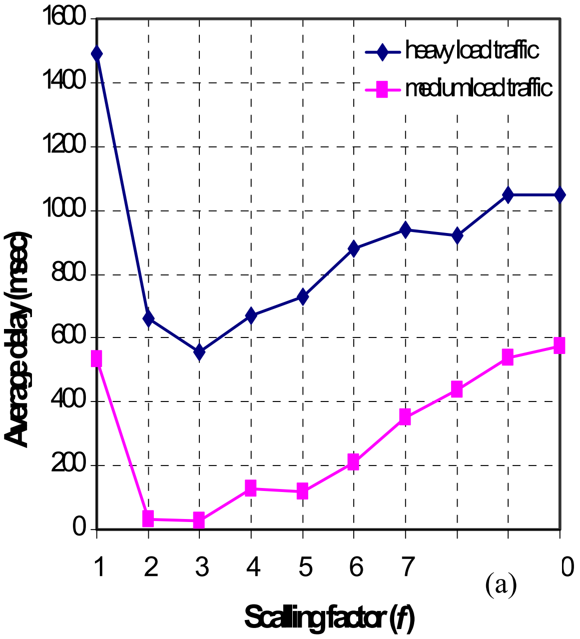


Fig. 5. Average delay and average throughput as a function of weighting factor (λ), (a) average delay and (b) Average throughput.



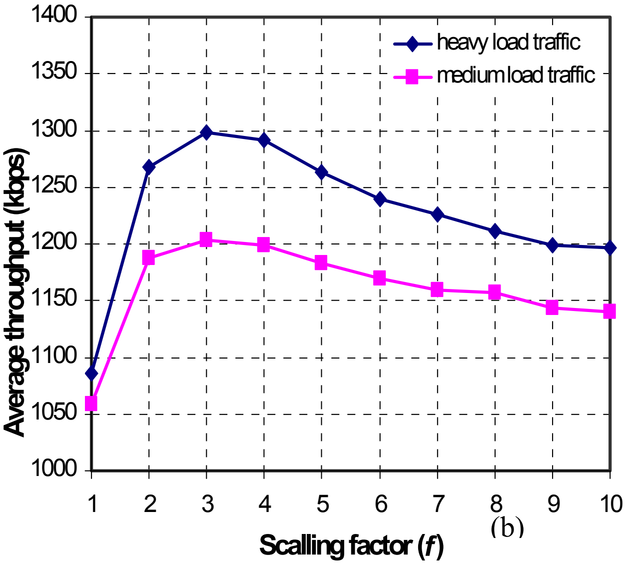
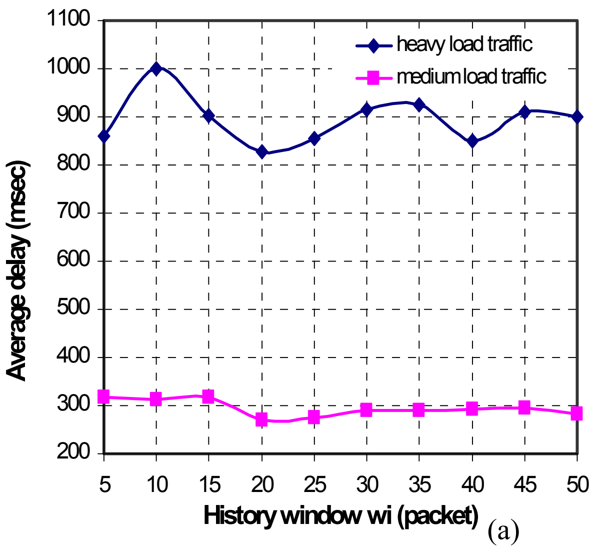


Fig. 6. Average delay and average throughput as a function of scaling factor (f), (a) average delay and (b) Average throughput.

Figures 6a and 6b show the average delay and average throughput as a function of scaling factor (f) in heavy and medium load cases. The scaling factor (f) was varied in the range of 1 to 10 with an increment of 1. A significantly low value of (f), e.g. f =1, resulted in high values of delay and low values of average throughput in heavy and medium load cases. Similarly, a significantly high value of (f), e.g. f = 10, resulted also in high values of average delay and low value of average throughput. According to Figures 6a and 6b, an appropriate value of (f), i.e. around 3, provided a tradeoff between the average delay and average throughput. The value of (f), i.e. around 3, provided the lowest average delay and the highest average throughput in heavy and medium load cases as depicted in Figures 6a and 6b. It can be observed that the variation in the value of the scaling factor (f) could result in a significant variation in the network performance. Therefore, this feature will be used with other parameters such as packet loss rate for providing service differentiation in single and multi-hop networks. In this study, the value of f = 3 was considered for the following simulations.

Figures 7a and 7b demonstrate the effect of the history window (wi) on the average delay and average throughput in heavy and medium load cases. The size of history window (wi) was varied in the range of 5 to 50 with an increment of 5 packets. The simulation results of average delay are shown in Figures 7a for heavy and medium load cases. The value of (wi) around 20 provided the lowest values of average delay in heavy and medium load cases. According to Figure 7b, the highest average throughput was achieved when the (wi) size was around 25 in heavy load case, while the highest average throughput was achieved when the (wi) size was around 20 in medium load case. Therefore, the history window (wi) around 20 was selected for the following simulations since it provided a balance between the heavy and medium loaded cases. Furthermore, it provided a tradeoff between the average delay and average throughput.

Note that, the history window (wi) values around 20 could maintain small values of average delay compared to smaller values of (wi). Therefore, a history window size equal 20 was used in this chapter as indicated in the previous paragraph. Because too small values of (wi) probably was insufficient to provide adequate information about the current and the previous network conditions. Moreover, too large values of (wi) could cause late update in the adaptation process (i.e. adjusting *CW* and *DIFS*) in which performance degradation might occur. Subsequently, choosing an appropriate size of (wi) result in minimum average delay and maximum average throughput.



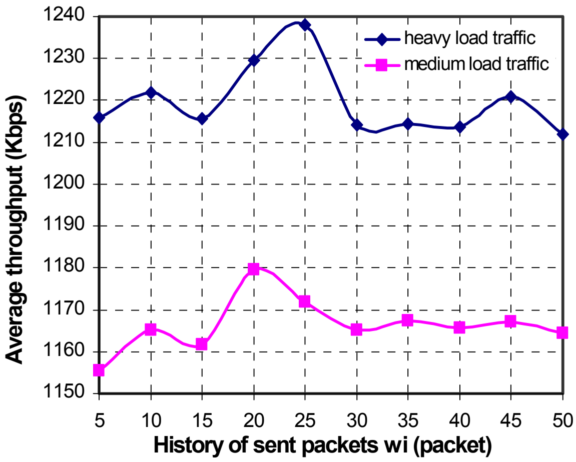


Fig. 7. Average delay and average throughput as a function of history window (wi), (a) average delay and (b) average throughput .

5.2 Performance Evaluation of CW Adjustments With Heavy Load Traffic

The Ratio based and *CRV* schemes were validated for heavy load traffic. Different network topologies sizes (5, 10 and 20 connections, i.e. small, medium and large networks) were considered for this purpose. Additionally, some other scenarios were introduced in order to critically investigate the behavior of the Ratio based and *CRV* schemes. This included the case where the sources transmitted different traffic types.

The offered load delivered into the network for the heavy load traffic was approximately 80% of the channel capacity. This implied that 1.6 Mbps were transmitted by all the active senders in the network. Therefore, the transmission rate of each source was equal ($1.6 Mbps / n$), where n represents the number of connections.

Small Network Size (5 Connections). This simulation consisted of 40 stations as shown in Figure 4; only 5 connections transmitted at heavy load to 5 destinations. Around 80% of the channel capacity (more than 1600 Kbps) was offered to the network. The transmission rate of each source was 320 Kbps *CBR* traffic.

Figure 8a shows the average delay for the four schemes. The Ratio based and the *CRV* schemes were able to maintain low average delay at heavily loaded traffic. It can be seen that the average delay was 57% and 50% smaller than that for the legacy IEEE 802.11 DCF and the *EIED* scheme respectively when the Ratio based scheme was employed. Similarly, the *CRV* scheme also outperformed the IEEE 802.11 DCF and *EIED* schemes by 55% and 48% respectively. Indeed, the two proposed schemes provide a lower delay (less than 400 msec). The *CRV* scheme showed more variations especially at the beginning and at the end of simulation. This was due to the lack of network history since the number of active stations in the network was very small and each station transmitted large number of packets which required several adjustments of $CW_{success}$ and $CW_{collision}$. Once the system selected proper values of $CW_{success}$ and $CW_{collision}$ these fluctuations became less. Furthermore, the fluctuations became less when the number of active stations increased as discussed later.

As indicated in Table 2, the Ratio based and *CRV* schemes achieved small values of average jitter less than 10 msec. The improvements reached 22% and 15% when the Ratio based scheme was used and reached 41% and 36% when the *CRV* scheme was employed over the IEEE 802.11 DCF and *EIED* schemes respectively. Moreover, the *CRV* had a mean jitter 24% less than the Ratio based scheme. High value of jitter in the IEEE 802.11 DCF was caused by the sharp variations in the *CW* size, which resulted in a large variation in the Backoff Interval (BI), and consequently led to large values of delay and jitter.

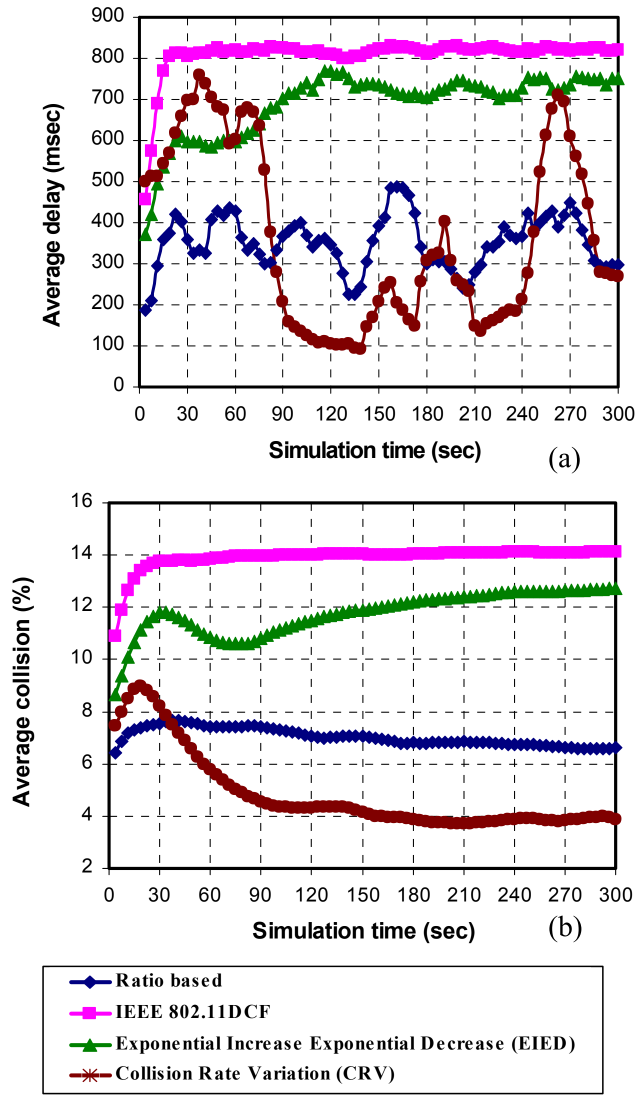


Fig. 8.The network parameters for 5 connections at heavy CBR traffic, (a) average delay (msec) and (b) average collision rate (%).

As discussed earlier, the MAC efficiency and the collision rate were related to each other. This implied that the reduction in the number of collisions led to an improvement in the performance of the protocol (i.e. improve the MAC efficiency by increasing the number of successful packets transmission with respect to the total number of packets sent). In term of collision rate, the *CRV* scheme had the superiority over other schemes. The collision rate obtained was considerably lower than the values for IEEE 802.11 DCF and *EIED* schemes as shown in Figure 8b.

The *CRV* scheme had the best performance. It had less delay and less collision than the IEEE 802.11 DCF, *EIED* and the Ratio based schemes, respectively. The quantitative statistics for a small network scenario in heavy load network are summarized in Table 2.

Table 2. Statistical results obtained for four different schemes in a small size network (5 connections) at heavy load CBR traffic.

Parameter	**Ratio Based Scheme**	**IEEE 802.11 DCF Scheme**	**EIED scheme**	**CRV scheme**
Average delay (msec)	345	810	699	365
Average jitter (msec)	9.9	12.8	11.8	7.6
Average throughput(Kbps)	1297	1227	1252	1227
Average packet loss (%)	7.8	21.1	16.4	9.0
Average MAC Efficiency (%)	92.9	85.7	86.8	95
Average collision (%)	7.0	13.9	11.9	4.9

Medium Network Size (10 Connections). In this scenario, the topology shown in Figure 4 was used. The offered load was 80% of the channel capacity which was equally distributed among the 10 connections. Each source transmitted 160 Kbps to its corresponding destination.

The values of average delay and jitter for all schemes were increased when the number of active stations was increased from 5 connections to 10 connections with the same a mount of traffic. For instance, the values of average delay were increased by 44%, 55%, 54% and 47% in the Ratio based, IEEE 802.11 DCF, *EIED*, and *CRV* schemes respectively. This implied that the contention between stations became significant factor. In Figure 9a, the Ratio based and the *CRV* schemes showed a smaller mean delay. For instance, a reduction of 65% and 59% was observed in the average delay when the Ratio based scheme was employed compared to the IEEE 802.11 DCF and *EIED* schemes respectively. Similarly, the *CRV* scheme achieved a small average delay which was 9% higher than that obtained for the Ratio based scheme. Note that in case of 5 connections, the Ratio based and the *CRV* schemes experienced high fluctuations. In case of 10 connections, these fluctuations became less, because of the proper selection of the *CW* size when the network became busier.

According to figure 9b high values of collision rate were observed especially at the first 30 seconds of the simulation. This was due to the impact of routing information exchange during the initial period of the simulation which, once established, this effect became less along with the simulation time. The Ratio based scheme achieved better performance compared with other schemes. The quantitative results of the assessed QoS and other QoS parameters for medium size network are summarised in Table 3.

Table 3. Statistical results obtained for four different schemes in a medium size network (10 connections) at heavy load CBR traffic

Parameter	Ratio Based Scheme	IEEE 802.11 DCF Scheme	EIED scheme	CRV scheme
Average delay (msec)	621.6	1788.0	1520	681.9
Average jitter (msec)	21.3	40.1	36.3	16.5
Average throughput (Kbps)	1240	1025.5	1089	1160
Average packet loss (%)	7.9	27.1	19.5	9.6
Average MAC efficiency (%)	91.4	81.1	83.7	92.7
Average collision (%)	8.6	17.0	14.9	6.3

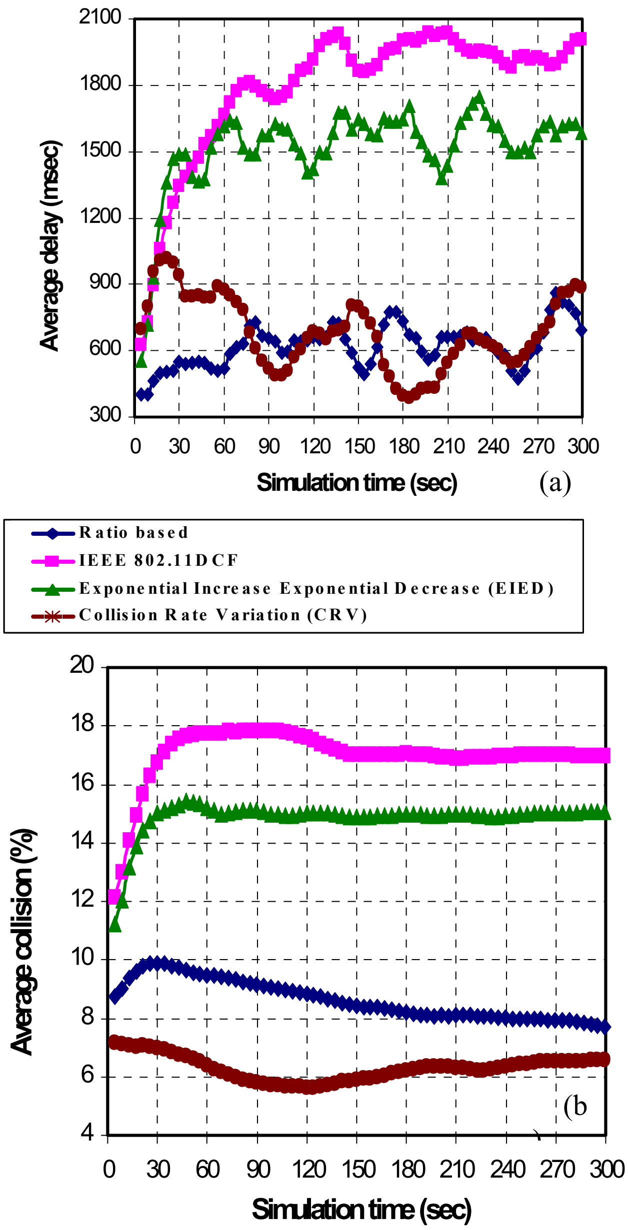
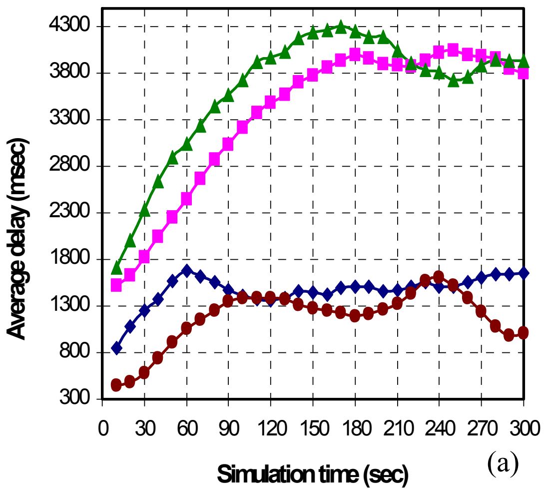


Fig. 9.The network parameters for 10 connections at heavy CBR traffic, (a) average delay (msec) and (b) average collision rate (%).

Large Network Size (10 Connections). The performance of the four schemes was negatively affected when the network size was increased from a small network size (i.e., 5 connections) to a medium network size (i.e., 10 connections). However, this impact could be significant as the network size became larger. In this section, the performance of the four schemes is evaluated when the number of active stations was increased to 20 connections. The volume of *CBR* traffic represented 80% of channel capacity where each source transmitted 80 Kbps.

Figures 10a and 10b show that the performance of the four schemes was degraded in 20 connections network. However, the Ratio based and *CRV* schemes still performed better than the other two schemes. The mean delay was 57% less than the obtained delay when the IEEE 802.11 DCF and *EIED* schemes were used. The mean jitter value for the Ratio based scheme were 47% less than the values obtained when the IEEE 802.11 DCF and *EIED* schemes were employed. Similarly, the average throughput improved by 19% and 15% compared to the IEEE 802.11 DCF and *EIED* schemes respectively. This was due to the reduction in the number of packets drop, where only less than 11% was lost when the Ratio based and *CRV* schemes were used. On the other hand, more than 24% of packets were lost when the IEEE 802.11 DCF and *EIED* schemes were used.



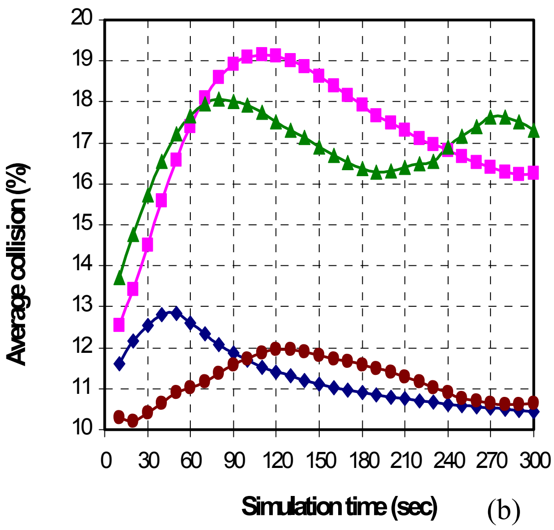


Fig. 10. The network parameters for 10 connections at heavy CBR traffic, (a) average delay (msec) and (b) average collision rate (%).

As indicated in Table 4, the IEEE 802.11 DCF had a mean MAC efficiency of 78% which was 11% less than the one obtained for the Ratio based scheme. The other schemes also displayed improvements in their MAC efficiency values. This implied that each scheme was able to adjust its backoff timer, particularly the *CW* size, until the behaviour of each scheme became stable. However, the Ratio based and the *CRV* schemes achieved MAC efficiency 10% higher than the other two schemes. Because the Ratio based and *CRV* schemes considered part of the network history to tune their backoff timer by getting a suitable *CW* size after successful and unsuccessful transmission; whereas the other two schemes only considered the current network state.

The collision rate obtained is shown in Figure 10b. The collision rates achieved by the four schemes were similar when the traffic load was light. However, at heavy load traffic, the Ratio based and the *CRV* schemes were able to maintain a lower collision rate than the IEEE 802.11 DCF and *EIED* schemes. This behaviour can be explained by the fact that the Ratio based and *CRV* schemes used an adaptive mechanism to adjust the *CW* size based on the collision rate history the stations experienced. As a result, a considerable reduction in the collision rate values was obtained which improved the network performance. The statistical results for this scenario are summarised in Table 4.

Table 4. Statistical results obtained for four different schemes in a large size network (30 connections) at heavy load CBR traffic.

Parameter	Ratio based scheme	IEEE 802.11 DCF scheme	EIED scheme	CRV scheme
Average Delay (msec)	1465	3348	3635	1180
Average jitter (msec)	48.2	95.2	92.7	33.9
Average Throughput (Kbps)	1147	928	972.0	974.4
Average loss (%)	11.0	24.7	23.9	8.0
Average MAC efficiency (%)	88.7	78.7	80.4	88.1
Average collision rate (%)	11.3	17.2	16.9	11.2

It is worth noting that, the trend of the curves for all schemes was smoother when the network size was increased. This was due to the reduction in the number of packets sent by each station which required smaller adjustments of the *CW* size for each station.

The network performance was affected when the number of transmitting stations was increased. This implied that the network size and the offered load played a major role in the performance of ad-hoc networks. Figures 11 depicts the collision rate as a function of the network size for the four schemes.

In Figure 11, the performance of a small network (i.e. 5 connections) was better than the medium and large ones. As expected, delay, jitter and packet loss of all schemes increased with the increase in the network size because of large *CW* values (high competition between contending stations). Furthermore, the network with 20 connections caused large number of collisions due to the high competition which also led to less MAC efficiency. However, the proposed schemes achieved better performance than the two other schemes, whatever the number of connections is. For instance, at heavy load case for 5, 10 and 20 connections, the IEEE 802.11 DCF and *EIED* achieved poor performance, while the Ratio based and the *CRV* schemes, they maintained higher performance for all network sizes.

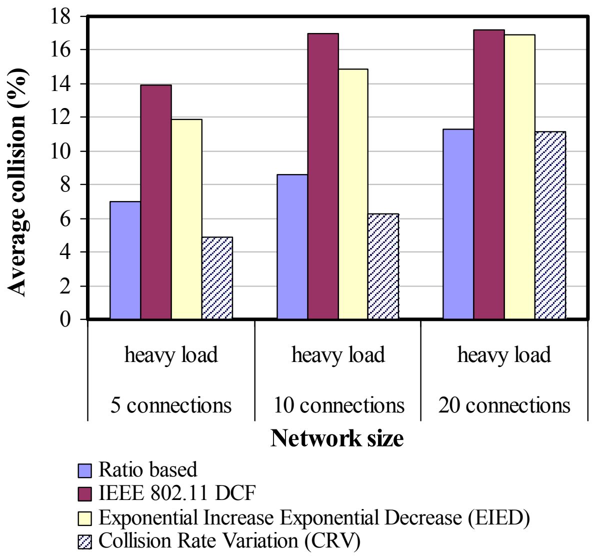


Fig. 11. Collision rate as a function of network size at heavy load *CBR* traffic.

Ratio Based and Collision Rate Variation in a Realistic Scenario

The performance of the Ratio based and *CRV* schemes was evaluated against an increasing number of active stations over time. This was carried out in order to examine the performance of these schemes when the network was experienced highly changing configurations. Here, the network topology shown in Figure 4 was used with twenty stations transmitting *CBR* traffic, using a 512 bytes packet size, to twenty different destinations using the basic access mechanism. The simulation time was 400 seconds. Every 5 seconds a new *CBR* source with 80Kbps generation rate started its transmission. At the 100th second of the simulation, 20 sources were active in the network (i.e. contending to access the channel) and sending video packets to 20 destinations. These 20 *CBR* sources remained active to the 300th second in order to sustain heavy load throughout the 200 seconds (i.e. from 100 to 300 seconds). At the 300th second, the number of active stations was reduced by one every 5 seconds until all sources stopped their transmission at the 400th second.

According to Figure 12, the value of average delay increased with the simulation time (due to the increase of the number of active stations). However, the Ratio based and *CRV* schemes maintained 50% of average delay when the IEEE 802.11 DCF and *EIED* schemes were employed. The maximum values of average delay were observed between the 200th and 300th second because of high competition between the contending stations. In the IEEE 802.11 DCF and *EIED* schemes each station selected a large *CW* size in order to avoid collisions at the cost of wasting several idle time slots which in turn led to high values of delay. The sharp transition from a large *CW* size to *CWmin* in case of IEEE 802.11 DCF and to half of the current *CW* size of the *EIED* scheme after successful transmission increased the amount of jitter. Thereafter, the average delay started to decrease since the number of sources decreased by one every 5 seconds.

The Ratio based and *CRV* schemes maintained approximately similar values of delay as the other two schemes up to 100th second, since the network was still lightly loaded and the number of contending stations was less than 20 connections. After the 100th second, the network became busier and the load heavier, therefore, the Ratio based and *CRV* schemes performed better and maintained lower values of average delay and average jitter. This was due to the capability of the Ratio based and *CRV* of adaptively selecting the *CW* size after successful and unsuccessful transmission in a way that achieved a tradeoff between collisions decrease and idle time slots increase.

Similarly, the average throughput was 16% and 11% higher than the IEEE 802.11 DCF and *EIED* schemes, respectively when the Ratio based scheme was used and 11.6% and 6% higher when the *CRV* scheme was employed. The reduction in the average throughput and the increase in the number of packet loss when the IEEE 802.11 DCF and *EIED* schemes were used were due to the following; in the IEEE 802.11 DCF scheme, as the station resets its *CW* to *CWmin* after successful transmission or decreases it to the half of its current value in *EIED* scheme, the station forgets about the collision history. In this case when all stations kept transmitting with the same data rate; it is likely that the new transmission noticed contention and collisions as before. This in turn increased the collision rate especially during a high contention period as shown in Figures 12b. This was mitigated by keeping some history of the observed successful and collisions packets. In this case instead of resetting the *CW* to *CWmin* after successful transmission or doubling it after collisions, the *CW* size was changed adaptively based on the history of collision rate.

The behaviour of the Ratio based and *CRV* schemes was apparent on both the achieved MAC efficiency and the collision rate parameters. For instance, the Ratio based scheme had a 90% average MAC efficiency and 8.3% average collision rate; whereas 81% average MAC efficiency and 14% average collision rate were observed for the IEEE 802.11 DCF scheme. The *CRV* scheme also achieved higher performance than the IEEE 802.11 DCF and *EIED* schemes.

It can be concluded that the Ratio based and *CRV* schemes were capable to adaptively adjust the *CW* values after successful and unsuccessful transmission based on the history of each individual station. Moreover, both schemes were able to achieve an efficient tradeoff between collision decrease and idle time slots increase in a way that QoS for the transmitted application was achieved. Since the original protocol and the EIED mechanism cause a sharp decrease or a sharp increase of the CW value after successful or unsuccessful transmission. Additionally, both schemes do not consider the history of the network condition as the proposed schemes.

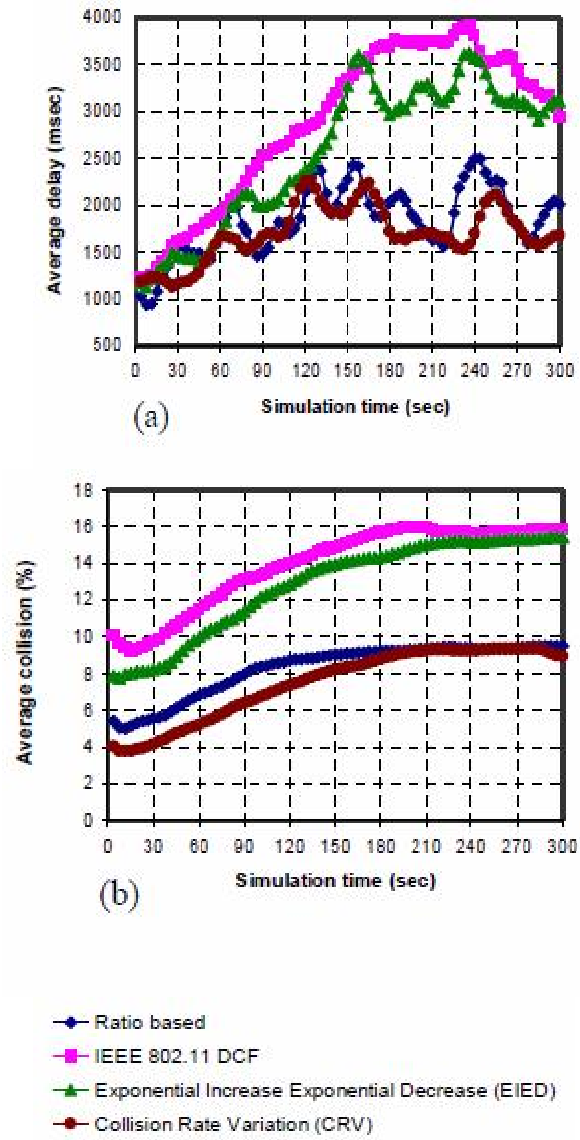


Fig 12. QoS parameters when the number of connections was changed over time, (a) average delay (msec), and (b) average collision rate (%)

6. Conclusions

The main objective of this paper is to describe the developed adaptive techniques namely Ratio based and *CRV* scheme that were used to enhance the performance and to improve the QoS of the IEEE 802.11 DCF scheme.

The Ratio based and *CRV* schemes extended the legacy IEEE 802.11 DCF mechanism by dynamically adjusting the *CW* value for each station according to the current and past history of successful and unsuccessful packet transmissions. The aim of developing these approaches was to reduce the probability of collisions in an attempt to improve QoS in IEEE 802.11 DCF protocol. The

Ratio based and *CRV* schemes are easy to implement since they do not require major modifications to the IEEE 802.11 DCF frames format. The simulation results indicated that the Ratio based and *CRV* showed better performance than the other two schemes regardless of the network size, traffic type, and the access mechanism used. For instance, the average delay reduced by 59% and 56% as compared with the standard IEEE 802.11 DCF and *EIED* schemes, respectively. The *CRV* scheme performed better than the Ratio based the IEEE 802.11 DCF, and the *EIED* schemes in most scenarios.

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Appendix

```
Ratio based scheme when collision occurs
 [wi] = 20, flag = 0; f = 3, CWmin = 31; CWmax =1023;
 If (history window == [wi]  packets) {
        Count the number of collided packets from wi
        Count the number of successfully received acknowledgment packets  from wi
        Compute the current collision ratio using Eq. 1;
        Compute the average collision ratio using Eq. 2;
       //to avoid starvation for some stations monitor the behavior of each I individual station.
        If (CW size is grater than > (f +1) * CWmin ) {
                    Increment flag;
                    I f( flag == f +1) {
                                CW = CW min ;
                        } else {
                                flage = 0;
                    Compute CW size using Eq .5;
                                Apply Equation 6;
                            }
        }
 }
```

Fig. 1. Ratio based scheme in case of unsuccessful transmission.

```
Ratio based scheme when successful transmission  occurs
 [wi] = 20, flag = 0; f = 3, CWmin = 31; CWmax =1023;
 If ( history window == [wi]  packets) {
      Count the number of collided packets from wi;
      Count the number of successfully received  acknowledgment packets  from wi;
      Compute the current collision ratio using Eq. 1;
      Compute the average collision ratio using Eq. .2;
      Reset the collision counter;
      Reset the success counter;
     //to avoid starvation for some stations monitor the behavior of each   individual station.
      If (CW size is grater than > (f +1) * CWmin ) {
                    Increment flag;
                    I f( flag == f +1) {
                                CW = CW min ;
                        } else {
                                flage = 0;
                    Compute CW size using Eq. .3;
                                Apply Equation 4;
                            }
        }
 }
```

Fig. 2. Ratio based scheme in case of successful transmission.

```
Collision Rate Variation (CRV) scheme for adjusting CW size
 [wi] = 20, flag = 0; f = 3, CWmin = 31; CWmax =1023; CRV =0 ;
 If (history window = = [wi] packets) {
        Count the number of collided packets from wi;
       Count the number of successfully received
        acknowledgment packets  from wi;
        Compute the current collision ratio using Eq. 1;
        Compute the average collision ratio using Eq. 2;
        Reset the collision counter;
        Reset the success counter;
        Compute the collision rate variation value for each   station using Eq. 7;
        If (CRV[N] < 0) {
        //to avoid starvation for some stations monitor  the behavior of each station.
        If (CW size is grater than > (f +1) * CWmin ) {
                    Increment flag;
                        If( flag = = f +1) {
                               CW = CW min ;
                                } else  {
                               flage = 0;
                               Compute CW size using Eq. 8;
                               Apply Eq. 9;
 Use the computed CW size after successful     transmission as Follows: CWsuccess[N] = CW[N];
                                }
                         }
        }
        else If (CRV[N] > 0) {
      //to avoid starvation for some stations monitor the  behavior of each station
        If (CW size is grater than > (f +1) * CWmin ) {
                    Increment flag;
                               I f( flag == f +1) {
                                           CW = CW min ;
                                            } else  {
                                           flage = 0;
                               Compute CW size using Eq. 8;
Apply Eq.  10;
Use the computed CW size after unsuccessful transmission as follow:  CWcollision[N] = CW[N];
                                          }
                    }
        }
 }
```

Fig. 3. Collision Rate Variation scheme (CRV).