A Novel Collision Ratio Based Scheme For Improving The Performance Of Wireless Network

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Abstract: The fast growth of wireless computer networks and multimedia applications means it is essential that these applications can be transmitted over the standard IEEE 802.11 Medium Access Control (MAC) protocol with high performance. Therefore, the aim of this paper is to develop a new schemed named Ratio Based that provides effective and efficient Quality of Service (QoS) provisioning in IEEE 802.11 DCF in a fair, scalable, and robust manner. Simulated wireless networks based on Network simulator (NS) package were carried out to examine and evaluate the impact of the proposed Ratio Based scheme on the network performance. The findings revealed that the IEEE 802.11 DCF protocol performed inadequately when transmitting various applications due to the limitations inherent in its operation. The study showed that inappropriate values of CWmin resulted in significant network performance degradations and demonstrated that it was important to select an appropriate set of MAC protocol transmission parameters in order to provide better performance. Ratio based scheme was developed to dynamically adjust the CW values according to the current and past network conditions. Using this scheme significant improvements were achieved in the performance of IEEE 802.11 DCF protocol.

Index Terms: Ratio Based Scheme, Wireless Networks, Contention Window (CW), Medium Access Control Protocol (MAC), Collision Ratio.

1. INTRODUCTION

THIS paper proposes a new mechanism for improving the IEEE 802.11 DCF protocol performance. This is a Ratio based scheme. The Ratio based scheme uses the collision rate value of the current and the past history of the network conditions to adaptively adjust the protocol parameters such as Contention Window (CW) size for each individual station. The aim of developing this approach is to reduce the probability of collisions among the contending stations in a heavily loaded network in an attempt to improve the whole network performance. The proposed scheme is evaluated and compared with the standard IEEE 802.11 DCF protocol. The relevant studies are described in the next section. A detailed description of the proposed Ratio based scheme is presented in section 3. The simulation model is presented in section 4. The results obtained are analysed and discussed in section 5. Conclusions are given in section 6.

2 RELATED WORK

Several algorithms that dynamically changes the value of CW to improve the performance of the IEEE 802.11 DCF protocol have been proposed and are described in, [1-4]. For example, in [1], the Linear/Multiplicative Increase and Linear Decrease (LMILD) backoff algorithm is presented. In the LMILD scheme, colliding stations increase their CW multiplicatively, while other stations overhearing the collisions increase their CW linearly. After successful transmission, all stations decrease their CW linearly. An adaptive DCF scheme was proposed in [3]. The proposed approach is based on adjusting the backoff procedure based on the knowledge of collision and the number of freezes time the backoff timer of the station experiences. The study showed that, the proposed scheme outperformed the IEEE 802.11 DCF scheme in terms of throughput. Several recent methods 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 the backoff counter as reported in [5]. In [6] 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 a variable length IFS, service differentiation can be achieved. In [7], the adjusted IFS parameter with other parameters such as quantum rate and deficit counter was used to provide QoS mechanism. Their results showed that QoS can be supported using an adjusted IFS length. In [8], the authors proposed a method for optimising 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, it was based on storing several network configurations using a database which imposed high computational overhead. Most of the discussed schemes require an exchange of information between stations. They also require sophisticated computations as the case in [8]. Other schemes impose major modifications to the structure of the IEEE 802.11 DCF as the case in [9]. Most studies only consider one or two of the QoS parameters. 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. They are as simple as the BEB to implement while significantly outperformed the IEEE 802.11 DCF and the EIED schemes.

3 APPROACH DESCRIPTION

The standard 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 [10, 11]. The DCF scheme does not consider the past history of the network or the readily available information. In order to make the protocol behave correctly, the protocol parameters such as CW should be adaptively adjusted to adapt to the dynamic changes in the number of contending stations and in the amount of traffic over time. This can be achieved by tuning the CW value after each successful and unsuccessful transmission. These adjustments

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are carried out locally for each station at runtime for the case of successful transmission and the case of collision.

3.1 Case for Successful Transmission

After each successful transmission, the DCF mechanism resets the CW of the station to its CWmin (i.e. CWnew = CWmin) 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 a 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 Ratio based scheme is proposed in order to mitigate burst collisions. In the Ratio based scheme, the CW size is adaptively adjusted as follows: The CW size is adjusted after computing the current collision ratio for each station, since collisions 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.

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

Where, $Num(collisions_{wi}[N])$ is the number of collisions for station N that is extracted from the history window wi, $Num(successful_{wi}[N])$ represents the number of packets that have been successfully acknowledged for station N that is extracted from the same history window wi, $R_{current}^{wi}[N]$ is the current collision ratio of station N. The $R_{current}^{wi}[N]$ 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 $R_{current}^{wi}[N]$ 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. To reduce or to alleviate the random fluctuations in the computed $R_{current}^{wi}[N]$ an Exponentially Weighted Moving Average (EWMA) is used to smooth the series of collision ratios (i.e. $R_{current}^{wi}[N]$ value) as given in Equation 2.

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

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

The instantaneous collision ratio $R_{current}^{wi}$ and the average collision ratio $R_{average}^{wi}$ are calculated based on the size of the total number of packets sent in wi. The size of wi is selected not to be so large as to obtain 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. 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. This was done in order to achieve a trade-off 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 $R_{average}^{wi}$, the new CW size for station N after successful transmission is computed based on Equation 3:

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

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

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

3.2 Case for Collision

In the legacy IEEE 802.11 DCF (IEEE, 1999), the CW is doubled after each collision. If the maximum limit known as the 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 according to Equation 5:

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

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

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

In the implementation of Ratio based scheme, each station adjusts its CW value locally and independently. Some of these stations may have small values of CW that cause a selfish access to the medium. This can occur after obtaining a short period of DIFS and a small duration of back off interval for several consecutive times. This causes starvation for other stations in the network. In such a case, a monitoring mechanism is used to observe the collision ratio values of past transmission of these selfish stations and it also observes the CW and DIFS of the starved stations. If the selfish stations have small values of CW and DIFS while starved stations still have large values, a penalty is applied for the selfish stations from accessing the medium by resetting the CW and DIFS values of the starved station to the minimum. Therefore, fair access to the medium can be achieved. Part of the pseudo code of the Ratio based scheme is illustrated in Figures 1 and 2.

```
Ratio based scheme when collision occurs
[wi] = 20, flag = 0; f = 3, CWmin = 31; CWmax =1023;
If ( history window[1] == [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 Equation 7.1;
        Compute the average collision ratio using Equation 7.2;
        //to avoid starvation for some stations monitor the behaviour of each individual station.
        If (CW size is greater than > (f +1) * CWmin ) {
                Increment flag;
                I f( flag == f +1) {
                        CW = CW min ;
                } else {
                        flag = 0;
                        Compute CW size using Equation 7.5;
                        Apply Equation 7.6;
                }
        }
}
```

Figure 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 Equation 7.1;
        Compute the average collision ratio using Equation 7.2;
        Reset the collision counter;
        Reset the success counter;
        //to avoid starvation for some stations monitor the behaviour of each individual station.
        If (CW size is greater than > (f +1) * CWmin ) {
                Increment flag;
                I f( flag == f +1) {
                        CW = CW min ;
                } else {
                        flag = 0;
                        Compute CW size using Equation 7.3;
                        Apply Equation 7.4;
                }
        }
}
```

Figure 2: *Ratio based scheme in case of successful transmission.*

4. SIMULATION MODEL

To evaluate the validity of the Ratio based scheme and compare its performance with the standard IEEE 802.11 DCF standard, the Network Simulation package (NS) was used [12]. A simulated network model with different scenarios were used for the simulation. Stations in this model transmitted different CBR traffic based on the selected scenario. The parameters used in these simulations were based on the IEEE 802.11 network configurations. In all simulations, 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 scheme by means of a comparison with the IEEE 802.11 DCF standard. These scenarios included varying the network size (small, medium, and large network sizes), traffic load (light, medium, and heavy load), and the variation in the number of active stations over time.

5. RESULTS AND DISCUSSION

This section provides the simulation results for the proposed method and compares them with the standard IEEE 802.11 DCF scheme. This section is split into two main subsections. The sensitivity analysis and parameter tuning of the Ratio based technique is presented in a subsection and the results obtained when the Ratio based is used to adjust the CW size.

5.1 Parameters Tuning

In this section, the influence of the history window size (wi), scaling factor (f) and weighting factor (λ) is investigated. The results demonstrated that the right combination of these parameters could 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, and heavy and medium load cases was used. Average throughput and average delay were considered as the main metrics. The weighting factor λ was varied over the range 0 to 1. Figures 3a and 3b depict the average delay and average throughput as a function of the weighting factor λ, respectively. Every single point of the results obtained represent an average of 10 simulations in order to avoid the bias of random number generation. It can be observed from Figure 3a that the lowest average delay corresponded to λ = 0.65. Figure 3b shows that the highest average throughput corresponded to λ = 0.7. Consequently, the value of λ = 0.6 was selected since it achieved a trade-off between average throughput and average delay.

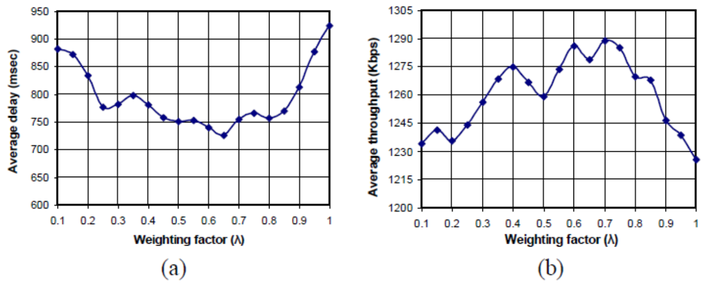

Figure 3*: Average delay and average throughput as a function of weighting factor (λ), (a) average delay and (b) average throughput.*

Figures 4a and 4b depict the average delay and average throughput as a function of the scaling factor f for the heavy and medium load cases. The value of f was varied over the range 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. A significantly high value of f, e.g. f = 10, resulted also in high values of average delay and a low value of average throughput. According to Figures 4a and 4b, a value of f, i.e. around 3, provided a trade-off 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 4a and 4b. The value of f = 3 was considered for the following simulations.

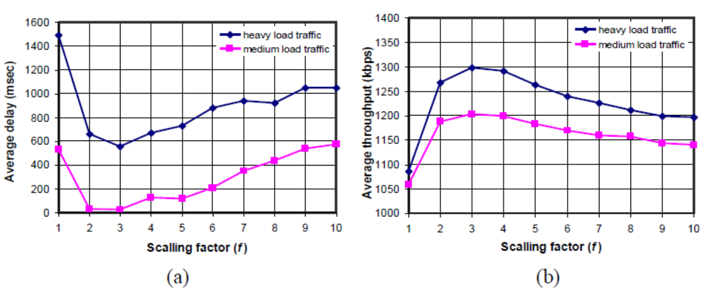

Figure 4*: Average delay and average throughput as a function of scaling factor (f), (a) average delay and (b) average throughput.*

Figures 5a and 5b demonstrate the effect of the history window wi on the performance. The size of the history window wi was varied over the range 5 to 50 with an increment of 5. The simulation results of average delay are shown in Figures 5a. A value of wi around 20 provided the lowest values of average delay. According to Figure 5b, the highest average throughput was achieved when the wi size was around 20. Thus, a history window wi of around 20 was selected for the following simulations as it provided a trade-off between the average delay and average throughput. Note that, the wi values around 20 could maintain small values of average delay compared to smaller values of wi. Therefore, a wi size equal to 20 was used. Too smaller value of wi were probably insufficient to provide adequate information about the current and the previous network conditions. Moreover, too large values of wi could cause late updates in the adaptation process (i.e. when adjusting CW and DIFS) in which performance degradation might occur. Subsequently, choosing an appropriate size of wi resulted in minimum average delay and maximum average throughput.

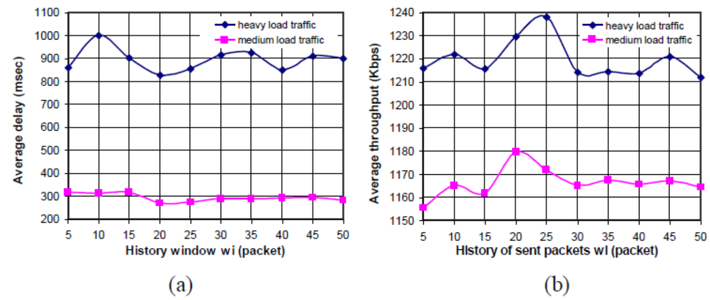

Figure 5: *Average delay and average throughput as a function of history window (wi), (a) average delay and (b) average throughput.*

5.2 Ratio based Scheme Validation

The Ratio based scheme was validated for heavy load traffic. Different network topologies sizes (5, 10 and 20 connections, i.e. small, medium and large networks) were considered to critically investigate the behaviour of the proposed method. This included the case when the number of sources was increased over time. 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 was transmitted by all active senders in the network. Therefore, the transmission rate of each source was equal $(1.6Mbps/n)$, where n represents the number of connections. The values of average delay and jitter for both schemes were increased when the number of active stations was increased from 5 to 10 connections with the same amount of traffic. For example, the values of average delay were increased by 44%, 55%, in the Ratio based, IEEE 802.11 DCF schemes, respectively. This implied that the contention between stations was a significant factor. The Ratio based scheme displayed a smaller mean delay. A reduction of 65% was observed in the average delay when the Ratio based scheme was employed compared to the IEEE 802.11 DCF. A good level of performance was obtained when the Ratio based scheme was used. The quantitative results are summarized in Table 1. 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. Figure 6 depicts the collision rate a function of the network size for the proposed and the standard schemes.

Table 1*: Statistical results for Ratio Based and IEEE802.11 schemes*

Parameter	Ratio based scheme	IEEE 802.11 DCF scheme
Average delay (msec)	621.6	1788.0
Average jitter (msec)	21.3	40.1
Average throughput (Kbps)	1240.7	1025.5
Average packet loss (%)	7.9	27.1
Average MAC efficiency (%)	91.4	81.1
Average collision (%)	8.6	17.0

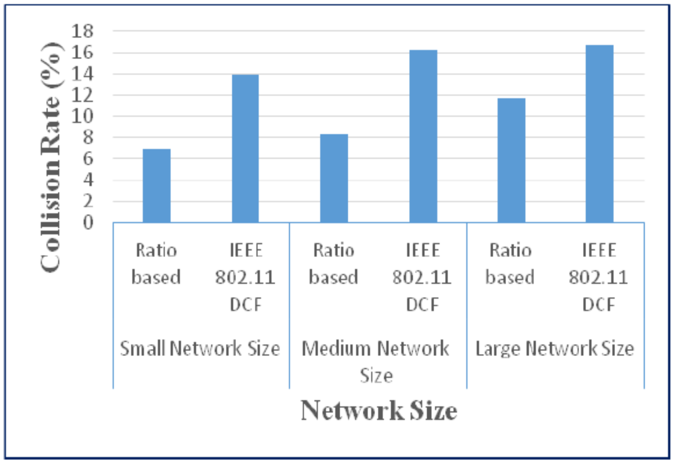

***Figure 6**: Collision rate as a function of network size for the Ratio Based and IEEE 802.11 DCF schemes.*

In conclusion the proposed Ratio based schemes were capable of adaptively adjusting the CW values after a successful and unsuccessful transmission based on the history of each individual station. Moreover, it was able to achieve an efficient trade-off between collision decrease and idle time slot increase to achieve better performance for the transmitted application.

6. CONCLUSIONS

The developed adaptive technique namely Ratio based was used to enhance the performance and to improve the service provided by the IEEE 802.11 DCF scheme. The Ratio based scheme extended the legacy IEEE 802.11 DCF mechanism. The aim of developing this approach was to reduce the probability of collisions in an attempt to improve the IEEE 802.11 DCF protocol performance. The Ratio based is 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 showed better performance than the other two schemes regardless of the network size, traffic type, and the access mechanism used. In conclusion the proposed Ratio based schemes were capable of adaptively adjusting the CW values after a successful and unsuccessful transmission based on the history of each individual station. Moreover, it was able to achieve an efficient trade-off between collision decrease and idle time slot increase to achieve better performance for the transmitted application.

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