Improving the Bandwidth Sharing in IEEE 802.11

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Abstract—In this paper, we propose a new solution to cope with the unfairness limitations of the Distributed Coordination Function (DCF) algorithm. Our solution is based on multiple backoff windows principle. We demonstrate through simulations the efficiency of our proposal that enables fair bandwidth sharing and increase total network throughput.

I. INTRODUCTION

One of the major concerns in current IEEE 802.11 wireless local area networks (WLANs) is ensuring fair and efficient sharing of the common bandwidth among competing access nodes while maximizing the network throughput.

Actually, the access in such networks is arbitrated by the use of the distributed coordination function (DCF) algorithm, which is based on Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) technique. This algorithm (DCF) strongly participates in the success of IEEE 802.11b thanks to its simplicity. Nevertheless, this basic concept presents a major drawback related to its inherent throughput unfairness limitations, known in literature as the 802.11b anomaly [1][2]. Accordingly, the throughput of each access stations is drastically reduced once one station moves far away the access point (AP). Indeed, due to fading and interferences, the current IEEE 802.11b protocol reacts by degrading the transmission bit rate of the moving station from its nominal 11Mbit/s rate to 5.5, 2 or 1Mbit/s. As a result, the moving station throughput as well as all the contending access nodes throughput are degraded due to the unfairness limitations of the CSMA/CA-based DCF algorithm.

To alleviate this problem, we suggest a new strategy based on multiple backoff windows concept. We refer to this technique as the DCF-MB (DCF Multiple Backoff). Considering our scheme, access nodes are classified into different sets (each set have its backoff window) according to their physical transmission bit rate (11, 5.5 or 1Mbit/s).

The rest of this paper is organized as follows. In section II, we revise the related works presented in the literature, pointing out our position relative to these works. Section III analyses the DCF anomaly through simulation illustrations. In section IV, we describe our proposed solution. Then, section V, simulation results are given to show the fairness introduced by our scheme. Finally, conclusions are drawn in section VI.

II. RELATED WORKS

In the wireless literature, several studies dealt with the analysis of the unfairness behavior of the DCF protocol due to the basic CSMA/CA algorithm [1][2]. These works studied this concern without providing particular solutions. Specifically, the work in [1] analyzed theoretically the DCF anomaly by deriving simple expressions of the useful throughput. Furthermore, in [2], authors focus on the short-term unfairness of CSMA-based medium access protocol. They evaluated the short-term fairness degree through experimental and analytical methods.

Recently, some service differentiation schemes have been proposed for the IEEE 802.11 DCF to support QoS feature [5][3][4]. The basic idea consists in providing a priority scheme for the DCF. The differentiation is simply achieved through varying the amount of time a station would sense the channel to be idle and the length of the contention window for a backoff. Such methods give an access priority for the shared medium to hosts with stringent QoS requirements but without resolving the above-mentioned unfairness issue.

In this study, we adapt these priority mechanisms to achieve fairness. As a key distinguishing feature from existing literature, we provide an effective solution to the unfairness concern with minor changes in the DCF algorithm.

III. IEEE 802.11 DCF ANOMALY

The IEEE 802.11b standard defines two access methods: the DCF technique, which is based on the CSMA/CA protocol, and the centralized Point Coordination Function (PCF). Unlike DCF, the PCF method provides free collision access via a central arbitration by a point coordinator, which resides in the AP. Even though, the PCF method is rarely implemented in todays products due to its complexity. In contrast, DCF thanks to its simplicity is the main reason of the tremendous growth in IEEE 802.11 installation.

As stated before, the DCF access method is based on the CSMA/CA principle. Accordingly, a host wishing to transmit a frame senses the channel activity until an idle period equal to Distributed Inter Frame Space (DIFS) is detected. Then, the station waits for a random backoff interval before transmitting. The backoff time counter is decremented in term of time slots as long as the channel is sensed free. The counter is suspended once a transmission is detected on the channel. It resumes with the old remaining backoff interval when the channel is sensed idle again for a DIFS period. The station transmits its frame when the backoff time becomes zero.

If the frame is correctly received, the receiving host sends an acknowledgement (ACK) frame after a Short Inter Frame Space (SIFS). If the sending host does not receive this ACK frame, a collision is assumed to have occurred. In this case,
the sending host attempts to send the frame again when the channel is free for a DIFS period augmented by the new backoff calculated as follows.

For each new transmission attempt, the backoff interval is uniformly chosen from the range $[0, CW]$ in term of slot of times. At the first transmission attempt of a frame, $CW$ equals the initial backoff window size $CW_{\text{min}}$. Following to each unsuccessful transmission, $CW$ is doubled until a maximum backoff windows size value $CW_{\text{max}}$ is reached. Once the frame is successfully transmitted, the $CW$ value is reset to $CW_{\text{min}}$. Figure 1 illustrates the DCF mechanism.

In essence, the DCF algorithm ensures equal access to the shared medium among all the contending stations. However, equal access probability does not guarantee a fair medium occupancy among all the hosts. Specifically, a station moving away from the AP may result in the degradation of its nominal bit rate (i.e. 11Mbit/s) to 1Mbit/s. In this case, it captures the channel for a period 11 times longer than the period required by a station close to the AP to transmit the same frame. In this regard, this kind of access policy may not be desired since it is extremely penalizing for all the stations. In addition, this issue affects the total network throughput.

To illustrate this anomaly, we consider the simple example of 3 station-access network. The 3 contending access stations are situated at different distances from the AP. Accordingly, the first station, which is the closest node to the AP, transmits at a bit rate equal to 11Mbit/s. The second station transmits at 5.5Mbit/s and the third station at 1Mbit/s. We assume that packets arrive with the same rate at each station buffer level according to a Poisson process. In this example, the arrival rate is set high enough, so that, there is always at least one frame in each host buffer.

Moreover, in our simulation, station 2 is activated at $t_1 = 10s$ and station 3 is activated at $t_2 = 40s$. This scenario enables us to check the network throughput evolution. We note that the DCF parameter settings used in our simulations are depicted in Table I.

As depicted in Fig. 2, during the first 10s, only station 1 is activated. Its useful throughput is maximal and attains 6.41Mbit/s, which represents nearly 0.6 of its transmission bit rate (11Mbit/s). This difference is mainly due the backoff delay, SIFS and DIFS free periods left on the medium for each frame transmission.

Once the station 2 is activated, the first station throughput logically reduces. But, this reduction is dramatic since the new useful throughput 2.42Mbit/s is less than the half of the old throughput (6.41Mbit/s). Moreover, we point out that both stations present the same throughput although their different bit rates. Indeed, the throughput of the first station is decelerated due the relatively low bit rate of station 2. This is typically due to the CSMA/CA policy, which allows fair access probability between both stations but does not ensure a fair medium occupancy in term of time. In this case, station 2 occupies the channel twice more time than the first station. As a result, station 1 is unfairly penalized as well as the total network throughput, which significantly decreases as it passes from 6.41Mbit/s to 4.84Mbit/s.

This anomaly is more pertinent when station 3 is activated. In this case, the useful throughput of each station is limited to only 0.57Mbit/s and the total throughput becomes 1.71Mbit/s.

IV. THE PROPOSED SOLUTION: DCF-MB

To relieve this issue, we suggest a method that ensures a fair channel sharing in term of time occupancy among the contending nodes instead of ensuring fair access probability. To achieve this, we give different access priority to different hosts according to their transmission bit rate classes (11, 5.5 or 1Mbit/s). Let us revisit the example of section III. As stated before, thanks to its relatively high transmission bit rate (i.e. 11Mbit/s), station 1 sends the same frame 2 times faster than station 2 and 11 times faster than station 3. In view of this, station 1 has to access the channel 2 more times than station 2 and 11 more times than station 3 in order to obtain a fair time occupancy.

This aim can be simply accomplished, while keeping almost
unchanged the existing DCF algorithm. To do so, we provide each class bit rate \( C_i \) with its associated initial contention window size \( CW_{\text{min}}(i) \) for backoff procedures. Specifically, \( CW_{\text{min}}(1) \) associated to class \( C_1 \) (i.e. 11Mbit/s) is set equal to 31 as specified in the standard. Moreover \( CW_{\text{min}}(i) \) of class \( C_i \) is derived as follows:

\[
CW_{\text{min}}(i) = CW_{\text{min}}(1) \frac{r_i}{r_1}
\]

where \( r_i \) denotes the bit rate of class \( C_i \).

Specifically, in our study, we assume 3 classes of stations. According to (1), we get \( CW_{\text{min}}(1) = 31 \), \( CW_{\text{min}}(2) = 60 \) and \( CW_{\text{min}}(3) = 330 \), which are the window sizes of classes \( C_1 \) (11Mbit/s), \( C_2 \) (5.5Mbit/s) and \( C_3 \) (1 Mbit/s), respectively.

Doing so, we guarantee, for instance, that the average backoff counter timer of class \( C_1 \) is the half of that of class \( C_2 \) (5.5Mbit/s). Hence, we ensure that class \( C_1 \) stations access the medium twice more times than \( C_2 \) stations.

Finally, we underline that the main advantage of this method is its simplicity. It requires minor modifications in the existing DCF. Indeed, each station modulates its contention window size according to its current physical bit rate. This decision is taken locally, at the station level, without requiring any extra communications with the AP, keeping thus the simplicity and the distributed feature of DCF.

V. PERFORMANCE EVALUATION

In this section, we analyze the impact of our proposed DCF-MB scheme on the network performances using simulation approach. To achieve this, we develop our own event-driven simulator.

In order to gauge the efficiency of our proposal, we first apply our DCF-MB scheme using the same scenario of section III and the results are reported in Fig. 3. Recall that according to this scenario, we have 3 stations belonging to different class bit rates (\( C_1 \), \( C_2 \) and \( C_3 \), where station 2 is activated at \( t_1 = 10s \) and station 3 is activated at \( t_2 = 40s \).

Figure 3 shows that the initial useful throughput of station 1 (i.e. 6.41 Mbit/s) is divided by 2 when station 2 is activated and is divided by 3 when station 3 joins the network. Unlike the classical DCF (see Fig. 2), thanks to our method, the performance of station 1 only depends on the number of sharing access stations and no more on their relative positions with respect to the AP. In other words, the fact that station 2 transmits at 5.5Mbit/s or more or less does not really affect the station 1 throughput. According to our scheme, the utilization time of the medium is equally shared among the different stations. Moreover, each station uses its proportion of time according to its transmission bit rate. In this regard, using a low bit rate, the station will transmit less without penalizing the remaining contending stations. Based on Fig. 3, we can observe that the useful throughput of station 1 is the double of the station 2 throughput and 11 times the station 3 throughput.

As explained before, one of the major concerns with DCF is the drastic degradation of the total network throughput due to the relatively far away stations with respect to the AP. Figure 4 confirms this issue, where the total throughput significantly degrades once station 2 and 3 join the network. Figure 4 also shows that our DCF-MB scheme alleviates this issue. Indeed, the increase of sharing nodes degrades less significantly the total network throughput when using DCF-MB. Specifically, when the number of sharing nodes is 3, the throughput obtained thanks to our DCF-MB is 4.21Mbit/s whereas it is limited to 1.71Mbit/s with the classical DCF.

Note that the slight decrease of the total throughput with DCF-MB when station 2 and 3 are activated is due to two main reasons. First, station 2 and 3 transmit at relatively low bit rates with respect to station 1 during their utilization of the medium, which reduces the total network throughput. Moreover, increasing the number of access stations increases the collision probability among different nodes frames, leading thus to increasing bandwidth waste.

In this context, Fig 5 shows the total network throughput evolution with the network density. We refer by the network density as the same number of access nodes \( n_i \) composing each bit rate class \( C_i (i = 1,...,3) \). In this case, the network density varies from 1 to 7, that is, the total number of access nodes varies from 3 to 21. Again, Fig. 5 shows that the total network throughput decreases with the increase of access nodes for both cases (DCF and DCF-MB). Moreover, this figure exhibits once more the significant gain introduced by
our method.

Figures 6 and 7 show the average useful throughput of each class bit rate for the DCF and DCF-MB cases, respectively. Figure 6 shows that, using the classical DCF, all the access stations have the same useful throughput although their different transmitting bit rates. Moreover, the useful throughput of each class is very low (less than 0.6Mbit/s). This is typically due to the limitations of the classical DCF.

On the other hand, enabling our DCF-MB scheme, this issue is alleviated. Figure 7 shows that the throughput is fairly distributed among different classes. In addition, the throughput per class significantly increases. Specifically, when density is equal to 1, a station belonging to class $C_1$ benefits from a throughput around 2.5Mbit/s, whereas the same station has a throughput less than 0.6Mbit/s when DCF-MB is disabled.

Finally, we conclude this section by studying the impact of our scheme on the collision in the network. In such network, a collision between two stations occurs when their associated backoff counters expire at the same time. Figure 8 depicts the collision probability according both DCF and DCF-MB schemes. To achieve this, we use the same scenario used in section III. According to Fig. 8, we can observe that the collision probability reduces when DCF-MB is enabled. This is a direct result of the utilization of different contention windows for the different classes of stations.

VI. CONCLUSION

In this paper, we proposed an improvement of the existing DCF scheme in order to cope with its unfairness limitations. To achieve this, we used different contention window sizes for each class of bit rate. We motivated the use of the proposed scheme since it allows achieving fairness among contending access nodes while improving the total network throughput.

REFERENCES