Dynamic AIFSN tuning for improving the QoS over IEEE 802.11 WLANs

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Abstract—**The original version of the IEEE 802.11 standard is not able to provide the required Quality of Service (QoS) for real-time applications. The IEEE 802.11e amendment was developed to overcome this situation, introducing the Enhanced Distributed Channel Access (EDCA) as a new channel access method. This method makes it possible to prioritize the different types of traffic through a group of Medium Access Control (MAC) parameters. The most important role of these MAC parameters is played by the Arbitration Inter-Frame Space Number (AIFSN). Although the AIFSN can be modified during a transmission, the commercial Access Points (APs) only use the combination defined in the standard. Therefore, we propose a new adaptation scheme for network traffic priorities involving the construction of a J48 decision tree classifier with the main goal of enhancing the voice and video communications. This classifier calculates a new set of AIFSN values by taking into account the current network conditions, maintaining the interoperability with the legacy Distributed Coordination Function (DCF) applications. The results show that our proposal improves upon the voice+video performance results obtained by the AIFSN standard values by up to 20%. Furthermore, this scheme is fully compatible with the commercial network cards available on the market.**

Keywords*—*QoS, 802.11e, EDCA, Artificial Intelligence

I. INTRODUCTION

Over the past few years, society has incessantly tended towards the use of wireless communications and social networking technologies. In this regard, the IEEE developed the 802.11 standard [1] in order to define a protocol for offering local area interconnectivity between different devices. The importance of Wireless Local Area Networks (WLANs) based on this standard has grown considerably due to their simplicity of deployment, their low cost and their multimedia content support.

Accordingly, the access mode to the Internet is changing towards wireless models and playing an increasingly important role, principally due to the emergence of devices such as smartphones and tablets, which are usually equipped with IEEE 802.11 interfaces. As a consequence, consumption patterns are also changing, and the demand for multimedia services is growing fast, especially in real-time applications, e.g. videoconferences and VoIP. For these reasons, it is essential to guarantee an adequate level of Quality of Service (QoS). In fact, this requirement has a direct impact on user perception.

Initially, the original IEEE 802.11 standard was not able to differentiate traffic flows and provide the required QoS. To improve the differentiation of services in IEEE 802.11 networks and to increase their performance, the IEEE 802.11e amendment [2] was developed. As a prioritization method, this amendment introduced a new contention-based channel access method: Enhanced Distributed Channel Access (EDCA). This mechanism offers a way of differentiating every single type of traffic by using user priorities.

Even though there is a lot of research in the field of QoS for the IEEE 802.11 standard, there are still some limitations in the aforementioned amendment that should be overcome. These limitations include the necessity of offering backward compatibility with the stations that only support the original IEEE 802.11 standard, and the fulfilment of the existing temporal restrictions in voice and video streaming transmissions. Given the diverse conditions that may arise in an IEEE 802.11 network, finding traffic patterns gains importance when it comes to improving the QoS provided. In this context, the application of artificial intelligence techniques may contribute to enhancing the performance of such a network.

The main aim of this paper is to improve the voice and video communications and satisfy the temporal restrictions of these types of traffic. To achieve this objective, we propose a prediction scheme for the Arbitration Inter-Frame Spacing Number (AIFSN) priority values based on network conditions. As a result, the amount of collisions in the network is reduced and the overall network performance is directly improved. The major contribution of this proposal focuses on its capacity to process and update the AIFSN values, which are carried out by dynamically using a group of simple rules at the Access Point (AP). In this way, the stations remain unaltered. In contrast to other proposals, no additional control traffic is introduced in the network when communicating the new values of the parameters. The proposed model requires small changes in the firmware of the commercial APs, maintaining full compatibility with the current commercial devices.

The remainder of this paper is organized as follows. Section II reviews the IEEE 802.11e amendment and some proposals that aim to provide a suitable QoS. In Section III we present the proposed prediction scheme. The construction of the J48 decision tree classifier is discussed in Section IV. The results of the performance evaluation and a comparison with the default AIFSN values are described in Section V. Finally, Section VI provides some concluding remarks on our proposal.

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II. QOS IN IEEE 802.11 NETWORKS

Initially, the original IEEE 802.11 standard introduced two medium access functions: the Distributed Coordination Function (DCF) and the Point Coordination Function (PCF). However, these access functions are not able to differentiate the traffic flows and provide the required QoS. Therefore, the IEEE formed a working group with the task of developing the IEEE 802.11e amendment that considered these aspects.

A. *IEEE 802.11e*

The IEEE 802.11e amendment was developed with the aim of providing QoS support and meeting the voice and video streams requirements over IEEE 802.11 WLANs [2]. As backward compatibility must be kept, a distinction is drawn between the stations that support QoS (QSTAs) and the stations that do not offer such support (nQSTAs), only using DCF. For this purpose, the 802.11e amendment implements the Hybrid Coordination Function (HCF) and, thus, its two contention-based channel access methods: HCF Controlled Channel Access (HCCA) and EDCA. To this end, the HCF coordination function implementation is mandatory for all the QSTAs. Nevertheless, only EDCA is supported by the commercial network cards on current devices as a method for accessing the wireless medium.

The EDCA channel access method distinguishes between eight different User Priorities (UPs). Moreover, four Access Categories (ACs) are defined, which are derived from the UPs and are able to classify and prioritize the traffic streams. In this way, in order from highest to lowest priority, Voice (VO), Video (VI), Best Effort (BE) and Background (BK) access categories are considered, as shown in Figure 1. Each one of these ACs works on its own transmission queue and is characterised by an EDCA parameter set. This EDCA parameter set specifies a priority level by using an AIFSN value, a Transmission Opportunity interval (TXOP) and the duration of the Contention Window (CW). Thus, the AP sends this EDCA parameter set through beacon frames to the stations of a Basic Service Set (BSS). The IEEE 802.11e amendment allows the APs to modify the aforementioned values. However, no mechanism is considered in this amendment for carrying out this task and most commercial devices do not implement such a service.

The AIFSN determines the Arbitration Inter-Frame Spacing (AIFS), which is the period of time that a station has to wait until it is allowed to initiate a new transmission. The AIFS for each AC is shown in Equation 1, where the *SlotTime* denotes the duration of a slot according to the physical layer, and the Short Inter-frame Space (SIFS) refers to the amount of time used by high priority actions that require an immediate response.

$$AIFS[AC] = AIFSN[AC] \cdot SlotTime + SIFS \tag{1}$$

Moreover, the stations are assigned an AIFSN value according to their priority, which must be higher than or equal to 2. In order to provide a fair transmission for the DCF stations, the IEEE 802.11e amendment defines a standard combination of AIFSN parameters, as shown in Table I. Meanwhile, the CW size determines the length of time that a station must wait until it is able to conclude the Backoff algorithm. In this way, the CW values are assigned in an inverse order to that of the priority of the corresponding AC. Similarly, the TXOP duration is longer for ACs with greater temporal restrictions.

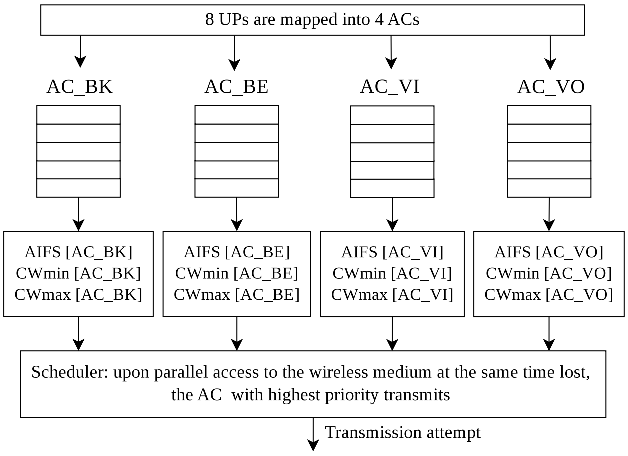

Fig. 1. EDCA Access Categories Mapping

TABLE I. DEFAULT EDCA PARAMETER SET

AC	CW_{min}	CW_{max}	AIFSN	TXOP
AC_BK	aCW_{min}	aCW_{max}	7	-
AC_BE	aCW_{min}	aCW_{max}	3	-
AC_VI	$(aCW_{min}+1)/2-1$	aCW_{min}	2	6.016 ms
AC_VO	$(aCW_{min}+1)/4-1$	$(aCW_{min}+1)/2-1$	2	3.264 ms

With regard to these parameters, the AIFSN plays the most important role in order to ensure optimum traffic differentiation. In [3], J. Villalón et al. show several test scenarios in which a set of values for the AIFSN and CW are taken into account. In this case, they prove that the AIFSN has a greater relevance when identifying priorities than the CW. This conclusion was also reached by J. Hui et al. in [4], who proved that both the collisions and access media delay decrease, allowing for an improvement in the network's global throughput.

B. *Dynamic adaptation in IEEE 802.11e*

Wireless network conditions, such as the network's load, can change over time. Consequently, several dynamic proposals that consider the aforementioned circumstances have emerged. Their main aim is to adapt the EDCA parameter set, i.e. to identify the optimal values for the AIFSN, CW_{max}, CW_{min} and TXOP parameters.

An approach with this same goal is presented in [5], where R. He et al. take into account three possible load levels, showing the behaviour of the proposed scheme under different network conditions. This proposal achieves a reduction in the number of retransmission attempts and an enhancement in the global network performance. In spite of this, there is a drop in the amount of voice and video information transmitted, which impairs its temporal restrictions.

In [6] T. Nilsson et al. introduce an adaptation scheme by using the CW size, achieving better results than EDCA. However, compatibility with legacy DCF stations is not considered.

A. Banchs et al. introduce in [7] a way of offering backward compatibility with the DCF stations. This algorithm is able to prioritize the voice and video traffic streams over the others. As the priority of the DCF stations cannot be modified by updating the EDCA parameter set, the CW size is increased by retransmitting packets that are properly received by the DCF stations. In this way, the priority of the stations that use this medium access function decreases. Nevertheless, unnecessary traffic is introduced into the network.

The design of an analytical model to improve the network performance has also been taken into account. Nevertheless, most of these models make assumptions that may not be fulfilled in real transmissions or are not able to keep backward DCF compatibility. In [8] J.R. Gallardo et al. define a model by using Markov chains. However, they consider the same bit rate for all the stations. By contrast, in [9] this parameter is properly modelled from a formal point of view by Y. Hammal et al. Nonetheless, only the stations that use DCF and PCF as a medium access function are considered.

III. DYNAMIC AIFSN TUNING

Since the IEEE 802.11e amendment was published, special attention has been given to the QoS features. It is therefore of particular interest to researchers to find schemes that improve the features of the EDCA channel access method. However, the existence of legacy DCF stations requires maintaining backward compatibility between them and those that use EDCA. Although the different EDCA parameters can be adapted to network conditions, they cannot be modified in the case of DCF stations. In order to provide an optimum level of QoS, EDCA allows a dynamic adaptation of the channel access parameters over time. Nevertheless, this feature is not used in commercial APs, mainly due to the complexity involved in determining the current network conditions. In this way, the devices that support EDCA as channel access method utilize the standard values of the EDCA parameter set, not considering network conditions.

The main goal of our proposal is to enhance the offered QoS level and maximize the performance of the voice and video traffic. In other words, our scheme aims to identify the optimal AIFSN values and adapt them to the network conditions in order to enhance the performance offered by the default EDCA parameter set. At the same time, it seeks to ensure backward compatibility between the stations that use EDCA and DCF in the BSS. Our main aim is to enhance the audio and video performance by decreasing the collisions between these application types. Accordingly, a reduction in the global retransmission attempts and an increase in the network's overall performance are achieved.

When a transmission takes place, there is a large number of variable parameters that may determine the channel conditions. Accordingly, deploying an adaptive scheme for the priority setting through the AIFSN values is not a simple task. The main conditioning factors are described below.

- *Number of active applications of each type of traffic.* This is a parameter that can be identified in a simple way by the AP. However, this value at a particular moment in time is insufficient. That is because it cannot provide further information about the current conditions of the network, i.e., the scheme will not be allowed to obtain real information about the current occupancy of the wireless channel.
- *Applications bit rate.* Linked to the previous one, this factor provides more detailed information about the state of the wireless medium. Unfortunately, it is difficult to calculate in real-time. To identify these values it is necessary to introduce periodical control traffic in the network. Nevertheless, this feature is not typically used in IEEE 802.11e.
- *Transmission rate.* Every single station may carry out its transmissions by using a different transmission rate. Therefore, the specific period of time that each of them keeps the channel busy is different. This parameter would be a good way of estimating the network conditions. Nonetheless, this value needs to be used jointly with the above factors.
- *Presence or absence of DCF legacy stations.* The existence of DCF applications restricts the use of priority parameters in EDCA due to the fact that these values cannot be duly adjusted for these stations.

TABLE II. PROPOSED SET OF AIFSN VALUES

	S0	S1	S2	S3	S4	S5	S6	S7	S8	S9
BK	7	8	9	8	9	12	10	12	14	14
BE	3	4	5	4	5	6	6	8	10	12
VI	2	2	2	3	3	3	4	5	6	7
VO	2	2	2	2	2	2	2	2	2	2

Due to the inherent variability of the aspects that are part of a wireless network transmission, we must consider a scheme with low computational complexity and capacity to adapt itself to changes over time. On the basis of these requirements, artificial intelligence techniques are used in order to find and interpret traffic patterns. Furthermore, such techniques are capable of making decisions based both on their previous decision and the behaviour of the network.

As a way to address the problem, a J48 tree classifier has been chosen. Before deciding on the use of this classifier, many others, such as the Naive Bayes classifier, have been taken into account. However, the main features of this classifier are its low computational complexity, its self-explanatory capacity and its high degree of adaptability to the problem. In [3] and [4] it is concluded that the AIFSN is the most important factor in the EDCA parameter set. As a consequence, in our proposal the function of the J48 decision tree is to identify the set of AIFSN values that achieves the highest voice+video normalized throughput regardless of network saturation.

In order to achieve our goal, 9 sets of AIFSN values are chosen according to the studies in [3] and [4] (see Table II). The selected values aim to enhance network performance, mainly by reducing the collisions between the different types of traffic. For that reason, the AIFSN value relating to each AC is suitably separated from each other. However, in those cases in which the AIFSN for video traffic is higher than 2, its priority to access the wireless channel is reduced in comparison with the legacy stations.

As the classifier needs to acquire knowledge about the circumstances of the network, an extensive set of tests is performed by taking into account a wide range of traffic levels. As part of these tests, the aforementioned 9 sets of AIFSN values are considered with the aim of finding an alternative value to the default one in order to enhance the network performance. When all the results have been obtained, they must be refined in order to provide only the right information to the classifier. In this way, only the data concerning those AIFSN configurations that maximize the voice+video normalized throughput will be provided. Initial tests included several outcomes, such as the number of applications of every type of traffic or the percentage of occupancy of the wireless medium. Due to the wide variety of resulting parameters, it was necessary to perform a variable selection to discard those that were unrelated. In this way, the selection of the lowest number of parameters is vital in the construction of a classifier that is as simple as possible. After carrying out this supervised variable selection, only the global occupancy level of the wireless channel and the particular level of each type of traffic are considered by the model. These few factors are able to provide a good approximation of the network conditions while allowing the construction of a simple and accurate classifier.

The aforementioned parameters are used as an entry point for the J48 tree built and must be calculated periodically. In our case, they will be calculated once per second. After this period of time, the classifier checks whether the previously selected AIFSN values are already the most favourable combination or whether they need to be modified. Once the optimal AIFSN set has been calculated by the AP, it is responsible for distributing these values embedded in an EDCA parameter set. Distribution is handled through the beacon frames and, therefore, no additional control traffic is introduced into the network.

Thus, the proposed scheme has low complexity due to the fact that the AP only has to perform simple operation checks by using the described classifier, and there is no need to send additional control traffic. Furthermore, this scheme only requires making a few minor adjustments to the APs and no changes are made to the commercial network cards. Therefore, total compatibility with existing devices is maintained at the same time an enhancement in network performance is made possible, especially for voice and video traffic.

IV. J48 DECISION TREE CLASSIFIER CONSTRUCTION

As described in the previous section, the J48 tree classifier requires a considerable amount of information in order to build a proper model. The information is obtained from the results of the set of tests performed previously. These tests are carried out by using Riverbed Modeler 18.0.0 [10], and their conditions are shown below.

A group of 18 scenarios has been designed with regard to the set of tests. These scenarios consider applications that utilize EDCA and those that only make use of DCF as a channel access method. Every scenario is composed of a variable percentage of applications of every type of traffic (BK, BE, VI and VO), and only uplink traffic is taken into account. In this way, eight different combinations of the same scenario with different traffic load levels are considered, causing the number of stations to range from 10 to 80, in steps of 10 stations. Moreover, all the simulations are performed twice with the aim of evaluating two possible values for the transmission rate. In our case, 12 Mbps and 36 Mbps have been selected for all the stations. In order to provide a further evaluation, all the tests have been carried out by using 60 different random seeds.

TABLE III. TRAFFIC PARAMETERS USED FOR CLASSIFIER CONSTRUCTION

	Packet size	Data rate
DCF	552 bytes	512 Kbps
BK	552 bytes	512 Kbps
BE	552 bytes	512 Kbps
VI	1064 bytes	800 Kbps
VO	104 bytes	20 Kbps

Each type of traffic has its own transmission parameters, which are presented in Table III. The DCF, BK and BE traffic types are modelled by using a Pareto distribution with a location of 1.1 and a shape of 1.25, while the voice traffic is represented by a Constant Bit Rate (CBR) service using the G728 codec [11]. An exponential distribution is used for the video traffic, whose bit rate corresponds to the transmission of an H.264 [12] stream. Moreover, and due to the temporal restrictions of the voice and video traffic, deadline periods for these types of traffic are taken into account. In this way, when the delay of these applications is higher than 10 ms and 100 ms for voice and video, respectively, these streams are discarded.

The different tests are performed by using the values shown in Table II. As the default AIFSN values in some cases offer the highest performance, they are also included in the aforementioned table in order to carry out the same tests. The results of this combination will be compared with the ones achieved by our proposal. Among all the factors described above, the AIFSN plays the most important role because it will become the output of the classifier, which will be queried by the AP with the purpose of adjusting the traffic priorities. The previous parameters remain static during the complete simulation period. Therefore, the classifier is allowed to acquire knowledge from the data set that maximizes the voice+video normalized performance. If variable information were provided to the classifier during its development, the learning process would be unfeasible. Moreover, both the variables selection process and the J48 classification tree construction are performed using Weka 3.7.0 [13]. Once the model has been built, a 10-fold cross validation process is used, which results in a hit rate of 94.90%.

V. PERFORMANCE EVALUATION

The proposed scheme is evaluated through the design and execution of a set of 20 scenarios, including both DCF and EDCA stations. Twelve of the considered scenarios take into account DCF stations, while in the remaining eight only stations with EDCA support can be found. Each scenario is made up of 100 stations, which have a specific transmission probability depending on their AC, as shown in Table IV. These probabilities and the selected number of stations make it possible to test our proposal with different traffic load levels.

The scenarios have a duration of 300 seconds and are divided into two periods. During the first one, and every 30 seconds, the stations that are not transmitting any information try to start a new transmission with a probability associated

TABLE IV. DESCRIPTION OF THE SET OF TEST SCENARIOS

Scenario Number	Voice	Video	BE	BK	DCF
1	10%	1.5%	2%	2%	2%
2	10%	5%	2%	2%	2%
3	10%	7%	2%	2%	2%
4	8%	6%	3%	3%	7%
5	4%	2%	3%	3%	10%
6	3%	3%	4%	4%	8%
7	5%	3%	7%	7%	4%
8	6%	6%	10%	5%	5%
9	6%	9%	6%	6%	6%
10	8%	-	8%	8%	8%
11	-	6%	6%	6%	9%
12	6%	6%	6%	6%	6%
13	10%	8%	-	-	-
14	8%	4%	-	-	-
15	6%	10%	-	-	-
16	7%	7%	7%	7%	-
17	10%	-	8%	8%	-
18	-	8%	7%	7%	-
19	9%	8%	6%	6%	-
20	9%	7%	8%	-	-

TABLE V. VOICE+VIDEO NORMALIZED THROUGHPUT IMPROVEMENTS IN 30S INTERVALS

	With DCF traffic	Without DCF traffic
Unaltered	49.42%	35.52%
Losses	4.49%	2.55%
Gain [1%-5%]	27.20%	23.64%
Gain [5%-10%]	8.67%	6.68%
Gain [10%-15%]	6.06%	7.41%
Gain [15%-20%]	2.01%	4.48%
Gain [up to 20%]	2.16%	19.73%

to their AC (see Table IV). During the second one, the transmitting applications attempt to stop the transmission every 30 seconds with the same probability as that previously used. With this approach, many scenarios with a multitude of traffic loads are considered. Due to all scenarios being simulated by using 60 different random seeds and each of them being divided into 20 time intervals, in the end 24000 different intervals have been tested.

Each application utilizes a specific bit rate according to its AC. These values are the same as the ones in Table III. Nevertheless, during the test of the classifier built, different transmission rates have been taken into account. Furthermore, the stations are randomly distributed over the network coverage of the BSS. With the aim of modelling signal propagation through the wireless medium, the Ricean [14] model has been used. This model is characterized by a factor, k, which determines the ratio between the power in the line-of-sight component and the power in the scattered paths. In our case, a k factor of 32 has been used. Moreover, IEEE 802.11g [15] defines the physical layer of the network.

As part of the tests, a group of statistics that are able to summarize the main results have been considered. These statistics include the voice+video normalized throughput, the number of retransmission attempts and the overall throughput of the network. The first of these statistics refers to the sum of the normalized throughput of voice and video applications.

In Table V the voice+video normalized throughput results for the 24000 simulated intervals are shown. This table presents the percentage of 30 second transmission intervals during which our proposal has experienced losses or gains of voice+video normalized throughput with regard to the existence of DCF traffic. These values have been calculated in comparison with the results obtained from the standard AIFSN combination. It can be observed that a high percentage of the cases remain unaltered (49.92% and 35.52% for scenarios with and without DCF traffic, respectively). We have considered unaltered intervals to be those in which the gains or the losses are lower than 1%. These results are a consequence of having a low traffic load in most of the tested scenarios, where all the AIFSN combinations achieve maximum performance. It can also be seen that in a few intervals our proposal has a greater number of losses than the standard AIFSN combination of no more than 4.49% in the worst case. This situation is due to a group of wrong decisions made by the J48 classifier during the simulations. In addition, the usage of only one parameter as input for the J48 decision tree does not allow it to identify the network conditions completely. However, the number of scenarios in which this situation occurs is much lower than those in which our proposal improves upon the performance offered by EDCA. In fact, the results show that in many cases these gains are up to 20%. Finally, it can be clearly seen that the improvement achieved by the proposed scheme is much higher in the absence of DCF traffic.

The scenarios shown in Figures 2, 3 and 4 are a representative subset of those where the traffic proportion is more problematic for EDCA usage. The first five scenarios take into account both DCF and EDCA stations. However, in the remaining three only EDCA stations are considered.

During the simulations, twenty intervals with many different traffic load levels are taken into account. The first and the last five intervals have the lowest traffic load due to the fact that all the stations are starting or ending their transmissions. When the traffic load is low, all the tested AIFSN combinations offer the highest throughput. In this way, the results of both the standard AIFSN combination and those of the proposal are identical. For this reason, only the ten remaining intervals are shown in Figure 2, in which the standard values start to suffer traffic losses. In this figure, the voice+video normalized throughput is shown. It can be observed that in all cases the throughput achieved by our proposal is higher than when using the default AIFSN values. Furthermore, it is shown that the difference is even greater in scenarios without DCF traffic. In these cases, an improvement of up to 35% can be obtained.

The improvement achieved by our proposal is a direct consequence of decreasing the amount of collisions in the network. In Figure 3 it can be seen that our scheme offers a reduction in the number of the global retransmission attempts. The average reduction in all the scenarios is around 15%. These decreases have a direct effect on the overall performance improvement of the network. Figure 4 illustrates the described behaviour. Effective AIFSN values selection contributes not only to enhancing the voice+video performance, but also to improving the quality of the remaining types of traffic transmissions.

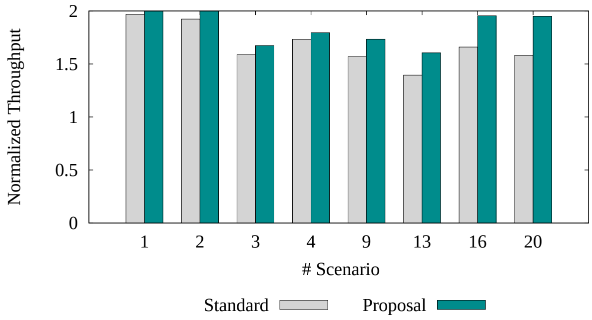

Fig. 2. Voice+Video Normalized Throughput

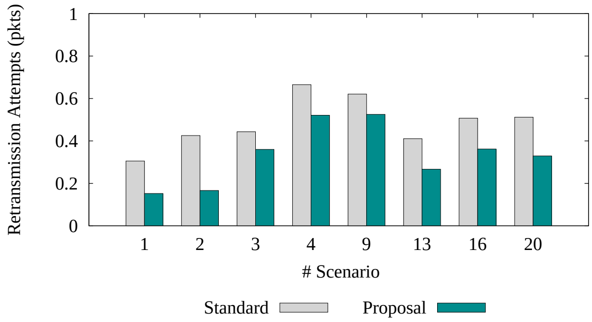

Fig. 3. Overall Retransmission Attempts

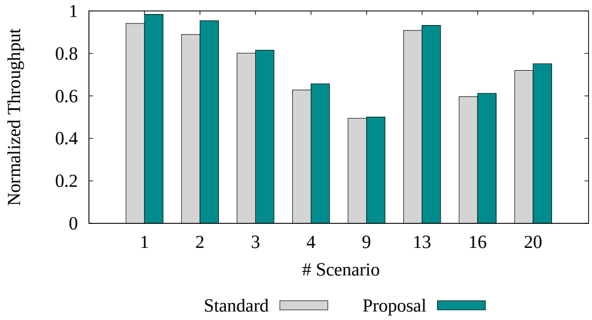

Fig. 4. Overall Throughput

VI. CONCLUSIONS

In this paper we have proposed a new prediction scheme that dynamically adapts the default AIFSN values with the aim of enhancing the voice and video communications This proposal is fully compatible with the legacy stations that only support the original IEEE 802.11 standard. The prediction scheme is implemented by carrying out the construction of a J48 decision tree classifier. In this way, the AP of the BSS is the only device that makes use of this classifier, recalculating the AIFSN values once per second. Moreover, the AP sends these values through an EDCA Parameter Set by using beacons. Accordingly, no additional traffic is introduced into the network.

The results have shown that our proposal achieves its initial goal, and is able to outperform the voice+video normalized throughput of the default AIFSN combination. In fact, this approach achieves an improvement of up to 20%. This fact leads to a reduction in the number of global retransmission attempts. Furthermore, separating the AIFSN values from each other for each AC contributes to reducing the collisions between the different ACs. Based on the above observations, the overall throughput of the network is also improved. The proposed scheme is fully compatible with existing commercial network cards, it only being necessary to perform minor changes to the APs. Moreover, its simplicity allows the algorithm to be executed in real-time.

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