Introducing Finer Prioritization in EDCA using Random AIFSN

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***Abstract*— The recently adopted WLAN standard IEEE 802.11e provides quality of service (QoS) differentiation by grouping the traffic into different access categories (ACs) with different priorities. It defines different arbitration inter-frame space number (AIFSN) on a per-category basis to ensure that each category has different probability of accessing the channel. Within an AC, random back-off mechanism is used to spread the traffic. However, when there are a large number of QoS stations (QSTAs) within an AC, the probability of two or more stations choosing the identical back-off values is increased leading to increased packet collisions. In this paper, we propose the use of randomized AIFSN. The random AIFSN method can be exploited to introduce finer priority values within an AC. Each AC is assigned an AIFSN interval and a probability distribution function (PDF) defined over that interval. The simulation results indicate that the proposed method leads to reduced probability for collisions and higher throughput. We also present some testbed results to verify the improvement using random AIFSN method.**

Keywords-WLAN, MAC, IEEE 802.11e, EDCA, AIFSN

I. INTRODUCTION

In the recent past, the affordability and high speed improvements in the IEEE 802.11 wireless local area network (WLAN) technologies have led to its widespread adoption throughout the world. The flexible wireless access capability of 802.11 has resulted in its deployment in offices, homes, and other commercial settings, such as convention centers and airports. At present there is a significant increase in the use of multimedia applications, such as streaming video, teleconferencing, wireless gaming and voice over IP. With the popularity of multimedia applications, there is a growing need to support multimedia over wireless networks. However, multimedia applications require QoS support such as guaranteed throughput, bounded delay and jitter. As a step towards meeting multimedia application requirements in WLAN networks, the 802.11 Working Group has been recently pursuing the standardization efforts for a new standard, called IEEE 802.11e [1], that provides service differentiation at the MAC layer.

There has been significant research exploring the different methods for providing traffic differentiation for IEEE 802.11 wireless networks. Several differentiation methods have been proposed involving the modification of the contention window (CW) size for the back-off procedure [2]-[4], assignment of different inter-frame space (IFS) access times for varying priority traffic [4]. The concerted research effort has resulted in the proposal of the IEEE 802.11e working group defining the use of ACs as a means to manage QoS. Although the Enhanced Distributed Channel Access (EDCA) mechanism of IEEE 802.11e guarantees the service differentiation, recent studies [5]-[7] have shown that under heavy load of high-priority traffic, low-priority traffic is starved of the bandwidth. To overcome this disadvantage, the authors in [8] proposed a mechanism involving the desynchronizing of EDCA functioning by assigning the non-integer AIFSN values to different ACs.

A typical home network can be visualized as having multiple multimedia streams. Again, some of these multimedia streams can be deemed more important than the others. For example, one might choose to prioritize the wireless television in the bedroom over the one in the living room or kid's room. However, the current EDCA mechanism doesn't provide any differentiation between the stations belonging to the same AC. Moreover, the priority levels supported by the IEEE 802.11e are rather limited in number, 4 among different QSTAs and 8 for internal traffic.

In [9], the authors introduced the concept of random AIFSN mechanism to achieve finer priority levels within an AC. Each AC is assigned an AIFSN interval so that, prior to a transmission attempt, the QSTAs choose a random AIFSN value which is an integer drawn from a given probability distribution function (PDF) defined over the AIFSN interval assigned to their AC. The proposed scheme does not lead to desynchronization among different QSTAs as in [8] because at any given time the stations choose integer AIFSN values albeit in a random manner, causing the expectation of AIFSN to be an non-integer value. Thus the priority level of different streams belonging to the same AC but different stations can be fine tuned by assigning appropriate probability distribution for picking up the AIFSN value.

In this paper, we extend the work in [9] to include a comparison with random CWmin scheme and also present some testbed results to show the actual improvement.

The outline for the remainder of the paper is as follows. In Section 2, we review the operation of 802.11e. The proposed mechanism is described in Section 3. Section 4 presents some simulation results examining the operation of proposed mechanism. Some testbed results are also provided to verify the practicality of the proposed method. Finally, we draw conclusions from this work in Section 5.

II. EDCA

IEEE 802.11e specifies a contention-based channel access method, called enhanced distributed channel access (EDCA). The EDCA mechanism provides QoS differentiation by grouping traffic into ACs with different priorities. There are eight priority values: {7, 6, 5, 4, 3, 0, 2, 1}, just like in 802.1D, out of which at least 4 are mandatory to be implemented. Traffic prioritization is accomplished by using the EDCA parameters - AIFSN, CW, and transmission opportunity (TXOP) - defined on a per-AC basis.

Prior to each transmission when the medium is busy, a station will defer until the medium is determined to be idle without interruption for a period of time equal to the AIFS for that queue (AIFS[*i*]) when the last frame detected on the medium was received correctly. Note that AIFS[*i*] is variable, assigned either by a management entity, or by the AP and measured in time is equal to the integer AIFSN[*i*] multiplied by the slot time plus SIFS.

The integer AIFSN must be greater than 2 for stations, and greater than 1 for the AP. In this way the AP has a higher priority for this channel access mechanism. The values of AIFSN for the different ACs is advertised in the beacons and probe response frames transmitted by the AP.

Similarly the minimum and maximum contention window limits are not fixed per PHY, as with DCF, but are variable values, assigned to each traffic category either by a management entity or by the AP. In this way each output queue contends for transmission opportunities. At each transmission opportunity, a traffic scheduling entity selects a frame for transmission. If the backoff timers for more than one queue reach zero at the same slot, then the frame from the highest priority queue is transmitted. These lower priority queues will treat this as a collision and will set their contention window values, as if they had experienced a transmit failure. The subtle difference is that retry bits are not set, as it would be done after an actual external collision on the wireless medium. The effect of the backoff procedure is that when multiple stations and/or queues of equal priority at one or more enhanced stations are deferring and go into random backoff, then the entity selecting the smallest backoff time using the random function will win the contention.

In the case of queues of unequal priority at enhanced stations, queues with shorter AIFS[i] periods will win the contention. Higher-priority queue will lose the contention if its AIFS is longer. In the case of a collision the contention window increases in the same way as for the DCF. Provided

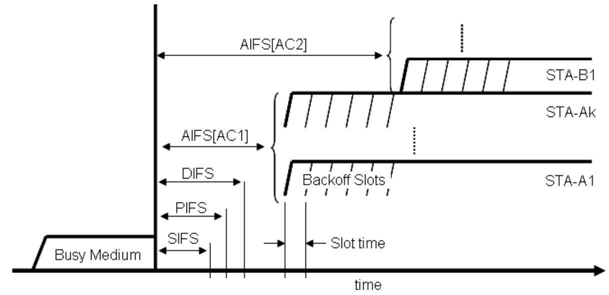


Fig.1 EDCA channel access mechanism

that the contention window is less than the maximum it is replaced by (CW[AC]+1)×2-1. Then another uniformly distributed backoff counter out of this new, enlarged CW is drawn with a uniform distribution over the range [0,CW[AC]] inclusive, to reduce the probability of a new collision. The CW never exceeds the parameter CWmax[TC], which is the maximum possible value for CW. The CW is reset to CWmin after every successful attempt to transmit, or when the long and short retry counters reach a certain limit. Assigning shorter contention windows to data with higher priority ensures that on average higher-priority data will get through before lower priority data. This mechanism ensures traffic separation within an AC as shown in Fig. 1. It is apparent that when the number of stations within an AC are increased, the probability of two or more stations choosing the same back-off value leading to packet collision are increased.

III. PROPOSED RANDOM AIFSN METHOD

According to the proposed scheme shown in Fig. 1, as with IEEE 802.11e, traffic prioritization is accomplished by using the AIFSN, CW, and transmission opportunity (TXOP) - defined on a per-AC basis. Just like in the EDCA prior to each transmission when the medium is busy, a station will defer until the medium is determined to be idle without interruption for a period of time equal to the AIFS for that queue (AIFS[*i*]) when the last frame detected on the medium was received correctly. However instead of being fixed, AIFSN is a discrete random variable taking values over the interval [*N*[AC], *M*[AC]], where *N* and *M* are predetermined integers specific to an AC. It must be noted that *N*[AC] and *M*[AC], as well as the probability density function of the discrete random variable AIFSN are variables, assigned either by a management entity,

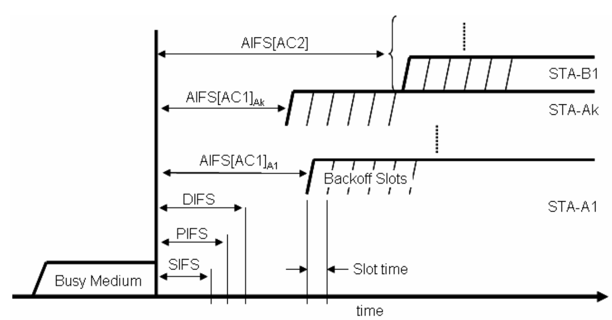


Fig. 2 Proposed channel access mechanism

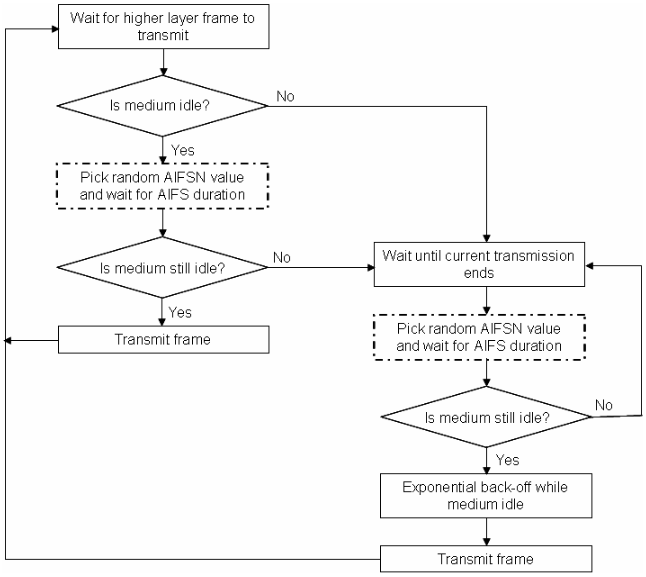


Fig. 3 Proposed medium access control logic

or by the AP. Such a mechanism reduces the number of stations within an AC choosing the same AIFSN value by a factor of (*M*-*N*+1), thus further reducing the probability of two or more stations choosing the same back-off value. The reduced packet collision probability results in greater channel access opportunity for the nodes belonging to other ACs as illustrated in Fig. 2. For the sake of completeness, Fig. 3 illustrates the proposed medium access control logic. The boxes with broken border depict the major difference between the proposed control logic and the EDCA mechanism. Instead of a fixed AIFSN value, a random AIFSN value is used.

IV. EVALUATION

In this section, we present simulation results to compare the performance of the proposed medium access scheme against the baseline IEEE 802.11e EDCA MAC. The simulation results are generated using the OPNET simulation tool. All stations are assumed to have IEEE 802.11g PHY layer and operate at 54Mbps PHY rate. Also, the default IEEE 802.11e EDCA parameters are assumed unless specified otherwise. Furthermore, for the ease of analysis, we assume that each QSTA has only one active AC. The performance of the proposed scheme is evaluated for the following two different scenarios.

A. Simulation Results

1) Finer Prioritization within an AC: We consider a typical home networking scenario as shown in Figure 4. There are three video streams and optional BE and voice streams. Now as the available bandwidth fluctuates, the performance of all 3 video streams is affected. If there is not sufficient available bandwidth for all 3 streams, then the current EDCA channel access mechanism would lead to performance deterioration for all 3 TVs. In the following, we show how the proposed random AIFSN mechanism can be used to allow for finer prioritization among the video streams without affecting the performance of higher priority traffic.

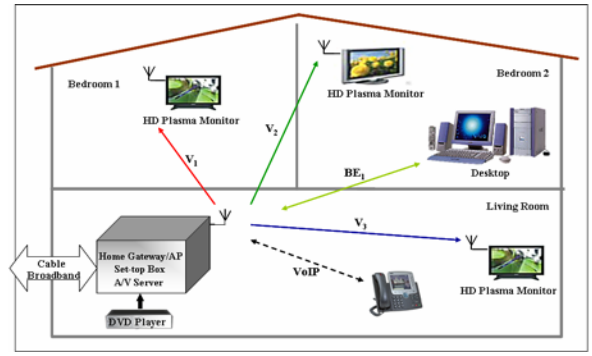


Fig. 4 Typical home networking scenario

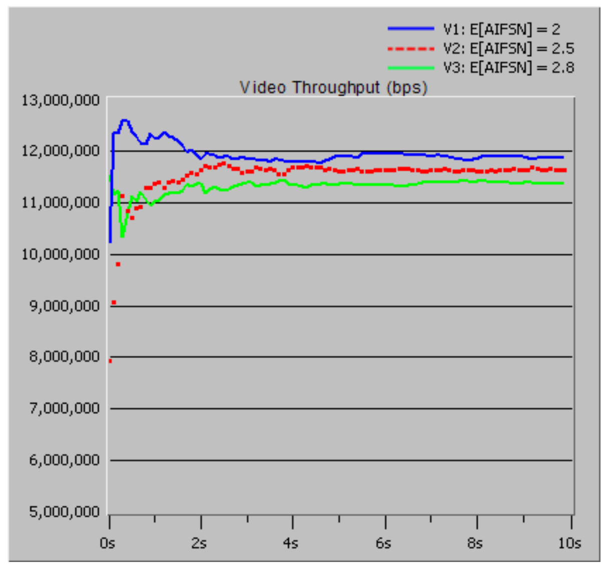


Fig. 5 Network with 3 video streams

Let us assume default EDCA parameters for all ACs except for video which choose AIFSN value from the interval {2, 3}.We further assume that the 3 video streams, choose the AIFSN value using the Bernoulli distribution (1) with different mean outcomes so that each video stream has unique mean AIFSN value.

$$P_{AIFSN}(AIFSN) = \begin{cases} p_i & AIFSN = 2 \\ 1 - p_i & AIFSN = 3 \end{cases} \qquad (1)$$

For a video stream, V_i, the mean AIFSN value is given by

$$\mathrm{E}[AIFSN] = 3 - p_i \qquad (2)$$

We choose $p_1 = 1$, $p_2 = 0.5$ and $p_3 = 0.2$, so that V_1 is assigned the smallest mean AIFSN value of 2 followed by 2.5 and 2.8 for V_2 and V_3 respectively.

Figure 5 shows the mean throughput curves for the three video streams under the assumption that no other traffic exists.

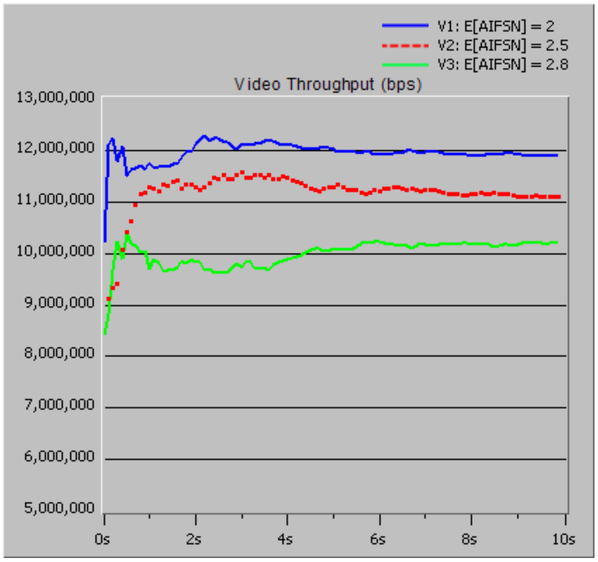


Fig. 6 Network with 3 video and 3 voice streams

It is apparent that the throughput performance of the three video streams is in accordance with their mean AIFSN values. However, there is not much separation between the curves because of sufficient available bandwidth. Thus all three TV streams enjoy good transmission quality.

Figure 6 shows the mean throughput curves for the three video streams in the presence of 2 voice traffic streams. It is evident, that V_1 is still able to maintain 12 Mbps transmission rate whereas V_2 and V_3 observe a decline in throughput due to less channel access opportunities in the presence of higher priority traffic. Note that a similar effect would be observed if the bandwidth availability is reduced due to PHY layer limitation. From Figures 5 and 6, we can conclude that random AIFSN mechanism is an effective method to assign finer prioritization with an AC.

2) *Traffic Spread using unifrom PDF:* We consider the following scenario as depicted in Figure 7. All the traffic is routed through the AP. For the proposed random AIFSN mechanism, all three ACs are assumed to use the default EDCA parameters [1] except for video AC which draws its AIFSN value from the set {2, 3}. Moreover, the video QSTAs use uniform distribution to determine the AIFSN value prior to each transmission attempt. We also consider an algorithm where the backoff value is picked from the set [0,CW] or [1, CW] with equal probability (which leads to triangular distribution for backoff value) inorder to distinguish it from the proposed random AIFSN mechanism.

Figure 8 presents the average number of retransmissions per AC. It is evident that the proposed scheme leads to reduced collisions for voice and video packets as there are less packets using AIFSN = 2. Whereas, the collisions for the best effort (BE) packets increases because of the large number of packets using AIFSN = 3. Also it should be noted that the proposed random AIFSN scheme has entirely different impact than making CW range random which performs similar to EDCA.

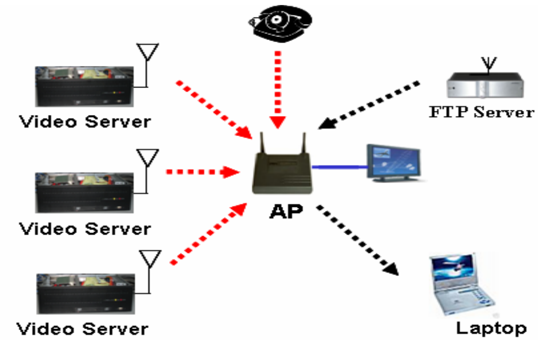


Fig. 7 Network topology

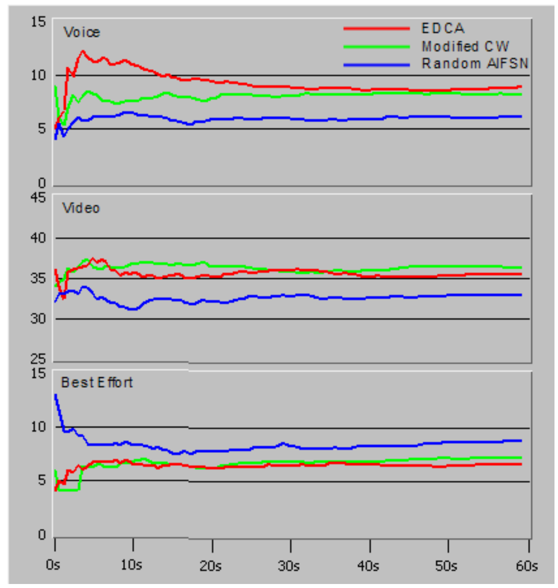


Fig. 8 Average number of retransmissions

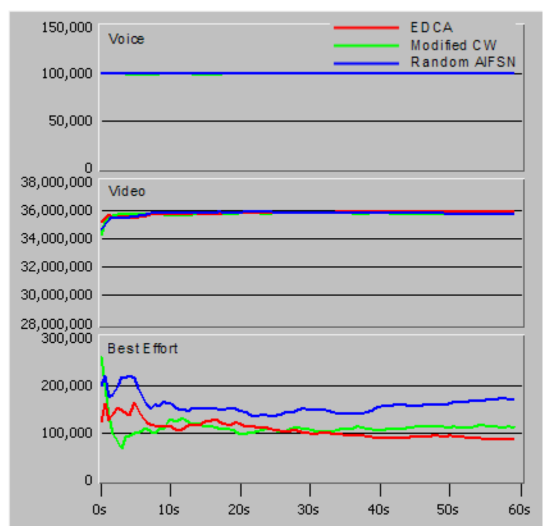


Fig. 9 Average throughput per AC in bits/sec

Figure 9 presents the mean throughput per AC. It is evident that the proposed scheme leads to throughput improvement for best effort traffic as it reduces the collisions and leads to efficient channel usage. Finally, Figure 10 illustrates the delay performance for the same scenario. It is

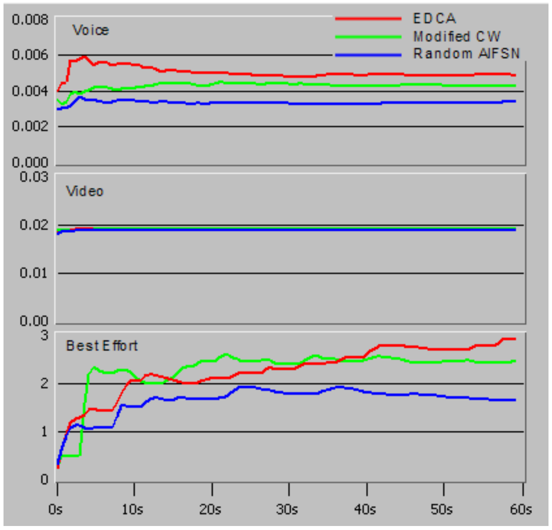


Fig. 10 Mean delay for different ACs in secs

evident that the proposed method reduces the end to end delay across all ACs. In particular, the delay for the voice traffic is reduced by 50%. This can be attributed to the fact that video QSTAs no longer use a fixed AIFSN value of 2 which is also used by voice streams. Thus, the voice traffic can have more frequent channel access leading to reduced delay.

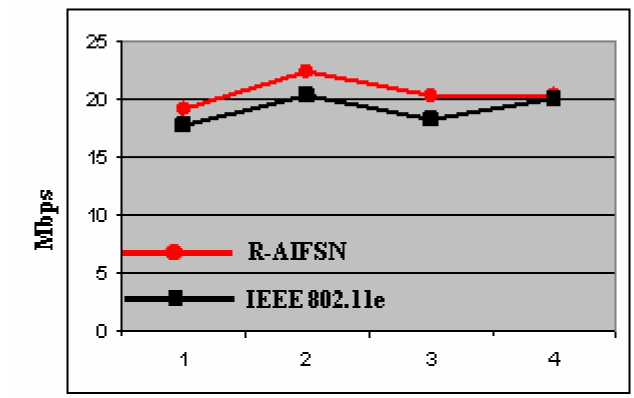
B. *Testbed Results*

In this section, we evaluate the proposed random AIFSN concept through an experimental testbed comprising of D-Link DWL G520 WLAN cards. An Open Source driver called Madwifi [10] is used to control the behavior of the Atheros chipset. Madwifi is a multi-core driver module that comprises of (i) a PCI hardware module for interfacing with PCI I/O bus, (ii) Atheros chipset specific module that acts as the glue between the hardware registers and the driver software, (iii) a device independent module which implements the IEEE 802.11e state machine.

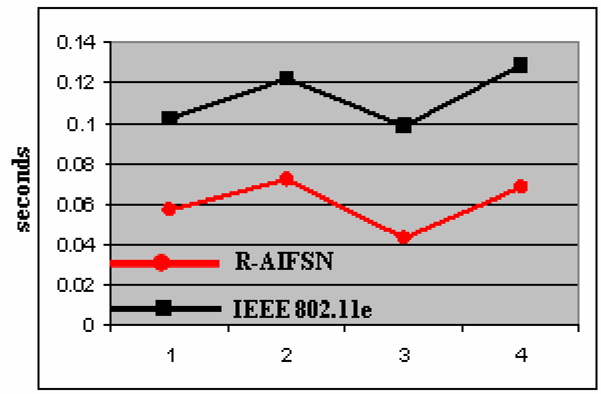
The experimental testbed used to evaluate the performance of the random AIFSN scheme is same as in Figure 4 with the exception of voice stream. All the stations have a PCI based Atheros WNIC cards. The AP is configured to create an IEEE 802.11e/g network operating in 2.462 GHz radio spectrum in Infrastructure mode. It uses the DHCP daemon to assign IP addresses to the wireless clients.

Table 1 Key simulation parameters (54 Mbps 802.11g PHY)

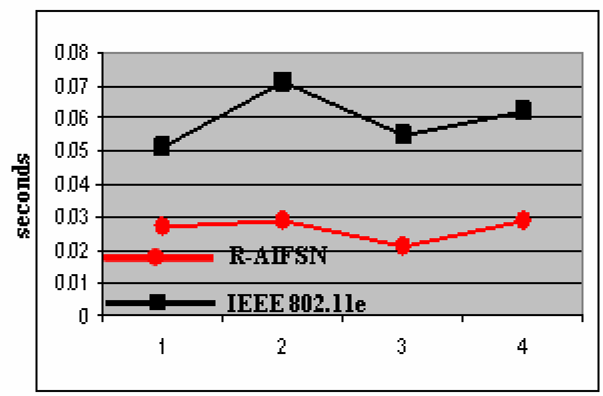
Parameters	**Video**	**B.E**
AIFSN (802.11e)	2	3
R-AIFSN Algorithm*	Uniform Random [2,3]	3
CWmin	7	15
CWmax	15	1023
TXOP	3008	1 MSDU
Band	2.462 GHz	



(a) Total throughput



(b) Delay

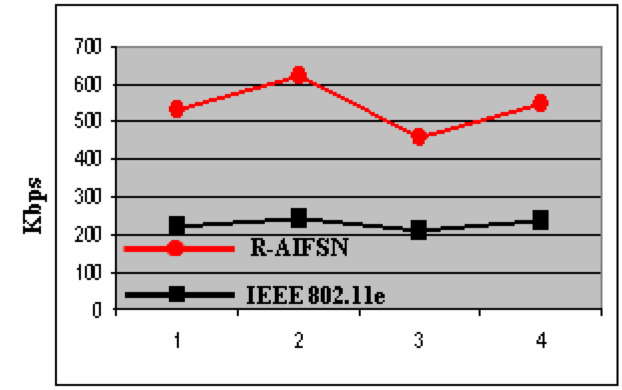


(c) Jitter

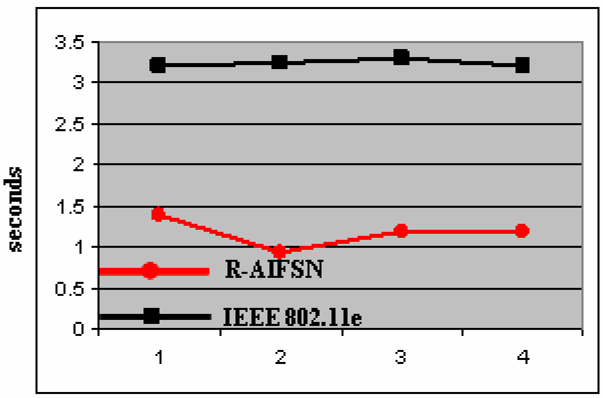
Fig. 11 Comparative video performance

Three different metrics – throughput, delay and jitter – are used to quantify the video performance. The x-axis denotes the observation numbers. It is evident from Fig. 11 that random AIFSN technique offers an improvement for all three metrics. While the throughput improvement is not significant, the random AIFSN technique offers significant improvement in delay and jitter, both reduced by a factor of 2.

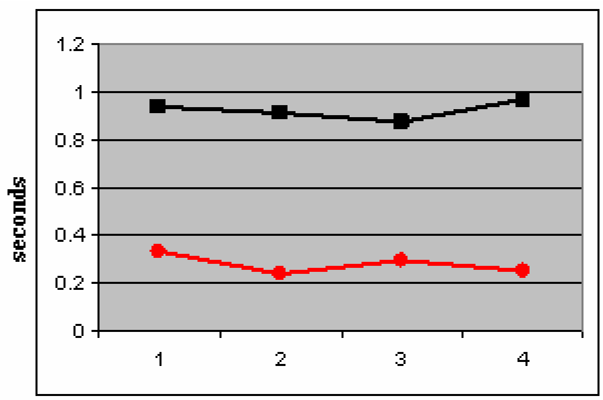
Figure 12 shows the comparative performance of random AIFSN technique against IEEE 802.11e EDCA for the best effort traffic. It can be observed that the throughput of best



(a) Total throughput



(b) Delay



(c) Jitter

Fig. 12 Comparative best-effort performance

effort increases by almost 250% whereas the delay and jitter are reduced by a factor of 3 and 4 respectively. These results follow similar trends as OPNET simulation results which indicate significant gains in best effort throughput and delay.

CONCLUSION

This paper advances an improvement to the EDCA mechanism in IEEE 802.11e, where the AIFSN is not a deterministic number, but random. The range of values of this random number and the probability density function for every AC are different. These are assigned by the AP, or by a management entity and may be updated dynamically. The proposed technology is advantageous especially when there are priority levels at which several streams are being transmitted. The benefits of the proposed mechanism are several. First, it leads to fewer collisions among streams transmitted at the same priority level. Second, it leads to higher throughput and reduced latency. Third, it leads to higher throughput even for streams transmitted at other priority levels that do not implement random AIFSN, but fixed AIFSN. Fourth, the proposed technology allows the prioritization of traffic streams that belong to the same AC by assigning to these streams different probability density functions for the AIFSN. The proposed method leads to improved overall network performance and is effective to assign finer prioritization with an AC.

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