A Traffic-aware Mechanism to Adjust Contention Window in 802.11e Wireless LANs

Azadeh Pirhayati
M.S. of Computer Engineering, Science and Research Branch, Islamic Azad University, Hamedan, Iran,
pirhayati.azadeh@gmail.com

Mohammad Nassiri
Assistant Prof, Faculty of Engineerii
Bu-Ali Sina University, Hamedan
m.nassiri@basu.ac.ir

ABSTRACT

IEEE 802.11e standard is proposed to support Quality of Service (QoS) in wireless local area networks (WLANs). The distributed access method of 802.11e, Enhanced Distributed Channel Access (EDCA), prioritizes traffic generated by delay-sensitive applications by increasing probability to access medium for this type of traffic. EDCA resets the Contention Window (CW) of mobile stations to a minimum value after each successful transmission. This static behavior is not adapted to dynamic conditions of wireless network as it degrades network performance when channel access requests increases.

Several mechanisms focusing on network adaptation have been proposed to improve the performance of IEEE 802.11e standard. The main limitation for these approaches is slow adaptation to the network state when the channel experiences bursty traffic.

In this paper, we propose a new dynamic approach for contention window adjustement for each Access Category (AC) according to the traffic and network conditions. We compare our proposal with the IEEE 802.11e EDCA standard as well as some other mechanisms in the literature. Simulation results show that our proposed approach outperforms EDCA of 802.11e as well as some other enhancement to the standard present in the literature.

Keywords

Wireless LANs, quality of service, contention window, IEEE 802.11e, EDCA, channel access.

1. INTRODUCTION

Today, most of the organizations, institutes and companies have provided their customers with local wireless networks. This has come true by establishing 802.11-based access points. The IEEE 802.11 standard in WLANs designed mainly for *best-effort applications.* It is wellknown that best-effort services never guarantee bandwidth, delay, error, quality of service, etc [1]. Due to the capacity limitations of wireless media, the 802.11 wireless LAN becomes a bottleneck for communication.

Moreover, providing quality of service over 802.11 wireless networks is quite challenging because both physical layer and medium access control sub-layer are designed for best effort data transfer.

Therefore, the 802.11e standard has been proposed to provide quality of service for multimedia traffic in wireless LANs. In other words, the objective was to reduce end-to-end delay and jitter for packets belonging to multimedia traffic [2].

The Hybrid Coordination Function (HCF) of 802.11e is used for medium access control. HCF comprises the contention-based Enhanced Distributed Channel Access (EDCA) and the centrally controlled Hybrid Coordinated Channel Access (HCCA). EDCA allows for four different access categories (ACs) at each station and a transmission queue associated with each AC. Each AC at a station has a module responsible for channel access. This module uses a set of static parameters like CW, AIFS, etc. However, using EDCA of IEEE 802.11e with static configuration of its parameters does not provide high quality of service for multimedia applications. This static behavior is not adapted to network state since it reduces the network performance and results in poor link utilization when channel access requests increases [3]. Several techniques have been proposed to improve the performance of IEEE 802.11e by adapting contention window to the network state [4, 5, 6, 7, 8, 10, and 11]. Although these techniques are all enhancements to EDCA, their main limitation is their slow adaptation to the network state when the channel experiences bursty traffic.

The rest of this paper is organized as follows: The next section briefly describes 802.11 DCF and 802.11e EDCA mechanisms. In Section 3, we review the state of the art. In Section 4, we propose our traffic-aware solution. In the next section, we evaluate our proposed mechanism and we compare its performance with some mechanism in the literature. Finally, in Section 6, we conclude the paper.

2. MEDIUM ACCESS CONTROL IN WIRELESS NETWORKS

In this section, we briefly review DCF and EDCA access method for wireless networks.

2.1. IEEE 802.11 Medium Access Control Layer

IEEE 802.11 standard has an access mechanism contention-based called "DCF". Distributed Coordination Function (DCF) uses Carrier Sensing Multiple Access with Collision Avoidance (CSMA/CA) mechanism [1]; that is the station wants to send a packet, monitors the channel until it is idle, and then it waits for a period of Distributed Inter-Frame Space (DIFS) length. After a DIFS period, the mobile station selects a random back off timer (time slots) within a back off window. The back off timer is within the interval [0, CW-1]. Counter value does not change when other stations are sending packets. The back off timer is decreased continuously when the medium is idle. When the back off timer is zero, the station has permitted to transmit and access to the medium.

CW is a value between [CW$_{min}$, CW$_{max}$]. In the first transmission, the CW value is equal to the initial value (CW$_{min}$). After each successful transmission, CW value is reset to CW$_{min}$. When a failure occurs, the mechanism tries to prevent stations sending packets simultaneously, and then CW value is doubled up to CW$_{max}$.

After transmitting a packet, the station expects to receive an acknowledgment (ACK) from the destination station after Short Inter-Frame Space (SIFS) time. If the acknowledgment is not received, the sender assumes that the transmitted packet was collided, so it schedules a retransmission and enters the back off process again.

Each station is only permitted in the beginning of each slot time. Generally, in DCF, all stations compete for resources and channels with the same priority and just support best-effort services. This service does not provide any distinct mechanism to support bandwidth, packet delay and jitter of high-priority traffic or multimedia streams [3, 6, and 9]. Medium Access Control Parameters are SIFS, DIFS, CW$_{min}$, CW$_{max}$ and Slot time.

2.2. IEEE 802.11e Medium Access Control Layer

IEEE 802.11e standard has a media access mechanism called "EDCA". This mechanism is based on contention. QoS in EDCA is provided with traffic classification into four types of Access Categories (ACs). These groups compete for access to the channel, and each AC has different priority of channel access. There are four parallel queues in each 802.11e station, which send packets. As Table 1 shows, for each AC four parameters are defined as:

- **AIFS[i] parameter which is the initial expectations for an empty channel,**

- **CW$_{min}$[i] parameter which is the initial size of CW,**
- **CW$_{max}$[i] parameter which is the maximum size of CW,**
- And TXOPlimit[i] parameter which is the number of frames that can be sent without the contention for channel access. "i" is the AC priority value known as 0 for video stream traffic (AC-VI), 1 for voice stream traffic (AC-VO), 2 for best-effort traffic (AC-BE) and 3 for background traffic (AC-BK).

Table 1: Access Categories and IEEE 802.11e parameters

Access Category (AC)	AC_VO	AC_VI	AC_BE	AC_BK
priority	0	1	2	3
AIFS	2	2	3	7
CW$_{min}$	7	15	31	31
CW$_{max}$	15	31	1023	1023
TXOPlimit	0.003008	0.00601	0	0

In EDCA like DCF Stations, each AC monitors the channel. If the channel is idle, the waiting time interval is equal to Arbitration Inter-frame Space (AIFS) length. A random timer in the interval [1, CW+1] is chosen and the countdown begins. When the back off timer is zero, the AC is permitted to transmit and access to the medium. In EDCA after each collision, the CW value is calculated based on equation (1). The current size of CW is CW$_{cur}$ [2].

$$CW_{cur}[AC] = 2 * CW_{cur}[AC] + 1 \qquad (1)$$

In This mechanism after successful transmission, the size of CW in AC[i] decreases to CW$_{min}$[i]. As seen in Table 1, higher-priority traffic parameter in EDCA is not as much as those of the lower-priority traffic. Hens, higher-priority traffic will enter the contention period and access the wireless medium earlier than the lower-priority traffic. For example, if "i" has lower priority less than "j" and equation (2) is proven.

$$CW_{cur}[i] > CW_{cur}[j] \qquad (2)$$

In IEEE 802.11e, whenever a station reaches the channel, it will be able to transmit one or more frames for a Transmission Opportunity time interval (TXOP). Txop length is defined by a parameter called TXOPlimit [2].

The main problem of EDCA in WLANs is that the values of parameters of each AC are static, and they ignore the wireless channel conditions.

Figure 1 shows the EDCA mechanism of IEEE 802.11e.
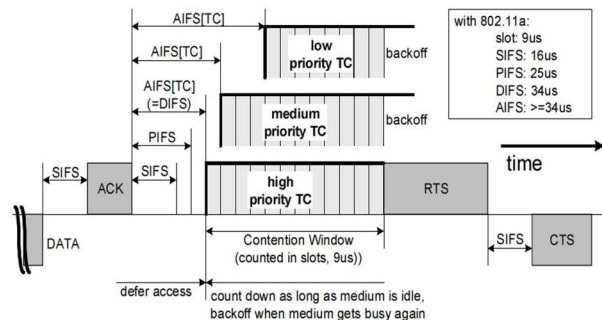
Figure 1: IEEE 802.11e EDCA channel access

3. RELATED WORKS

In [4], to improve the performance of IEEE 802.11e standard, a new technique has been proposed at unusual loading rates. This technique which refers to as Collision Rate-based Adaptive EDCF (CR-AEDCF) improves transmission of different categories of EDCA networks such as voice, video, etc.

CR-AEDCF technique after each collision or after a successful transmission changes CW value with dynamic procedural. When a collision occurs, the probability of more collision occurrence grows. After successful transmission of each packet, CW value is slowly reduced to avoid more collisions.

In this technique, CW value is based on three factors:

The first factor is current CW value. The second factor is the estimated average of collision rate at each station, and the third factor is the priority difference in each AC.

It is obvious that to AC with higher priority a small CW value is assigned, so it can access the medium earlier than other ACs.

Estimated Collision rate "F_{col}" is equal to the number of occurred collisions divided by the total number of packets sent from a station at a fixed time interval, and it is always a value between [0, 1]. To smooth the estimated values and to minimize the number of temporary collisions, they use an Exponentially Weighted Moving Average (EWMA) estimator. Average collision rate from equation (3) is obtained.

$$\bar{F}_{col} = (1 - \alpha) * \bar{F}_{col} + \alpha * \bar{F}_{cur} \qquad (3)$$

Alpha (also called the smoothing factor) effectively determines the memory size used in the averaging process.

Using the average collision rate, a Multiplicative Factor MF[i] is calculated, and it determines priority of ACs. The MF is defined in equation (4) and has a maximum value of 0.8.

$$MF[i] = \min((1 + (i * 2)) * \bar{F}_{col}, 0.8) \qquad (4)$$

Priority range varies from 0 up to 3, thus each AC takes a different Multiplicative Factor. The previous value of the CW (CW_old[i]) is multiplied by the size of each MF to achieve a new CW. In CR-AEDCF technique after a successful packet transmission, CW value is obtained from equation (5). This value is never less than CW_min.

$$CW_{new}[i] = \max(CW_{min}[i], CW_{old}[i] * MF[i]) \qquad (5)$$

In this technique when collision occurs, unlike the EDCA mechanism the size of CW can not be duplicated. Each AC uses a Persistence Factor (PF[i]) to increase the CW value. Obviously, despite the traffic with lower priority, the traffic with higher priority has fewer Persistence Factors. New collision probability will be reduced by using the PF and results in low latency. In CR-AEDCF technique, brand new value of CW will be obtained after each collision using equation (6).

$$CW_{new}[i] = \max(CW_{min}[i], CW_{old}[i] * PF[i]) \qquad (6)$$

It is expected that the CR-AEDCF technique improve the efficiency of all kinds of traffic ave. arely and perform EDCA mechanism that is used in 802.11e with adaptive CW change.

In [5], a simple Static Slow Decrease (SSD) scheme was evaluated. The main purpose of this scheme is to slowly decrease CW values by employing a static factor (with a value of 0.5). In SSD, the new value of CW after each successful transmission is calculated from equation (7). It is obvious that such an approach is unsuitable for all network conditions.

$$CW_{new} = 0.5 * (CW_{curr} - CW_{min}) + CW_{min} \qquad (7)$$

In [7], a Simple Recursive Adaptive Enhanced DCF (SR-AEDCF) technique uses dynamic network state to reduce the CW value. In this approach, we need to get the channel state information to adjust the CW value. SR-AEDCF technique uses an indirect recursive technique to reduce the size of CW, instead of direct measurements of the collision rate in CR-AEDCF technique.

In SR-AEDCF technique, network congestion level is obtained from previous CW values. CW value varies between CW_{min} and CW_{max}.

When the channel is crowd, CW value is near to CW_{max} and when the channel is idle, CW value is close to CW_{min}.

According to above, channel congestion level can be calculated using equation (8).

$$channel = CF * \left(\frac{CW_{cur} - CW_{min}}{CW_{max} - CW_{min}} \right) \qquad (8)$$

Confidence Factor (CF) has high weight between zero and one when the time interval between successive sent is in the millisecond range. When the interval is in the range of seconds or minutes, the weight is low.

Since CF maintains differences between the four groups, the audio and video applications should have higher weights. The CF value is obtained from equation (9). This function results in maximum 0.7 in short time interval and minimum 0.4 in the long-time interval.

$$CF = 0.3 * exp(-0.001t) + 0.4 \qquad (9)$$

After each successful transmission packet, a wireless node should decrease the CW to a value less than the current value of CW (CW_cur). Since equation (8) gives a value in the range of 0 to CF, equation (10) estimated distance precisely.

$$d = channel * (CW_{cur} - CW_{min}) \qquad (10)$$

Equation (11) that reduces the CW value in the SR-AEDCF technique, obtained by replacing equation (10) in CW_new=CW_min+d:

$$CW_{new} = CW_{min} + channel * (CW_{cur} - CW_{min}) \qquad (11)$$

Equation (8) generates a value close to zero when the channel is idle, and when it is congested, this equation produces a value close to 1*CF. Thus CW_{new} is a suitable view of the required counter value to send a given traffic priority considering the current network conditions.

Recently, a link adaptation strategy that provides differentiation not only at the MAC layer, but also at the PHY layer was proposed in [10, 7]. This strategy exploited the positive ACK procedure to evaluate the quality of the link. If the transmitter does not receive ACK frame, it concludes that the last transmission was failed. For each active link, a transmitter maintains two counters, a success counter and a failure counter. If a frame is successfully transmitted, afterwards the success counter is incremented by one, and the

failure counter is reset to 0. If the transmission fails, then the failure counter is incremented by one, and the success counter is reset to 0. These two counters are used to determine whether the quality of the link is good or not. The transmission rate is adjusted with respect to the link quality. Another recent approach that combines the slow decrease and the dynamic adaptation of CW was proposed in [11].

4. PROPOSED MECHANISM

In 802.11 and 802.11e standards when channel access demands increases, the CW value reduces to CW_{min}. It is proven that this static behavior is not effective in increasing channel performance [4, 12]. Since in a crowd wireless channel the collision probability is extremely high, the station may not success in transmitting its data and may decide to increases CW value to CW_{max}.

However, by reducing channel usage, collision probability will be decreased and CW value approach to lower values (near to CW_{min} and far from CW_{max}), by increasing the probability of collisions CW value will come close higher values (far from CW_{min} and near to CW_{max}).

The proposed technique called "mix-AEDCF" uses the network state information and estimated collision rate. Estimated collision rate "CR" is equal to the number of collision occurred divided by the total number of packets sent in a second. Since when the channel is idle, the collision rate is low (near to zero) and when the channel is congested the collision rate is high (close to one), collision rate can be a suitable factor to determine CW value in this method.

Like SR-AEDCF technique, a measure of network collision level is obtained from the CW_{cur}-CW_{min} divided by CW_{max}-CW_{min} to use the network state information. Since CR growing is related to the amount of collision; this rate can be used to estimate the confidence factor. It means that congestion level (CL) obtains from equation (12):

$$ \square\square = \square\square * \square\frac{\square\square_{\square\square\square} - \square\square_{\square\square\square}}{\square\square_{\square\square\square}\ \square\square\square_{\square\square\square}}\square \qquad (12) $$

After successful transmission of each packet, CW value will be decreased to a lower value than the current CW value CW_{cur}. This reduction is equal to distance size of CW_{cur}-CW_{min} at max. Estimated distanced is obtained from Equation (13).

$$ \square = \square\square * (\ \square\square_{\square\square\square} - \square\square_{\square\square\square}\ ) \qquad (13) $$

By substituting equation (12) in (13) and add it to the minimum value of CW, new value of CW is obtained. Equation (14) shows the CW value in proposed method mix-AEDCF after each successful transmission.

$$ \square\square_{\ \square\square\square} = \square\square_{\ \square\square\square} + \square\square * \square\frac{\square\square\square_{\ \square\square\square} - \square\square_{\ \square\square\square}^{\square}}{\square\square_{\ \square\square\square}\ \square\square\square_{\ \square\square\square}}\square \qquad (\square\square) $$

5. PERFORMANCE EVALUATION

SR-AEDCF and CR-AEDCF provide distinct mechanisms to determine dynamic network conditions. SR-AEDCF relies only on the current CW value to accurately evaluate channel performance and decide on the next CW.

In contrast, CR-AEDCF relies on statistics by keeping record of the number of all packet drops and the number of all transmitted packets. In this technique, any decision depends on the number of all lost packets, and algorithmic problem is a delay in being coordinated with the current channel

conditions. This contradicts with the nature of wireless systems, which tumble fast due to many factors. It is proven that SR-AEDCF technique adapts with network conditions rapidly. In next discussions, the existing techniques are evaluated using simulation.

To evaluate SR-AEDCF, CR-AEDCF techniques and mix-AEDCF proposed technique in comparison with 802.11e, focus on three parameters: 1- Throughput that is the number of bits transmitted per second. 2- Packet loss rate that is the number of lost packets before reaching their destinations. 3- End-to-end delay is the time to reach the packet to the destination. These parameters provide the QoS support clearly.

5.1. Simulation Topology

The simulation scenario consists of eight mobile nodes. Source nodes are numbered from 0 to 3 and destination node are from 4 to 7. Each node has a different priority being sent. Node 0 has taller priority than Node 1 and Node 1 has higher priority than Node 2 and etc. Each source has a fixed bit rate of 600 kilo bits per second (kbps) over the user datagram protocol (UDP) Sends. UDP is a connection less protocol at the transport layer that does not congestion control and does not guarantee packet transmission. In this scenario, the size of packets sent is 512 bytes and all nodes are in other's ranges. Figure 2 shows the simulation topology. To simulate the network simulator NS-2 [13] version 2.34 has been used. Node 0 in second 0, node 1 in second 10, Node 2 and Node 3 in sec 20 and sec 30 will start sending packets. Figures contained in each section, show an average of 10 times run the simulations.
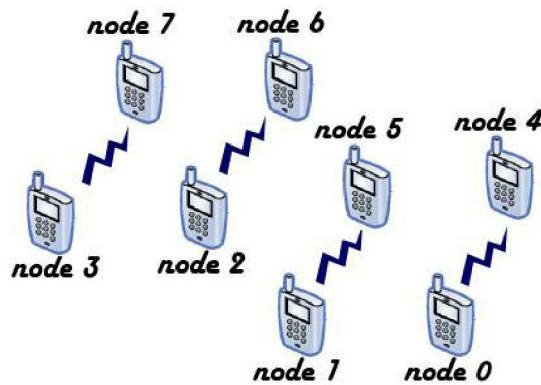

Figure 2: Simulation Topology

5.2. Throughput

The first criterion for evaluating techniques is the throughput. Throughput is the number of bits transmitted per second. This measure is determined by the destination node and determines show much data is transmitted in every node in the network. The throughput of each technique is calculated in each AC, and they are compared. In second 10, node 0 has only one sender and can occupy the entire available bandwidth, but with the increasing number of transmission nodes, throughput graphs show large fluctuations.

In comparison technique, the node with the highest priority (node 0), the CR-AEDCF performs better. The next

priority of the nodes 1, 2 and 3 of the proposed technique gives the highest throughput and other techniques are nearly constant throughput.

Since the nodes with lower priority are not denied access to the wireless network, the performances different of techniques on nodes 2 and 3 are common. Figure 3 and 4 show results of compared throughput for techniques to best-effort and background ACs. As you can see, by increasing the number of outgoing nodes, throughput of techniques decreases.

In Figure 3 you can see, the proposed technique mix-AEDCF compared to the others offers the highest throughput. Subsequently, the SR-AEDCF technique has high throughput and minimum throughput is depicted in CR-AEDCF technique.

In Figure 4 that is for background AC, the proposed technique has the highest throughput and after about 53 seconds of simulation, other techniques have work similar and 53 seconds later the SR-AEDCF technique works better than the 802.11e and CR-AEDCF technique offers the lowest throughput.

5.3. Packet Loss Ratio

The second measure is packet loss rate. This measure calculates the number of packets lost before reaching the destination. Packets are lost in transmission and provide the number of collisions at each node. Study on packet loss rate in a node gives different views about the impact of the adaptive algorithm is applied to the node. This can not be obtained from a measure of the throughput efficiency strictly.

Figures 5 and 6 show the missing packages sent divided by the packet sent in two best-effort and background ACs. As you can see in Figure 5, the proposed technique mix-AEDCF has the lowest percentage of lost packet and the percentage of missing packets CR-AEDCF more than all; SR-AEDCF technique also lost packets is less than the 802.11e and shows a better performance. It is clear from Figure 6 that in the background AC, the proposed technique has the lowest percentage of lost packet, and other techniques are more packet loss rate. Two measures of throughput and packet loss rate, clearly the proposed technique mix-AEDCF to adapting CW value with considering channel conditions is best.

Figure 3: Throughput Comparison for the Best-Effort Access Category (AC-BE) in node 2
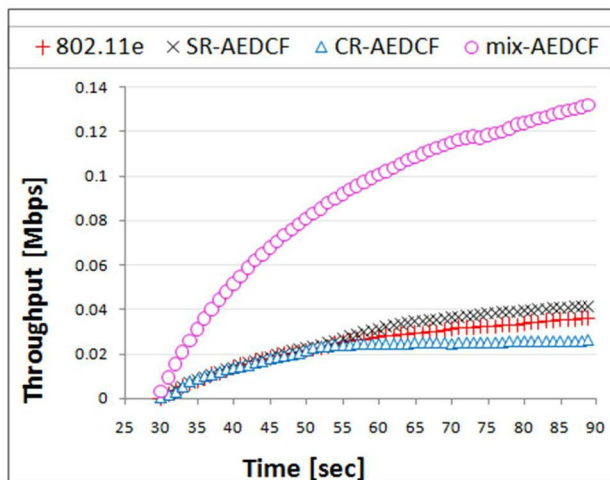
Figure 4: Throughput Comparison for the Background Access Category (AC-BK) in node 3
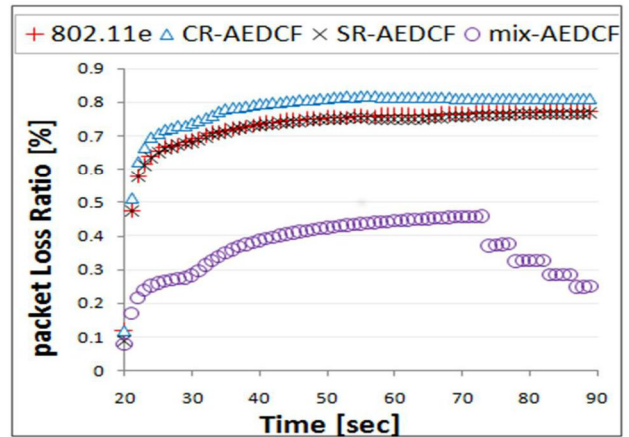

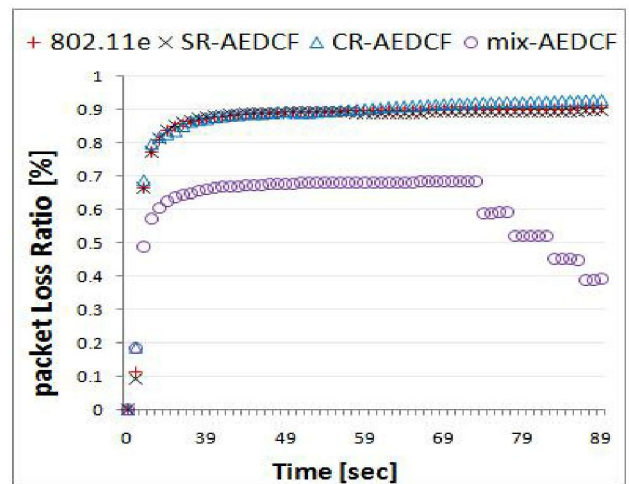Figure 5: Packet loss performance Comparison for the Best-Effort Access Category (AC-BE) in node 2

Figure 6: Packet loss performance Comparison for the Background Access Category (AC-BK) in node 3

5.4. Packet End-to-End Delay

The third criterion is measuring end-to-end delay of packets in each node. This measure calculates the arrival time of packets from source to destination. Packet delay represents the delay in wireless networks and reveals information that may not be derived from the missing data packet.

Figures 7 and 8 show the end-to-end delay in both nodes 1 and 3 for two video and background ACs. Inversing the transmitting nodes will increases delays time. For example, node 1 can compete to node 0, node 2 with two nodes 0 and 1 with higher priority.

In Figure 7, you can see that the minimum delay is in the proposed technique mix-AEDCF and then CR-AEDCF technique has less than delay. In SR-AEDCF technique to 65 seconds of simulation is more similar to 802.11e and after that has more delay.
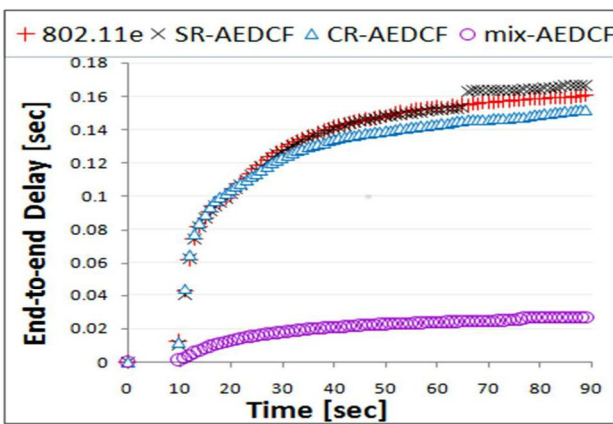

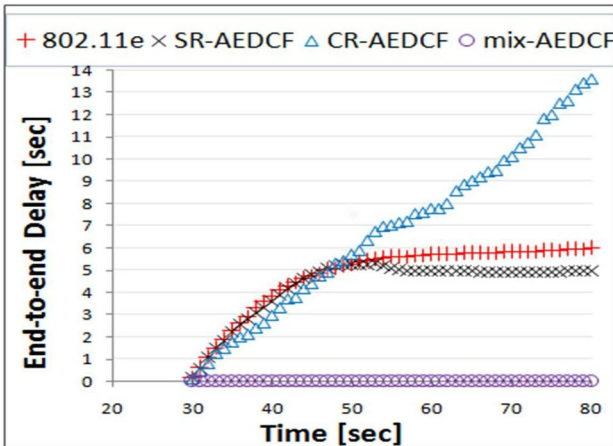**Figure 7: Packet end-to-end Delay for the Video Access Category (AC-VI) in node 1**

Figure 8: Packet end-to-end Delay for the Background Access Category (AC-BK) in node 3

As you can see in Figure 8, the proposed technique provides the best performance and the lowest latency. After 50 seconds of simulation, CR-AEDCF technique has the best performance and other techniques are similar. 50 seconds later the SR-AEDCF technique is more efficient and low efficiency is of the CR-AEDCF technique that has the maximum delay.

5.5. Transmitting at Equal Priorities

In this part of the scenario outlined in the techniques section 5.1 nodes with the same priority are competing. We will investigate obviously; the traffic with higher priority will be given prompt service. We assume that each of the four sources can produce traffic on the different queue and every 4 rows have the same priority. Each queue is chosen randomly by the server, and no priority traffic is given service. In this case, the bandwidth is divided equally between the nodes.

Figure 9 and 10 shows the throughput of the proposed technique in video and best-effort ACs in nodes 1 and 2. In Figure 9, you can see all the techniques are similar to 40 seconds and then SR-AEDCF has the best performance. Figure 10 shows that the throughput in mix-AEDCF proposed technique is higher than others.
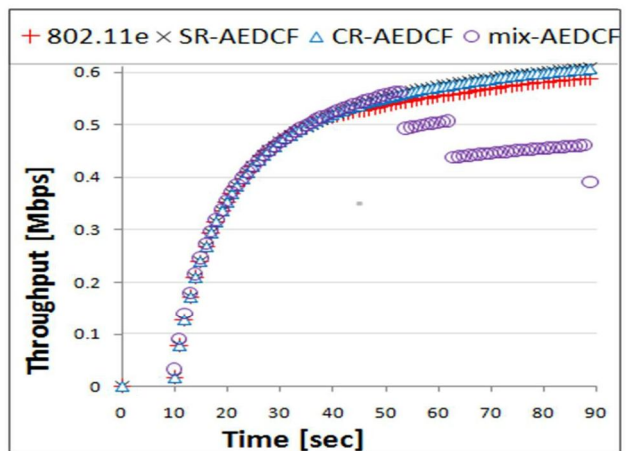

Figure 9: Throughput Comparison for the Video Access Category (AC-VI) for four nodes with equal priority in node 1
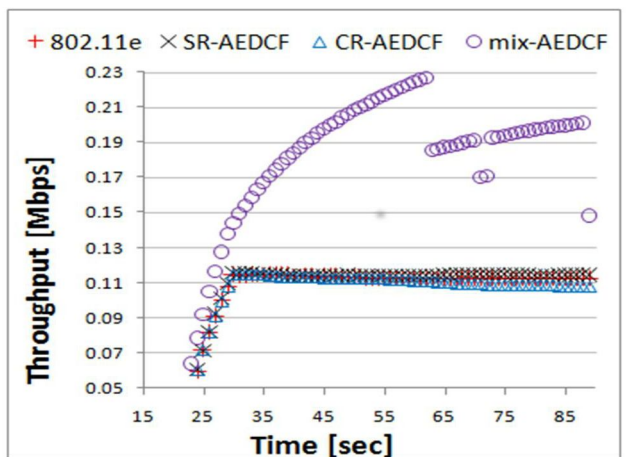

Figure 10: Throughput Comparison for the Best-Effort Access Category (AC-BE) for four nodes with equal priority in node 2

6. CONCLUSION

In this paper, we compare the performance of 802.11e standard and different techniques for adjusting the CW value. To evaluate these techniques, two scenarios are simulated using NS2 simulator. The evaluation focused on three

parameters. The order of these three parameters: throughput, packet loss rate and end-to-end packet delay. In evaluations, these techniques are evaluated under different traffic.

The results show that the performance of mix-AEDCF proposed technique is better than 802.11e standard and other techniques, which presented in this paper.

Up next, focus on parameters can be adjusted techniques to increase CW to offer the ability to adapt to the dynamic channel conditions local wireless networks.

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