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Distance Dependent Service Differentiation of the IEEE 802.11e EDCA on Single Access Point Based WLAN Systems

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Abstract

The IEEE 802.11e Enhanced Distributed Channel Access (EDCA) protocol allows class based differentiated Quality of service (QoS) in a wireless local area network (WLAN). Different fixed values of two certain parameters; contention window (CW) and arbitration inter frame space number (AIFSN), ensure higher or lower priority among this traffic classes, administrating different QoS in terms of throughput, delay, jitter etc. Previous simulation study illustrated, superior throughput and delay performance achieved by the highest priority voice traffic, compared to whatever achieved by the lowest priority background traffic; according to the deliberate design of the IEEE 802.11e EDCA protocol.

In this paper, we present our simulation study of the EDCA mechanism; augmented with the International Telecommunication Union (ITU) indoor propagation model, solidifying the outcome by ensuring an indoor or semi-indoor setup like todays real world WLAN system's deployment scenarios. Simulation study shows that a node accessing highest priority traffic through an AP from a high distance at high data rate not only suffers performance drops itself but also severely bottlenecks the performance of other client nodes accessing traffics with comparatively lower priority, even if those nodes are at close proximity from the AP. However, the negative impact over other traffic accessing nodes are much lower but not fully negligible, when a client node through the AP, tries to access lower priority traffic from a large distance. Hence, the intended service differentiation over different traffic classes closely depends on whether all the client nodes are at a close proximity from the AP.

Keywords*:* IEEE 802.11E, EDCA, ACCESS POINT (AP), VIRTUAL COLLISION (VC), STARVATION POINT.

1. INTRODUCTION

To maintain a better Quality of Service (QoS) and to integrate a superior performance in the world of WLAN, IEEE802.11e standard was emerged in the year of 2007 as an extension of the original standard IEEE802.11. As WLAN can provide easy internet access, it has become very much popular in recent years. The sheer number of deployed 802.11 based WLAN systems in office environments, in homes, and in public hot-spots are proofs of that. WLAN is mostly used for Internet access or for access to a wired Local Area Network (LAN) infrastructure. In both cases, the wireless station (STA) is often a client that retrieves a large amount of information from the wired network [1] (e.g. video streaming from a server on the Internet). An interesting observation on internet traffic is that they are normally asymmetric; there is always a large amount of downlink traffic from the Access Point (AP) to the client nodes with little uplink traffic from the nodes to the AP.

The IEEE802.11 provides two network configuration modes: infrastructure and ad hoc. It works in the first two layers of the OSI reference model, the medium access control (MAC) layer and the physical (PHY) layer. It provides two MAC methods: Distributed Coordination Function (DCF) and Point Coordination Function (PCF) [2]. The original standard IEEE 802.11 serves all transmitted frames with the same level of priority. As there is no service differentiation, IEEE802.11 failed to provide the required quality of service (QoS) performance. To provide a better QoS a new standard called IEEE 802.11e was deployed by enhancing the original standard. The IEEE 802.11e introduced a new access method called Hybrid Coordination Function (HCF) [3]. It provides two enhanced mechanisms: Enhanced Distributed Channel Access (EDCA) and Hybrid Coordinated Channel Access (HCCA). Unlike HCCA which is more suitable for infrastructure based WLAN systems, the EDCA mechanism can also be incorporated with infrastructure less WLAN systems.

IEEE 802.11 based WLAN systems are mostly deployed in the places which are the indoor or semi-indoor in nature (eg. Homes, offices) . Due to complex signal propagation situations (eg. Multi-path effect, Diffraction, Scattering, Object Shadowing) the transmission range is very short in closed environments. This paper focuses on how the EDCA mechanism differentiates services among different priority level traffics considering a single AP based WLAN system. However, our primary focus is to study the effect of AP-to- client node distance on service differentiation performance of the EDCA mechanism. . We all know, that the performance of a client node always degrades as it gets further away from the AP. In this paper, we are now considering only about the achieved throughput level; not about delay or packet drop rate or jitter. Now the question arises, whether due to that particular client nodes high distance from the AP, does other client nodes also faces performance degradation irrespective of their low distances from the AP or not. The designed and approved IEEE 802.11e EDCA mechanism already ensures the best possible performance of the highest priority traffic class, which we are also going to create in the first part of our simulation study, to create a baseline service differentiation performance of the EDCA mechanism on a single AP based WLAN system. In this paper we are trying to find, if this protocols design and its default parameter values also ensures that, the highest priority traffic accessing node unfairly worsens the performance of other comparatively lower priority traffic accessing client nodes.

2. OVERVIEW OF EDCA

The EDCA mechanism provides differentiated service by introducing four different traffic classes with different priority levels. This priority levels are called Access Categories (ACs). It allows four different access categories at each station and a transmission queue attached with each access category (AC). These ACs have different priority levels. Priority level 0 is assigned as the highest priority level and priority level 3 is assigned as the lowest priority level. To ensure service differentiation, different values of access parameters are assigned to different ACs. The main access parameters are contention window (CW) and Arbitration Inter Frame Space (AIFS). The later one was introduced with the EDCA mechanism. Details of these parameters can be found in [4]. Table I shows these parameter values for different ACs.

A. Contention Window (CW)

Just like DCF, EDCA depends on contention windows to generate a random waiting time for each AC. It is only after that waiting time an AC can try to send data packets. A highest priority AC, is assigned a minimum contention window, that is lower than (or at worst equal to) that of a lower priority AC. So, the random waiting time of an AC with higher priority level is smaller (or at worst equal to) an AC with lower priority level.

B. Arbitration Inter Frame Space (AIFS)

The AIFS is measured as the Short Inter Frame Space (SIFS) plus an Arbitration Inter Frame Space Number (AIFSN) of time slots [3]. The most important effect of the AIFSN setting is that the high-priority AC normally will be able to start earlier than a low priority AC to decrement the backoff counter after having been interrupted by a transmission on the channel.

C. Virtual Collision (VC)

EDCA supports four different ACs at each station. Every AC has its own transmission queue and every station has a virtual collision handler (VCH). When waiting time of an AC expires, the VCH allows that particular AC to send packets on the next time slot. However, if two different AC inside a same station tries to transmit packets on the same time slot an internal collision occurs inside the VCH. In this case, the AC with comparatively higher priority level wins the contention and the AC with lower priority level faces backoff [3].

Table I Contention parameters of different ACs

Priority Level	AC	CWmin	CWmax	AIFSN
0	Voice	7	15	2
1	Video	15	31	2
2	Best Effort	31	1023	3
3	Background	31	1023	7

3. ITU INDOOR PROPAGATION MODEL

ITU propagation model defines a radio propagation model which considers indoor attenuation factors. This propagation model estimates the path loss inside a closed area. Basically, this model is used for indoor environments and it incorporates not only the distance loss factor but also the floor penetration factor. Recently, ITU indoor path loss model is validated for 2.4 GHz range [6], which is also the mainstream operating frequency range of today's WLAN technology.

According to International Telecommunication Union (ITU) indoor path loss model is,

$$L = 20\log f + N\log d + P_f(m) - 28 \qquad (1)$$

As given in (1), we can see that it has three important parts. The first part accounts for the frequency specific signal loss in logarithmic scale; second part incorporates the logarithmic distance dependent signal attenuation multiplied by power decay index (N). $P_f(m)$ calculates the floor penetration loss if the concerned sender and receiver are in different floors. Some specific formulas for P_f

4. RELATED WORK

Many researchers have already put efforts in improving and fine tuning the EDCA mechanism. The important parameters that directly affect the performance of the EDCA mechanism and ultimately change overall (WLANs) systems performance have already been meticulously explored from many angles.

Most of the existing works on IEEE 802.11 and IEEE 802.11e performance are simulation based. In [4] we have found a comparison between the performance of 802.11 and 802.11e. Their conducted simulation study [4] shows that in case of 802.11e EDCA higher priority data flows get less delay and high throughput.

In [24/7] the effects of various contention window sizes have been shown. The default value of CWmin of 802.11 makes the network underutilized. The authors showed that, in case of small number of stations, if the CWmin is very small, number of collision increases and throughput decreases, delay increases. As soon as, the number of station increases, the channel is utilized fully and those problems become solved.

Performances of different EDCA parameters are evaluated in [25/8]. Four contention parameters which are CWmin, CWmax, persistence factor (PF) and AIFS have been tested in many combinations. The authors showed that, AIFS is the most effective parameter for protecting the higher priority traffic where using persistence factor and CWmin for differentiation help to have better performance of the low priority traffic.

In [9] two different approaches have been shown. In the first approach they showed that the access point should be responsible in the adaptation of the CW. In the second approach (named i-EDCA) they made some modification in the back off phase by removing the binary exponential backoff and introducing random IFS. They showed that i-EDCA has a better fairness property and prevents the low priority ACs from starving under higher loads in comparison to EDCA.

A dynamic adaptation algorithm is also proposed [10], where all the stations change CWmin size used for its backoff algorithm in run time according to its applications requirements and channel conditions. This also leads to dynamic priority provisioning among different access categorioes. Authors showed using simulation that, their proposed scheme increases throughput and channel capacity. Moreover, it also reduces packet delay and jitter compared to the default settings.

Though different authors try to evaluate performance by changing different parameters, we kept all the parameter into the standard form. We just try to observe how the performance of the entire system varies with the changes of the distance of the different priority accessing nodes

5. SIMULATION SETUP

The Network Simulator (NS2) [11] is used to conduct our simulation study. The original NS2 software supports the IEEE 802.11 only, and it was necessary to augment it with the new 802.11e. The EDCA setup is added using the TKN implementation of 802.11e [5], [11]. We also integrated ITU indoor propagation model with the NS2 software in this study.

A. Network Topology

We consider a wired/wireless topology. There are five wireless stations and all of them are configured in ad-hoc mode. We assumed a scenario, that one wireless station is connected to a wired network and acting as the access point (AP) and the remaining wireless stations are the client nodes. These nodes are accessing internet through that AP. We also considered in our assumed scenario, that the internet traffic is asymmetric, with little to no uplink traffic from the stations towards the AP, but majority portion of total traffic is downlink, from the AP towards the client stations. So, most of the service differentiation happens inside the VCH of the AP. Moreover, it ensures that no other nodes are contending to send traffic among them. So, there are no real collisions among different nodes in the system but only virtual collisions that happen inside the VCH of the AP.

The four client nodes are accessing traffics of only one AC. Moreover, none of the client nodes are accessing traffic of the same AC. There is no mobility in the system to avoid signal fading related to doppler spread.

TABLE II: COMMON SIMULATION PARAMETERS

Simulation Duration (sec)	Number of Simulation run / experiment	Packet size (byte)	Data Rate (kbps)		
			Initial Value	Final Value	Increment in each Simulation run
65	50	1024	100	5000	100

B. Simulation Scenario

Traffic of all AC follows Poisson distribution [12]. UDP is implemented as the transport layer protocol. We have used same packet size for all AC traffic. On every simulation run, the generated throughput (G_Thp) for every AC is same. Moreover, all the contention parameters of every ACs are kept at their default values. By doing this it becomes easier to evaluate how EDCA mechanism provisions service differentiation among different ACs. Table 2 summarizes some of the common simulation settings.

Table 3 summarizes the simulation parameters related to the ITU indoor propagation model. The operating frequency is 2472 MHz. In all of the simulations the minimum AP-to-node distance is beyond 16m.According to [6] we therefore used N=38(increasing impact of the distance-caused attenuation on the average signal strength). We considered a 50m by 40m topography. Also, for simplicity in this paper we considered that all client nodes including the AP are at the same floor so we can rule out floor penetration related signal losses.

TABLE III: ITU PROPAGATION MODEL PARAMETERS

Distance Power Loss Index (N)	Operating frequency (MHz)	Floor Attenuation (dB)	Transmission Power (dB)
38	2472	0	-15, -10

6. SIMULATION AND RESULTS

A. The Evaluation Process

In our simulation study, we used five different node arrangements and evaluated performance of the IEEE 802.11e EDCA mechanism. Throughout the whole simulation study, we followed the aforementioned scenario. All the parameters of EDCA mechanism remained at their default values. Except, we mainly manipulated the client nodes distance from the AP and observed overall systems performance, plus the service differentiation of the IEEE 802.11e EDCA mechanism.

A.1 First Arrangement:

In the first arrangement the AP is positioned at the centre of the topography. All four nodes are positioned exactly 20m apart from the AP (see Fig. 1). Performances of different ACs are analyzed .

A.2 Second Arrangement:

As shown in Fig. 2 both client nodes, accessing voice and video traffic are positioned at large distances from the AP and the other two nodes are at close distances from the AP.

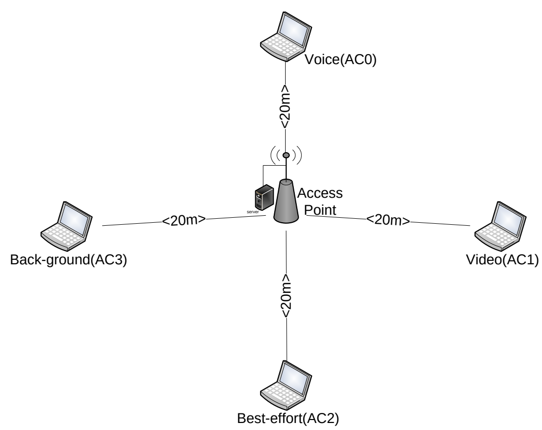


Figure 1: The AP is at the centre of the topography while client nodes are positioned at equal distances from the AP

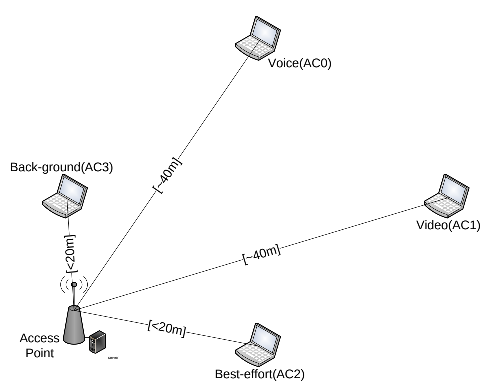


Figure 2: The AP in one corner of the topography and client nodes are placed at different

distances from the AP

A.3 Third Arrangement:

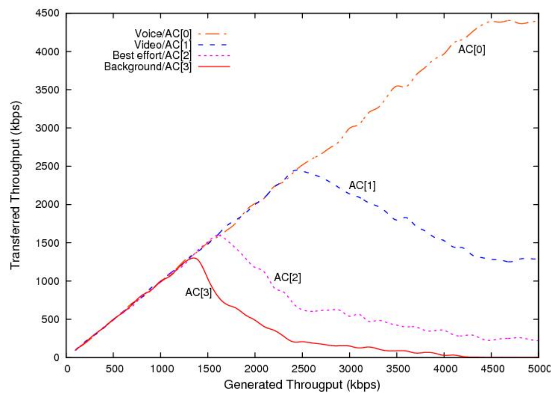
In this arrangement all settings are exactly like the second arrangement, except that positions of the client nodes, accessing video traffic and background traffic are interchanged.

A.4 Fourth Arrangement:

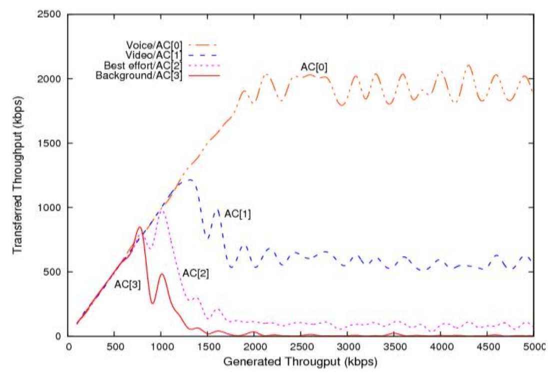
All settings are unchanged from the third arrangement but the transmission power of the AP is increased from -15dB to -10dB which ensures that the signal coverage is improved drastically.

A.5 Fifth Arrangement:

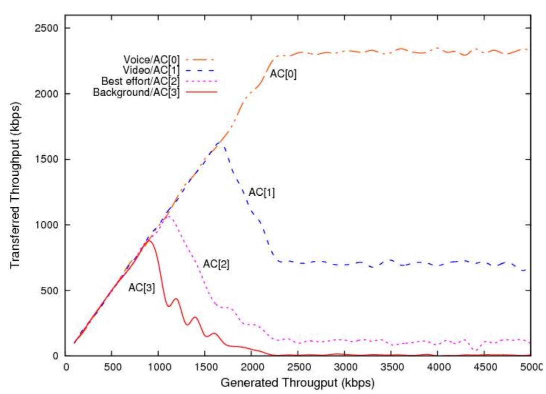
The client node that is accessing the voice traffic is now positioned at a close distance from the AP compared to the 2nd, 3rd or 4th arrangement. Otherwise, all settings are same as the 3rd arrangement.\



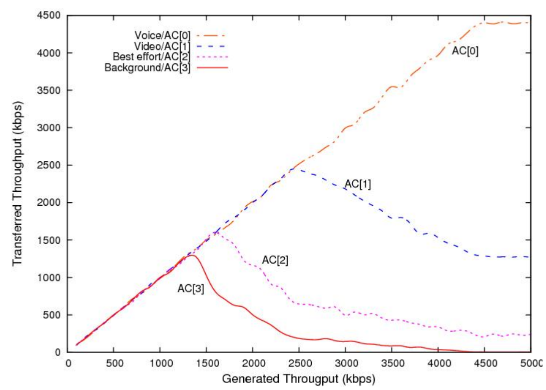
(a)



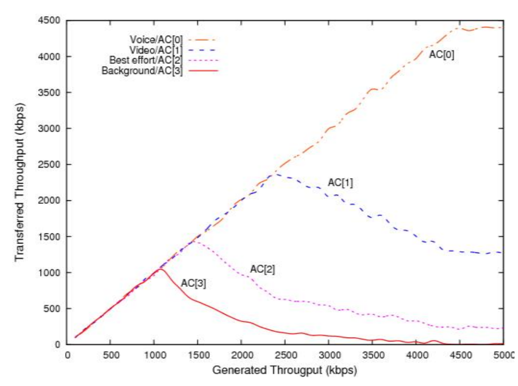
(b)



(c)



(d)



(e)

Figure 3: Generated Vs Transferred Throughput Curves of Voice, Video, Best effort and Background Traffic Access Category, observed in the simulation study with the first (a), second (b), third (c), fourth (d)

and fifth (e) node arrangements.

B. Results Analysis & Discussions

We carried out the simulation in five parts with five different node arrangements, mainly to study whether a client node accessing traffic while at a large distance from the AP faces performance degradation on its own or it also affects other client nodes performance as well. To ensure validity of this study we kept all EDCA parameter settings at their default values throughout the whole process.

When all client nodes are well within the coverage area of the AP and at a same distance from the AP in the first arrangement, we have observed that the voice AC due to its highest priority gets the best performance and the background AC with lowest priority gets the worst performance. Throughput starvation points for voice, video, best effort and background ACs are ~4100kbps, ~2400kbps, ~1600kbps and ~1300kbps respectively, as shown in Fig. 3a. These outcomes are similar to the result presented in [1].

However, in the second arrangement throughput starvation points for voice, video, best effort and background ACs are ~1900kbps, ~1200kbps, ~800kbps, ~800kbps respectively. The performance degradation of voice and video AC is expected as their sink nodes are at high distances from the AP. Though the client nodes accessing best effort and background ACs were in a small distance from the AP in this arrangement, surprisingly we observed that their performances have also been degraded. (see Fig. 3b).

In the third arrangement, the observed starvation points for voice, video, best effort and background ACs are ~2300kbps, ~1600kbps, ~1100kbps and ~900kbps respectively. Again the outcome of this simulation, with this arrangement is startling. The low distance between the AP and the client node accessing video traffic did not restore the performance level to the already observed level in the first part of our simulation study. More to our surprise, throughput starvation point for background and voice traffic have improved even though the client node that is attached to voice traffic has same distance and the client node attached to background traffic actually has much higher distance from the AP compared to the simulation done with previous arrangement (see Fig. 3c).

We did something *different* in our fourth arrangement. The client nodes positions are kept same as the 3rd simulation arrangement but the transmission power of the AP as well as all other nodes is increased three times from the previous arrangements. By comparing both Fig. 3a and Fig. 3d, we can clearly see that the performance levels of all the ACs are similar to the observed performance with the first arrangement.

In the 5th arrangement, placing the voice traffic sink node at a close distance from the AP confirmed that this node was indeed bottlenecking the performance of video traffic sink node in the 3rd arrangement. Because in this arrangement, the observed performances of voice and video ACs are very close to what we have observed in the 1st arrangement (see Fig 3a and Fig 3e). On the other hand, throughput starvation points for best effort and background ACs are ~1400kbps, ~1000kbps respectively, which is low compared to what we have observed in the 1st part of the simulation study. Again, the high distance of the background traffics sink node from the AP not only deteriorates its own performance but also deteriorates performance of that sink node of the best effort AC traffic, regardless of its low distance from the AP. However, the impact over besteffort traffic accessing node is lower. Moreover, there are no negative impacts over the other two clients nodes accessing voice and video traffic. By conducting the aforementioned simulation study with different node arrangements, our observations are as follows:

- If all the client nodes are well within the transmission range, then client nodes distance do not have considerable effect on the EDCA mechanism.
- If any client node is accessing traffic maintaining a large distance from the AP, then it faces performance degradation and also negatively impacts other client nodes performance even if other nodes are at close distances from the AP.

- This negative impact is much lower and also does not affect the ACs with higher priority (eg. Voice), if the traffic that the client node mentioned in the previous point is accessing comparatively lower priority traffic (eg. Background). However, the impact is tremendous on all other client nodes accessing comparatively lower priority traffic (eg, Video, Best effort or Background) if that same client node accesses the highest priority traffic (eg. Voice).
- This negative impact comes into play, if (in terms of throughput demands from the client nodes) the AP is moderately or heavily stressed.

CONCLUSION

Our Simulation study on IEEE 802.11e EDCA protocol is based over a single access point (AP) based WLAN system. The prime focus of this paper is to investigate the throughput performance of a client node related to its different distances from the AP. Furthermore, to inspect whether this varying distance of that particular node also changes the overall system's performance; plus any deviation from the observed base line service differentiation performance of the IEEE 802.11e EDCA protocol, when all the client nodes are situated at close vicinity from the AP.

The obtained results revealed that on a single AP based WLAN system; the EDCA mecganism provisioned the intended service differentiation among different priority levels as per the IEEE 802.11e protocols design, when all nodes are close to the AP. The Voice AC gets the best performance among all other ACs during our whole simulation study. However, once the sink node attached to voice AC traffic has high distance from the AP, and then it also becomes the biggest performance bottleneck for other client sink nodes attached to other AC traffics, even though these nodes are positioned at close distances from the AP. This phenomenon occurs with far less impact, when a client node is accessing lowest priority traffic.

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