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A Method For Theoretical Estimation of Maximum Achievable Throughput For The IEEE802.11e EDCA Mechanism

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Abstract

The IEEE 802.11e Enhanced Distributed Channel Access (EDCA) is the distributed channel access mechanism introduced by an amendment to the original IEEE 802.11 standard. Edca provides a class-based differentiated quality of service (QOS) to ieee 802.11 wlans. This paper presents a formula to find out the maximum achievable throughput theoretically for ieee802.11e edca mechanism. To avoid complexity, some assumptions are made. For simulation purpose, different packet sizes for different access categories (ACS) are observed. We find that, deviation between theoretically achieved values and observed values from simulations are very close.

Keywords: IEEE 802.11e, EDCA, Access Point (AP), Access Category (AC), Theoretical Maximum Throughput (TMT).

1. INTRODUCTION

Due to the rapid development of wireless technologies, Local Area Network (LAN) based on wireless communication became a reality. But it was after the IEEE802.11-1997 wireless networking standards release that WLANs really started gaining mainstream acceptance [1]. 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 [2] (e.g. video streaming from a server on the Internet). As we know, traffic patterns 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 IEEE 802.11 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)[3]. The original standard IEEE 802.11 failed to provide the required quality of service (QoS) performance as it serves all transmitted frames with the same level of priority. To provide a better QoS a new standard called IEEE 802.11e was deployed by enhancing the original standard.

The IEEE802.11e introduced a new access method called Hybrid Coordination Function (HCF) [4]. 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. So, EDCA is therefore the area of interest of this paper. EDCA mechanism provides differentiated service by introducing four different traffic classes with different priority levels. This priority levels are called Access Categories (ACs). According to EDCA mechanism voice data traffic has given the highest priority, video data traffic has given the second highest priority and best effort and background data traffic has given the third priority and fourth priority respectively[5].

The goal of this paper is to validate a formulae, originally derived to calculate the throughout upper bound of the IEEE 802.11 networks, over a single Access Point (AP) based WLAN system combined with the IEEE 802.11e EDCA mechanism. Theoretical Maximum Throughput (TMT) is the maximum throughput that can be achieved theoretically. In section 3 we talked about a paper where we can observe an equation that can easily calculate theoretical maximum throughput for IEEE 802.11. In This paper we try to modify that equation. In section 4, we have proposed an equation that can find out the Theoretical Maximum Throughput (TMT) for IEEE 802.11e. In section 5 we talk about simulation set up and we compared the values found from our proposed equation and from our simulation in section 6.

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 [5]. Table 1 shows these parameter values for different ACs.

2.1 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.

2.2 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 [4]. 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.

Table 1 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. RELATED WORK

Most of the existing works on IEEE 802.11 and IEEE 802.11e performance are simulation based. At first we went through a lot of papers, articles related to 802.11e based WLAN technology. In the paper [6] the author has found out the theoretical maximum throughput of the IEEE 802.11. According to the OSI model [3], 802.11 cover both MAC and PHY layer. The PHY layer is divided into two sub layer: PLCP and PMD. A service data unit (SDU) is the length of the payload that a particular layer provides to the layer above [6]. For MAC sublayer, it is called MAC service data unit (MSDU).So a packet coming from the upper layer to the MAC layer must have some overhead at each layer. Header and trailer are also added at the MAC layer. PLCP header and the PLCP preamble are also added at the PLCP sublayer. According to the [6] at the PMD layer IFS and backoff duration are also considered as overhead too.

To find out the delay in [6] all the overheads are converted into time. For 802.11 theoretical maximum throughput (TMT) according to [6], TMT= MSDU size / Delay per MSDU (1)

Where, Delay per MSDU = $(T_{DIFS} + T_{SIFS} + T_{BO} + T_{ACK} + T_{DATA})$ [6]. (2)

Here, for CSMA/CA and HR-DSSS from [6], T_{DIFS}= 50µs, T_{SIFS}= 10µs, T_{BO}= 310µs, T_{ACK}= 304µs, T_{DATA} = 192 µs + 8× (34 + MSDU)/Data rate (3)

4. MAXIMUM ACHIEVABLE THROUGHPUT (THEORETICALLY) FOR IEEE802.11E

In case of finding the theoretical maximum throughput for IEEE 802.11e EDCA we have tried to find out a similar type of equation. For Simplicity some assumptions are considered which are as following:

i. Data is flowing from AP to client nodes.
ii. Only one type of traffic class (AC[0]/AC[1]/AC[2]/AC[3]) has data .
iii. No packet losses due to collision.
iv. AP always has packet to send.
v. There is no fragmentation (frame/packet) in MAC layer.
vi. No losses occur due to buffer overflow at the receiving nodes.
vii. AP and all nodes have line of sight (LOS) and the distances are small.

In case of 802.11e EDCA, we know all data traffics are categorized into four different priorities. Those four ACs have different contention parameter values. So the backoff procedure varies for different access category traffics. In 802.11e protocol, DIFS time is replaced by arbitration inter frame space (AIFS) time. In addition, AIFS time also varies with different access categories. The backoff time is selected randomly following a uniform distribution from (0 to CWmin) giving the expected value of CWmin/2.

So the proposed equation of finding delay per MSDU for 802.11e EDCA,
Delay per MSDU [AC] =$(T_{AIFS\,[AC]} + T_{SIFS} + T_{BO\,[AC]} + T_{ACK} +T_{DATA})$ (4)

Where, AIFS [AC] = SIFS + AIFSN [AC] × slot time. [7, 8] (5)

T_{BO} [AC] = CWmin[AC] /2 × slot time. (6)

And, from [5],

T_{SIFS} = 10 µs, T_{ACK} = 304 µs, T_{DATA} = 192 µs + 8× (34 + MSDU)/Data rate.

For IEEE 802.11b, Slot time = 20 µs [7]. The contention parameters for different access categories are tabulated in Table I. So the theoretical maximum throughput for IEEE 802.11e EDCA, TMT [AC] = MSDU size/ Delay per MSDU [AC] (7)

5. PARAMETER SETUP FOR SIMULATION STUDY

We need to use different parameter for simulations and also need to make some assumptions.For Simulation purpose, the Network Simulator (NS2) [9] is used for all the arrangements. 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 [8], [9].

Table 2: Common Parameters Used Throughout the Whole Simulation Study

Antenna Type	Omni-directional	
Transmission Power	15 dBm	
Carrier Sense Threshold	-92 dBm	
Packet receive sensitivity	-82 dBm	
Channel Frequency	2.472GHz	
Channel Bandwidth	22MHz	
Queue Length	50 packet	
Queuing Method	FIFO with Droptail	
Routing Protocol	AODV	
MAC Protocol	IEEE802.11e EDCA	
Physical Layer Standard	IEEE802.11b	
Packet Retry Limit	7	
RTS/CTS Method	Off	
Data Rate	11Mbps	
Number of Access Point	1	
Number of Client Nodes	1-8	
Signal Propagation Model	Log Distance/Shadowing	
Transport Agent	UDP	TCP
Traffic Generator	Poisson	Ftp

A. Considered Parameters for Simulation

We used the mandatory (as per the standard) long preamble [10]. According to standard the preamble and PLCP header should always be transmitted at 1Mbps and so we also followed that standard. Actually all the control packets and field of a packet related to control are transmitted at 1Mbps. All the nodes have link layer delay of 50µs. For all data payload (i.e. MSDUs) we have used the maximum transmission speed of IEEE802.11b standard. We also set the packet size threshold value to 2000 bytes to make sure that in none of our simulation the packet gets partitioned.

B. Some Important Assumption

For simulation, we are considering a scenario where traffic, flows from only one access category which passes through the AP though there are not many data flows as it could create unavoidable unfairness situations among the flows. As per IEEE802.11e standard, the queuing method used in is FIFO with Drop-tail which is more prone to this type of unfairness. Simplicity demanded from us to make some assumptions which are following:

i. Data is flowing from AP to a single client node.
ii. Only one type of traffic class (AC[0]/AC[1]/AC[2]/AC[3]) has data .
iii. No packet losses due to collision.
iv. Only one flow of traffic.
v. AP always has packet to send.
vi. There is no fragmentation (frame/packet) in MAC layer.
vii. No losses occur due to buffer overflow at the receiving nodes.
viii. AP and all nodes have LOS and the distances are small.

6. ANALYSIS OF THE RESULTS AND DISCUSSIONS

For simulation, different packet sizes for different Access Categories (ACs) data traffic have been observed. First we tested using packet size of 1024byte, 512byte for all traffic classes. And then we used different packet sizes for different traffic classes.

Table 3: Maximum Throughput Found from Theoretical Calculation and Simulation for Voice Data Traffic for Different Packet Size

MSDU Size (Byte)	Voice Data Traffic (AC0) Mbps		
	TMT	Simulation Output	
		1 Flow	8 Flow
1024	5.87	5.82	5.71
512	4	3.96	3.85
220	2.17	2.14	2.08

Table 4: Maximum Throughput Found from Theoretical Calculation and Simulation for Video Data Traffic for Different Packet Size

MSDU Size (Byte)	Video Data Traffic (AC1) Mbps		
	TMT	Simulation Output	
		1 Flow	8 Flow
1024	5.55	5.51	5.42
512	3.71	3.67	3.54
1370	6.35	6.30	6.14

Table 5: Maximum Throughput Found from Theoretical Calculation and Simulation for Best Effort Data Traffic for Different Packet Size

MSDU Size (Byte)	Best Effort Data Traffic (AC2) Mbps		
	TMT	Simulation Output	
		1 Flow	8 Flow
1024	4.95	4.92	4.39
512	3.19	3.17	3.07
1500	5.99	5.97	5.86

Table 6: Maximum Throughput Found from Theoretical Calculation and Simulation for Background Data Traffic for Different Packet Size

MSDU Size (Byte)	Background Data Traffic (AC3) Mbps		
	TMT	Simulation Output	
		1 Flow	8 Flow
1024	4.72	4.69	4.63
512	3.01	2.92	2.9
300	1.99	1.97	1.93

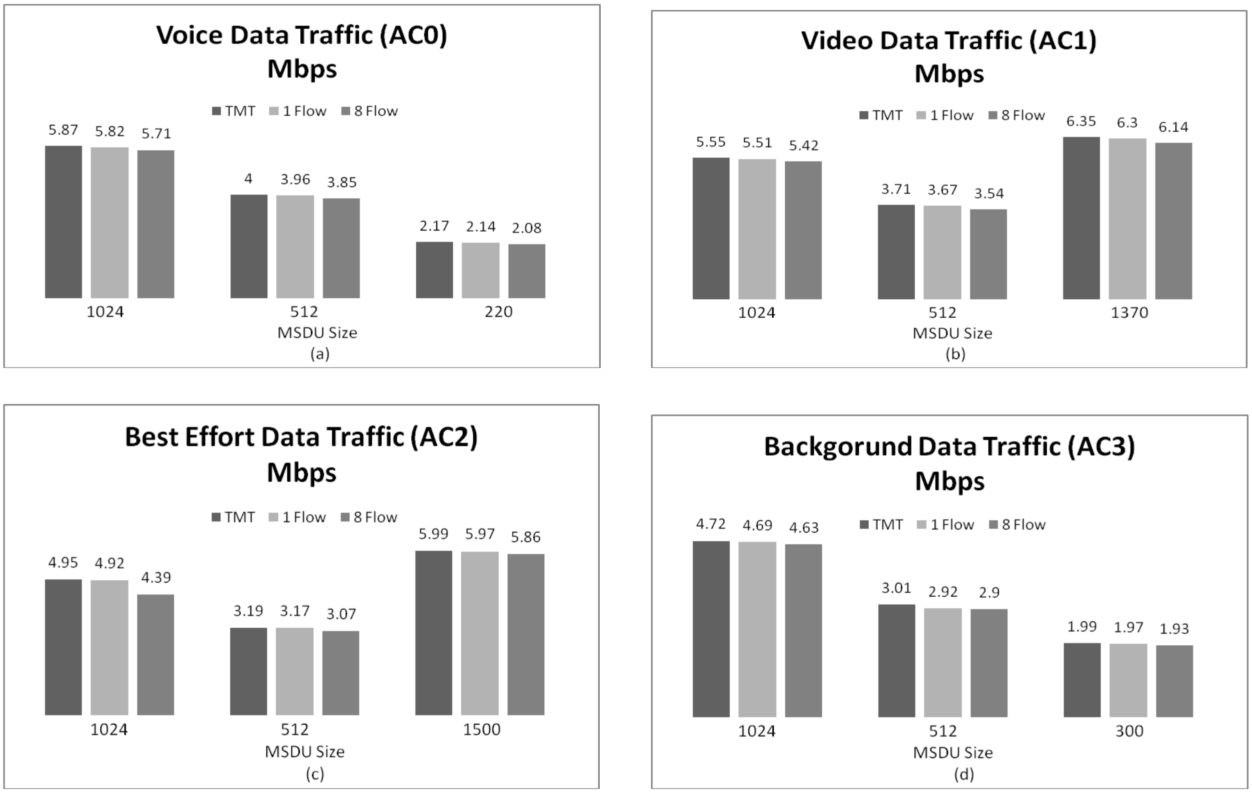

Fig. 1 Maximum Throughput Found from Theoretical Calculation and from Simulation (for 1 Flow and 8 Flows) for Different Packet Size of (a) Voice, (b) Video, (c) Best Effort, (d) Background data traffic access category.

We have used those hugely varying packet sizes to mimic the real life case. For example we tested for voice packet size of 220byte assuming G.711 codec is used [11]. Because in practical case, it is highly unlikely that for voice traffic packet size would be 1024byte. We did two related arrangements for simulation purpose. The 2nd arrangement had one single difference from the 1st arrangement. Instead of using 1 data flow similar to the 1st arrangement, now number of data flow is 8.We used slightly modified equation (see equation 4) from [6] to find the theoretical throughput value for a given packet size. After that, we also ran simulations.

Table 3 shows the comparison between theoretical maximum throughput (TMT) and maximum throughput found in our simulation study for Voice data traffic. In Table 4, Table 5, Table 6 we show the comparison between theoretical maximum throughput (TMT) and maximum throughput found in our simulation study for Video, Best Effort, Background data traffic respectively. For a better understanding, data are also presented in figure. The comparison between theoretical maximum throughput (TMT) and maximum throughput found in our simulation (for 1 Flow and 8 Flows) for different packet size for Voice, Video, Best Effort and Background data traffic Access Categories are represented in Fig. 1, Fig. 2, Fig. 3 and Fig. 4 respectively. From the tables and the figures we find that for one data flow and for 8 data flows the theoretically calculated maximum throughput and the achieved throughput by simulation are very similar.

Table 7: Theoretical and Simulation Value Deviation (in percentages) for Voice Data Traffic for Different Packet Size

MSDU (Byte)	Voice Data Traffic (AC0)	
Size	1 Flow	8 Flow
1024	0.85%	2.72%
512	1%	3.75%
220	1.38%	4.14%

Table 8: Theoretical and Simulation Value Deviation (in percentages) for Video Data Traffic for Different Packet Size

MSDU (Byte)	Video Data Traffic (AC1)	
Size	1 Flow	8 Flow
1024	0.72%	2.34%
512	1.078%	4.58%
1370	0.78%	3.31%

Table 9: Theoretical and Simulation Value Deviation (in percentages) for Best Effort Traffic for Different Packet Size

MSDU (Byte)	Best Effort Data Traffic (AC2)	
Size	1 Flow	8 Flow
1024	0.6%	11.31%
512	0.62%	3.76%
1500	0.33%	2.17%

Table 10: Theoretical and Simulation Value Deviation (in percentages) for Background Data Traffic for Different Packet Size

MSDU (Byte)	Background Data Traffic (AC3)	
Size	1 Flow	8 Flow
1024	0.63%	1.91%
512	0.99%	3.65%
300	1.005%	3.02%

Table 7, Table 8, Table 9, Table 10 represent the percentage deviation between the values found from theoretical calculations and from simulations for different packet sizes of Voice, Video, Best Effort and Background data traffic Access Categories respectively. The maximum difference observed was for voice traffic or AC[0] with packet size of 220byte, which is 1.38% (see Table 7) and the average difference is 0.832%. This is true for different packet sizes and for every access categories, when number of data flow is 1. But the difference increases when we tested for 8 data flows of same priority. Now average difference is 3.95% with maximum difference observed for Best Effort traffic or AC[2] with packet size of 1024byte,which is 11.31%

(see Table 9). The reason may be the extra delay, which incurs in the FIFO queue to process many data flows. And it has already been shown [12] that when it comes down to ensuring maximum bandwidth efficiency or fairness, FIFO with drop-tail is not a good queuing method.

CONCLUSION

We have tried to modify a formula for IEEE802.11e EDCA mechanism to find out the maximum achievable throughput theoretically. For simplification, we need to make some assumptions. We need to imagine that at a time, all of the receiving nodes are accessing only one type of AC traffic. We calculate theoretical maximum achievable throughput for all four access categories and also simulate for 1 data flow and 8 data flows. We find different results for different packet size. We find a very small deviation for most of the cases between the values observed from our theoretical calculation and from our simulation studies.

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