MINT

Master of Science in Internetworking

MINT 709 CAPSTONE PROJECT REPORT

PERFORMANCE ENHANCEMENT OF REAL-TIME APPLICATIONS OVER 802.11 WIRELESS LAN

Submitted by:

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Abstract

IEEE 802.11 based *wireless LANs* (WLAN) has accelerated the replacement of conventional wireline Ethernet LANs. The deployment of wireless technologies will play a significant role in next generation communication networks due to its simplicity and provision of a comprehensive communication environment. A multi-service network supports different services like voice, video and FTP which places different requirements on the network. Running real-time voice and video in the network requires *Quality of Service* (QoS) in terms of delay and throughput. But 802.11 does not have inherent QoS, thus IEEE proposed a standard with provisions for QoS in WLAN called 802.11e **[1]**. This standard mainly aims at providing QoS to time sensitive applications by using varying level of services based on traffic types. The 802.11e uses access method called *Hybrid Coordination Function* (HCF) which combines the functions of *Distributed Coordination Function* (DCF) and *Point Coordination Function* (PCF) from the 802.11 legacy. In this report, I will present WLAN network using 802.11g based stations with and without QoS and analyze results under various configurations using OPNET Modeller. I will use delay (in seconds), MAC delay (in seconds) and throughput (bits/second) as a performance matrix for evaluation of QoS.

Keywords WLAN - 802.11e - DCF - HCF – EDCA – QoS - Real-time applications – Performance Evaluation

1. Introduction

With increasing demand of WLAN due to its flexibility, ease of deployment, high speed and provision of mobility to the users, the expectations are high in terms of service and performance compared to wired networks. Real-time services require less delay than a file downloading application. Extensive research is being carried out to increase data rates and QoS of wireless networks to similar levels as that of wired networks. The architecture of 802.11 protocol concentrate on *Medium Access Control* (MAC) *layer* and *Physical layer* (PHY). MAC layer is responsible for governing the operations of WLAN by setting up rules to determine medium access and data transfer while PHY layer is left with details of transmission and reception of 802.11 frames.

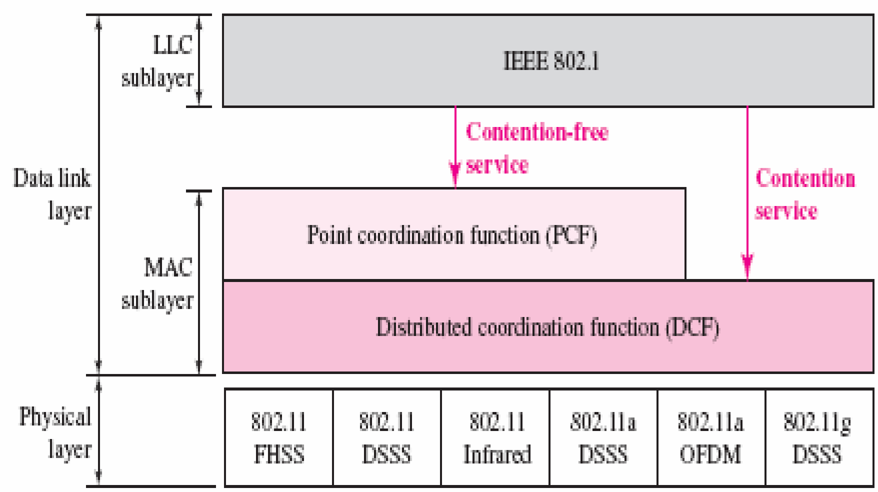


Fig 1.1 IEEE 802.11 Reference model [4]

WLAN has allowed multimedia applications to assume transmission rate of 54Mbps. But this may not be sufficient to ensure QoS for these delay sensitive applications. MAC controls the usage of wireless media. However, by nature, MAC is highly unpredictable due very extremely high probability of collision rate in the medium.

The 802.11 MAC layer used DCF for medium access mechanism. DCF is a contention-based method where wireless stations (STA) contend for gaining medium access for transmission. In order to support real-time traffic such as voice and video, the point coordination function (PCF) scheme has been advised as a non-compulsory option. The PCF is based on a centralized polling scheme for which a *point coordinator* (PC) residing in an *access point* (AP) provides contention-free services to the associated stations in a polling list.

PCF is already available in IEEE 802.11 to offer QoS but has not yet been implemented in practice due to its numerous technical limitations and performance drawbacks. Due to emerging technologies and considerable increase in QoS interests in WLAN networks, IEEE working group released 802.11e standard which will develop the existing MAC layer to accommodate QoS. In this report, I will describe 802.11 DCF and HCF mechanism in section 2, simulation scenarios with different configurations in section 3, performance evaluation in terms of delay, throughput of different scenarios with conclusion in section 4, future scope of the project section 5.

2. MAC Protocols

The IEEE 802.11 MAC specifies DCF as a fundamental access mechanism and 802.11e has EDCA as access mechanism.

2.1 Distributed Coordination Function (DCF)

DCF is based on listen-before-talk approach and use *Collision Sense Multiple Access with Collision Avoidance (CSMA/CA)* mechanism. The 802.11 MAC works with a single first-in-first-out (FIFO) transmission queue. The CSMA/CA constitutes a distributed MAC based on a local assessment of the channel status, i.e. whether the channel is busy or idle. If the channel is busy, the MAC waits until the medium becomes idle, then defers for an extra time interval, called the *DCF Inter-frame Space* (DIFS). If the channel stays idle during the DIFS deference, the MAC then starts the back-off process by selecting a random *back-off counter* (BC).

For each slot time interval, during which the medium stays idle, the random BC is decremented. If a certain STA does not get access to the medium in the first cycle, it stops its back-off counter. It then waits for the channel to be idle again for DIFS and starts the counter again. Thus, a new value is selected for each transmission attempt. As soon as the counter expires, the STA accesses the medium. MAC uses a virtual carrier sense function called *Network Allocation Vector* (NAV) which holds the duration for which the medium will be reserved for transmission of MAC frames and reception of ACK frames. Each STA chooses a random backoff timer which is uniformly distributed in an interval [0, CW – 1], where CW is the current *contention window size*. When frame transmission fails due to collision, the station doubles the CW until it reaches the maximum value, CW_{max}. If the maximum transmission retry limit is reached, the retransmission should be stopped, the CW should be reset to the initial value CW_{min} and the MAC frame is simply discarded.

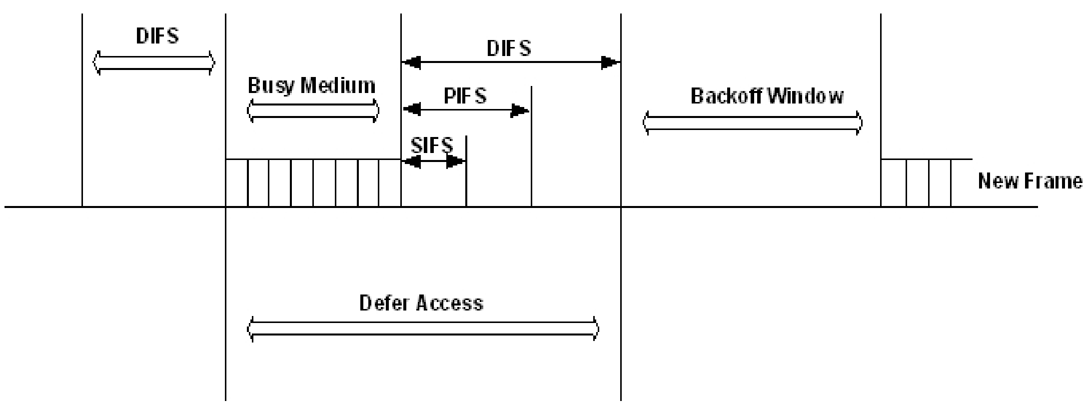


Fig2.1 DCF timing slots [5]

An *acknowledgement frame* (ACK) is sent by the receiver to the sender for every successful reception of a frame. The ACK frame is transmitted after *Short IFS* (SIFS), which is shorter than the DIFS.

As the SIFS is shorter than DIFS, the transmission of ACK frame is protected from other stations' contention. The CW size is initially assigned a CW_{min} and if a frame is lost i.e. no ACK frame is received for it, the CW size is doubled, with an upper bound of CW_{max} and another attempt with the BC is performed. After each successful transmission, the CW value is reset to $CW_{\mathbf{min}}$. All of the MAC parameters including SIFS, DIFS, slot time, CW_{min}, and CW_{max} are dependent on the underlying physical layer (PHY).

In order to avoid interference from others stations which may be hidden due to limited radio range, DCF employs RTS/CTS frame method to solve *hidden node problem*. Before the actual transmission of MAC frame begins, RTS/CTS frames are transmitted which contains the NAV value. The transmitting STA sends RTS (Request to Send) frame to the receiving STA, which is replied by CTS (Clear to Send) frame by receiver. All other stations within the range of transmitting and receiving STA will see these frames and NAV value, reside in the frames and tune their attempts according to it.

However, applications which are strictly time sensitive such as voice and video consistently have a higher demand for bandwidth. DCF has no way of traffic differentiation and serves all the applications with *Best-Effort* delivery service.

2.2 Hybrid Coordination Function (HCF)

The 802.11e standard used HCF as primary access mechanism scheme. HCF's primary mechanism is *Enhanced Distributed Channel Access (EDCA)* which is mandatory. To provide QoS, four different *Access Categories* (AC) are used. These ACs are FIFO queues which are mapped to eight different *user priorities* (UP) at MAC. As soon as the frame arrives at the MAC layer, a *Traffic Priority Identifier* (TID) is attached to it. A parameter knows as *Transmission Opportunity* (TXOP) is introduced to define the duration for which a QSTA holds the medium.

Enhanced Distributed Channel Access (EDCA)

EDCA is designed to provide prioritized QoS by enhancing the contention-based DCF. One of the main features of HCF is differentiated, distributed access to the medium for stations that enabled QoS known as QSTA. There are two ways of service differentiation in EDCA:

- Use multiple Inter-frame space values from different Access Categories
- Assigning different CW sizes to different Access Categories

Each data packet from the higher layer along with a specific user priority value should be mapped into a corresponding AC according to IEEE 802.1d bridge specification [**3**].

Priority	Access Category(AC)	Designation
1	0	Background
2	0	Standard
0	1	Best Effort
3	1	Excellent Effort
4	2	Streaming Multimedia
5	2	Interactive Multimedia
6	3	Interactive Voice
7	3	Reserved

Each QSTA represents 4 virtual stations, 1 for each AC. The data coming from layers above in a QSTA will be tagged as one of these 4 ACs. Each queue within QSTA will act as DCF STA with its own *Arbitrary Inter-frame Space* (AIFS) which is the modification of DIFS in DCF mode.

An AIFS is defined as:

$$\textbf{AIFS [AC] = SIFS + AIFSN [AC]} \times \textbf{Slot Time}$$

Where AIFSN is an AIFS Number determined by AC and physical setting, slot time is duration of the slots.

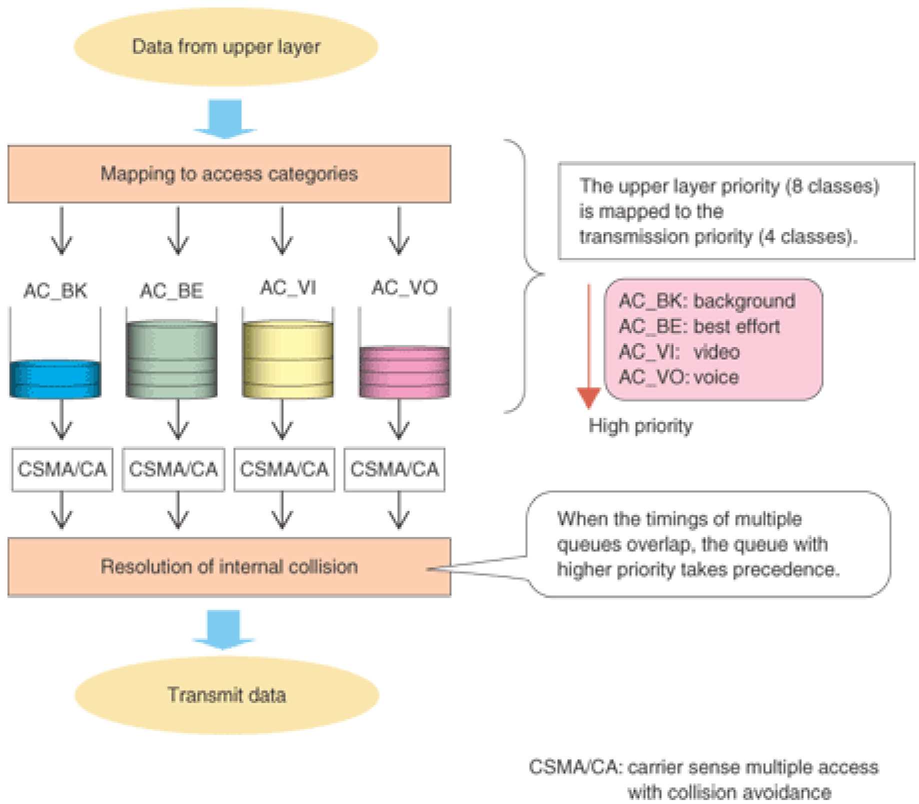


Fig2.2 Collision handling mechanism of EDCA[6]

Smaller the AIFS, higher the priority for the AC. So time sensitive applications like voice and video are given shorter AIFS in order to gain priority of medium access over other traffic types. If an internal collision occurs when more than ACs reaches the end of their backoff timers, priority is given to AC with shorter AIFS. The AC with smaller AIFS will be given medium access for time = TXOP.

During an EDCA TXOP, a STA is allowed to transmit multiple MAC protocol data units (MPDUs) from the same AC with a SIFS time gap between an ACK and the subsequent frame transmission. A TXOP limit value of 0 indicates that a single MPDU may be transmitted for each TXOP.

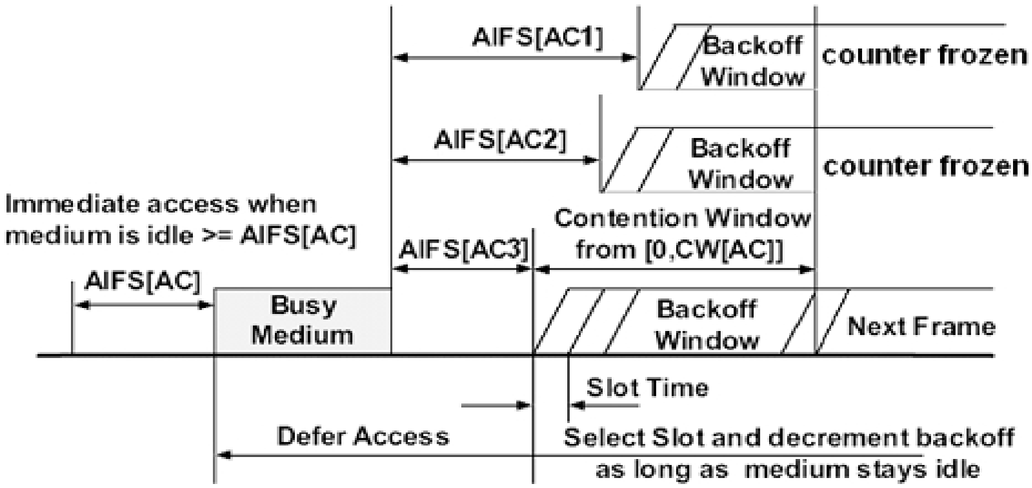


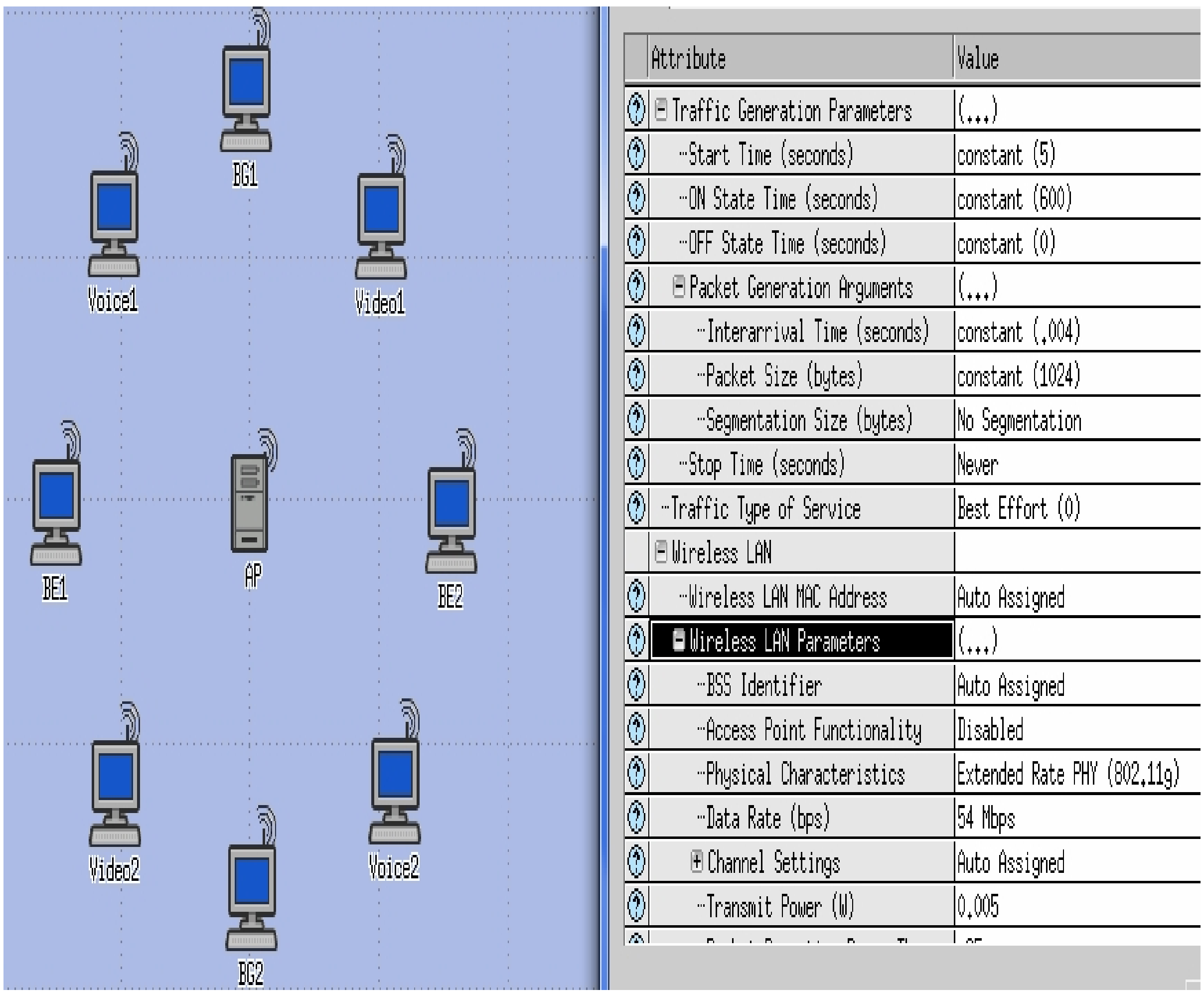
Fig2.3 EDCA timing slots [7]

The assumption for this project is the STA is transmitting only one data frame per TXOP round.

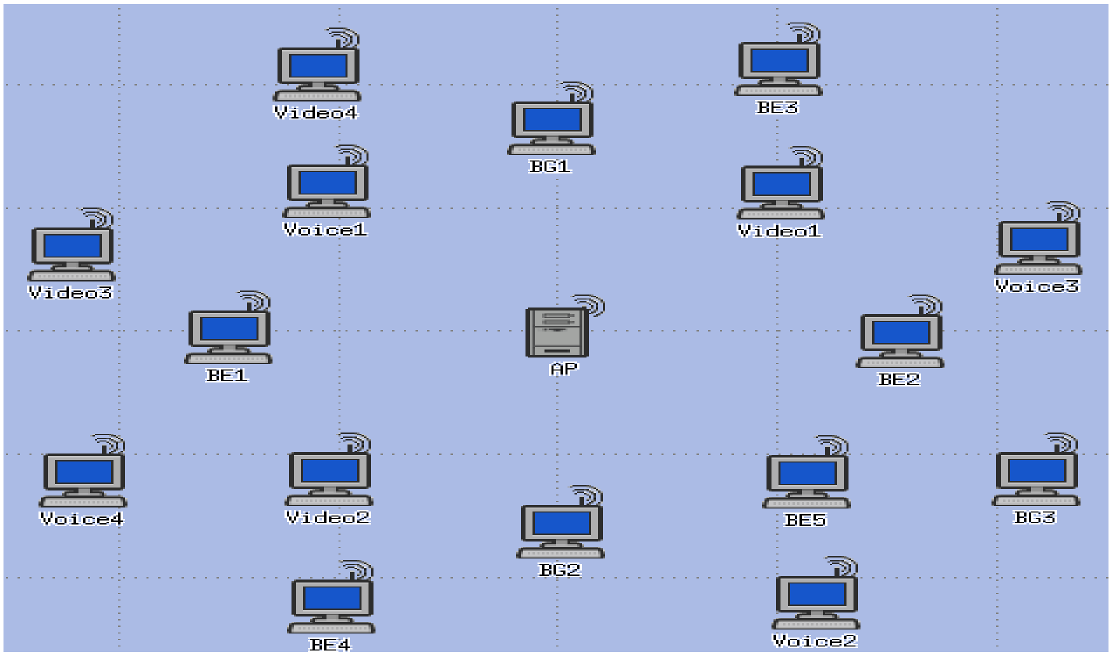
3. Simulations Scenario

I have used OPNET network modeller for simulation using 802.11g based STAs. The standard node model of *wlan_station_adv (fix)* was used in the simulation with 8, 16, 24 and 32 STAs connected to *wlan_server_adv* which act as an AP. All STAs are located within the BSS; each wireless station can directly communicate only with the AP. In the simulation, I will be testing the performance of 802.11e with different network scenarios, each with different number of nodes within BSS and analyze the performance of real-time application users. Assuming, the real-time users are having higher privileges in the BSS than other users, I will try to achieve satisfactory level of services for these users on the basis of performance matrix: delay, throughput.

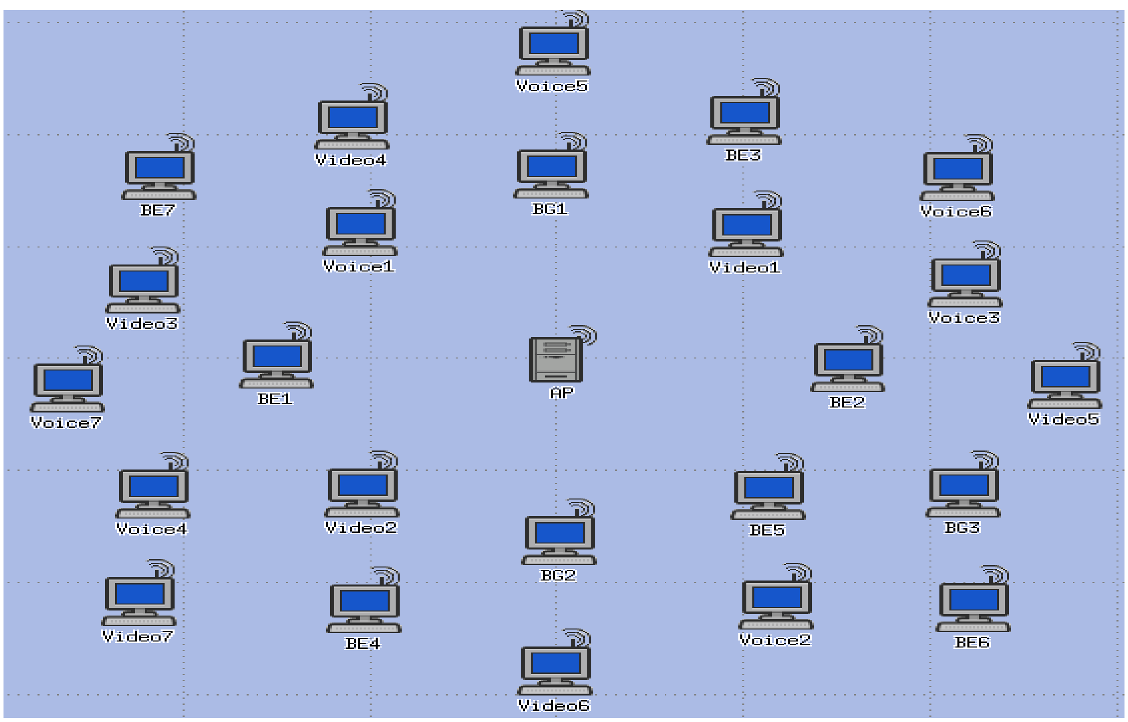
To demonstrate the effects of 802.11e on real-time application services, four scenarios are employed with different number of nodes operating in 802.11g **[2]** mode with PHY of 54Mbps and have a fixed packet length. The idea is to generate traffic regularly for real-time applications and measure their performance by fixed size packets based on CBR of 0.004s for both video and voice. Each node generates single type of traffic (voice, video, best-effort and background) to the AP. I gradually increased the number of nodes by 8 in each scenario with equal number of nodes for generation of voice and video traffic streams. I have made an assumption that there are no interferences from devices like microwaves and cordless phones within BSS, since 802.11g is susceptible to these kinds of interferences in the network.



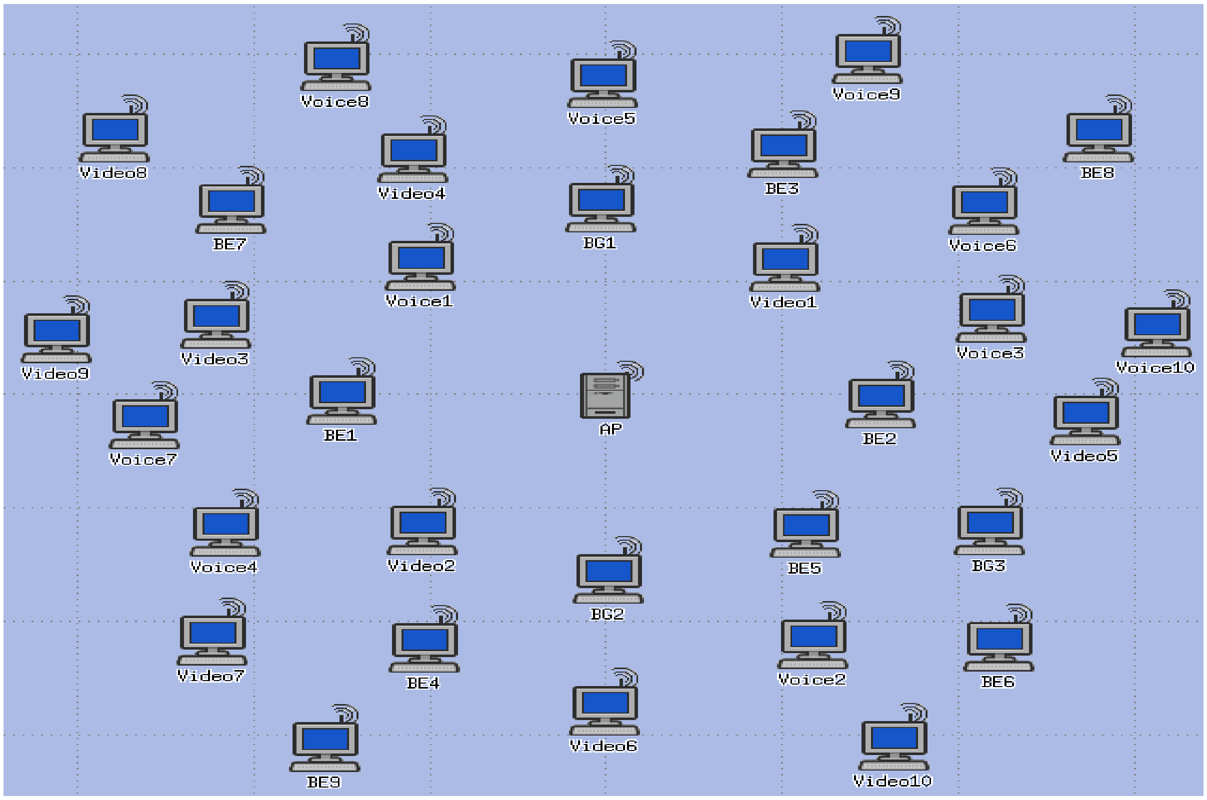
<u>**Scenario 1 Network Model 8 Nodes with Packet Generation Parameters**</u>



Scenario 2 Network Model 16 Nodes



Scenario 3 Network Model 24 Nodes



Scenario 4 Network Model 32 Nodes

All four scenarios are tested in DCF as well HCF (802.11e) modes. The STAs generate four different type of traffic: voice, video, best-effort and background. Following are the attributes for STAs generating four different type of traffic:

Attribute	Value
name	Video4
Destination Address	Random
⊟ Traffic Generation Parameters	(...)
Start Time (seconds)	constant (5)
ON State Time (seconds)	constant (600)
OFF State Time (seconds)	constant (0)
⊟ Packet Generation Arguments	(...)
Interarrival Time (seconds)	constant (.004)
Packet Size (bytes)	constant (1024)
Segmentation Size (bytes)	No Segmentation
Stop Time (seconds)	Never
Traffic Type of Service	Best Effort (0)
⊞ Wireless LAN	

Attributes for node generating video traffic

Attribute	Value
··name	BE3
··Destination Address	Random
⊟ Traffic Generation Parameters	(...)
··Start Time (seconds)	constant (5)
··ON State Time (seconds)	constant (600)
··OFF State Time (seconds)	constant (0)
⊟ Packet Generation Arguments	(...)
··Interarrival Time (seconds)	constant (.004)
··Packet Size (bytes)	constant (512)
··Segmentation Size (bytes)	No Segmentation
··Stop Time (seconds)	Never
··Traffic Type of Service	Best Effort (0)
⊞ Wireless LAN	

Attributes for node generating best effort traffic

Attribute	Value
··name	BG3
··Destination Address	Random
⊟ Traffic Generation Parameters	(...)
··Start Time (seconds)	constant (5)
··ON State Time (seconds)	constant (600)
··OFF State Time (seconds)	constant (0)
⊟ Packet Generation Arguments	(...)
··Interarrival Time (seconds)	constant (.004)
··Packet Size (bytes)	constant (256)
··Segmentation Size (bytes)	No Segmentation
··Stop Time (seconds)	Never
··Traffic Type of Service	Best Effort (0)
⊞ Wireless LAN	

Attributes for node generating background traffic

Simulation in DCF mode

The length of packet (in Bytes) is kept different for all four traffic types while inter-arrival time is constant 0.004 seconds which corresponds to the time required between generation of two successive packets at the STA. The start time tells when in simulation, the STA starts to generate packets. On and off times are like on and off switched for generating packets during the duration of the simulation which are set to 600 seconds (duration of simulation) and 0 respectively.

Initially, the simulation is performed in DCF mode for all four 8, 16, 24 and 32 nodes network scenarios for the duration of *10 minutes* as simulation time in OPNET. Type of service (ToS) field for all four traffic types are set to best-effort (0) as mentioned in DCF mode, hence all the nodes in the BSS have same priority over the usage of wireless medium during contention period. Since all stations are within the BSS, thus all stations can detect transmission from other stations. I have collected the simulation results for DCF in terms of Delay (s), Media Access Delay (s) and Throughput (bits/s).

Simulation in HCF mode

After performing simulation for DCF mode for each scenario, i have performed simulation involving EDCA based QSTA for corresponding scenarios with QoS set of parameters to differentiate and prioritize traffic generated from different nodes. The simulation time and traffic generation parameters are kept same except the change in ToS field. As EDCA different ACs can have different Contention Window (CW) to enhance the chances of higher priority traffic to access the medium first.

AC	**CWmin**	**CWmax**	**AIFSN**
AC[0]	31	1023	2
AC[1]	31	1023	2
AC[2]	((CWmin + 1)/2 - 1) = 15	CWmin = 31	3
AC[3]	((CWmin+1)/2 – 1) = 7	CWmin = 15	7

Contention Window size per AC

AC [0] categorizes background traffic, so parameters are similar to legacy DCF value with change only in AIFS.

AC [1] is slightly higher in priority than AC [0] with exception in AIFS which is lower.

AC [2] has a higher priority than AC [0] and AC [1] assigned to video with smaller contention window; CWmin = 31, hence CWmin for AC [2] is calculated as:

CWmin [2] = ((CWmin + 1)/2 - 1) = 15

AC [3] has the highest priority assigned to voice with smallest contention window; CWmin = 15, hence CWmin for AC [2] is calculated as: CWmin [3] = ((CWmin+1)/2 – 1) = 7

AIFSN is dependent on AC and physical settings so i took the default values in OPNET. Following are my EDCA parameters used in the simulation:

Attribute	Value
⊟ EDCA Parameters	(...)
⊟ Access Category Parame...	(...)
⊟ Voice	(...)
CWmin	7
CWmax	15
AIFSN	2
⊞ TXOP Limits	Default
⊟ Video	(...)
CWmin	15
CWmax	31
AIFSN	2
⊞ TXOP Limits	Default
⊟ Best Effort	(...)
CWmin	31
CWmax	1023
AIFSN	3
⊞ TXOP Limits	Default
⊟ Background	(...)
CWmin	31
CWmax	1023

4. Performance Evaluation

In my study, i will be assessing performance of both DCF and HCF modes for all four scenarios in terms of average: delay, MAC delay and throughput.

The *delay* parameter represents end to end delay of all the packets received by WLAN STAs and forwarded to higher layers. The *MAC delay* shows total of queuing and contention delay the frames. *Throughput* represents total number of bits send from one to end to the other.

DCF vs. EDCA

Here i will analyse the performance of both access mechanism on the basis of delay, MAC delay and throughput. I will compare Scenario 1 (8 Nodes) with Scenario 4 (32 Nodes).

<u>Scenario 1: No. of nodes = 8</u>

Delay

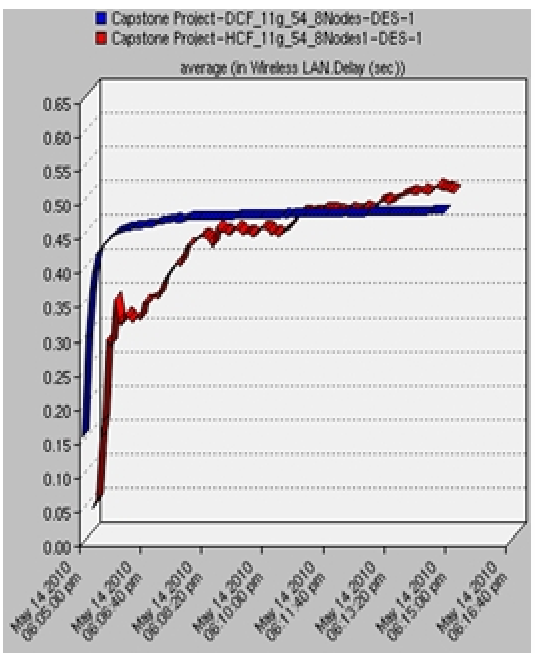


Fig4.1 Avg. delay for DCF vs. EDCF

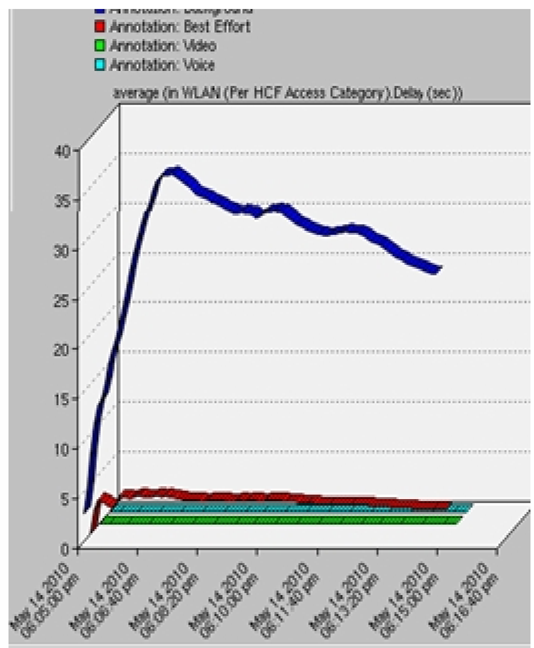


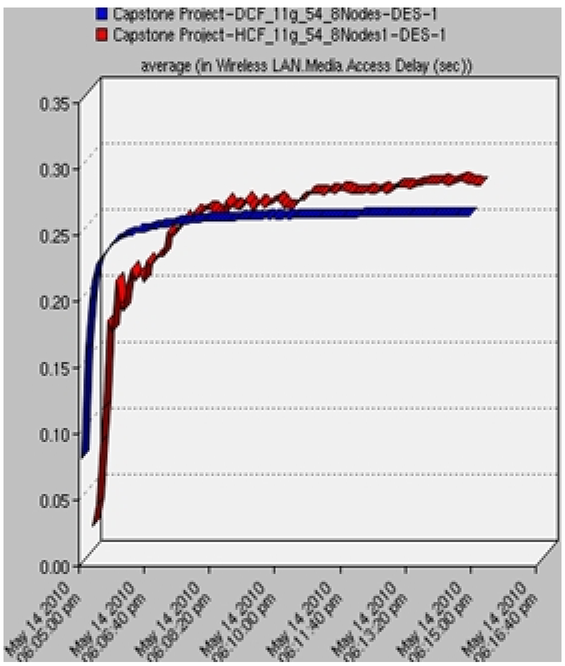
Fig4.2 Avg. delay/AC for HCF

Fig4.1 shows the delay for DCF vs. HCF in scenario 1 where there are 8 nodes: 2 for each traffic type.

Initially, the delay is higher for both modes as STAs and QSTAs are contending to gain medium access. As the simulation goes on, after 5 mins, delay for HCF mode goes high as STA with higher priority will gain medium access while other will have to wait in queue. The average delay here is *0.48s*.

The Avg. delay per HCF category in fig4.2 is shown. Here we can see that delay for voice category (AC [3]) is least followed by video (AC [2]). The differentiation of traffic works here with higher priority tagged ACs experiencing less delay.

MAC Delay



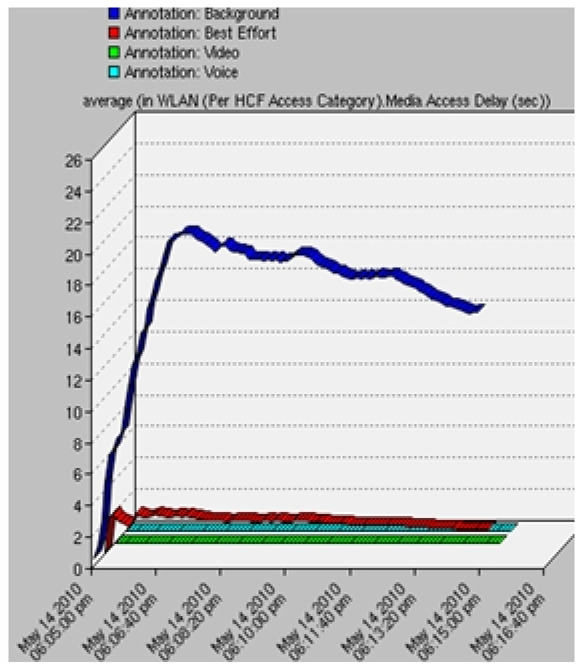
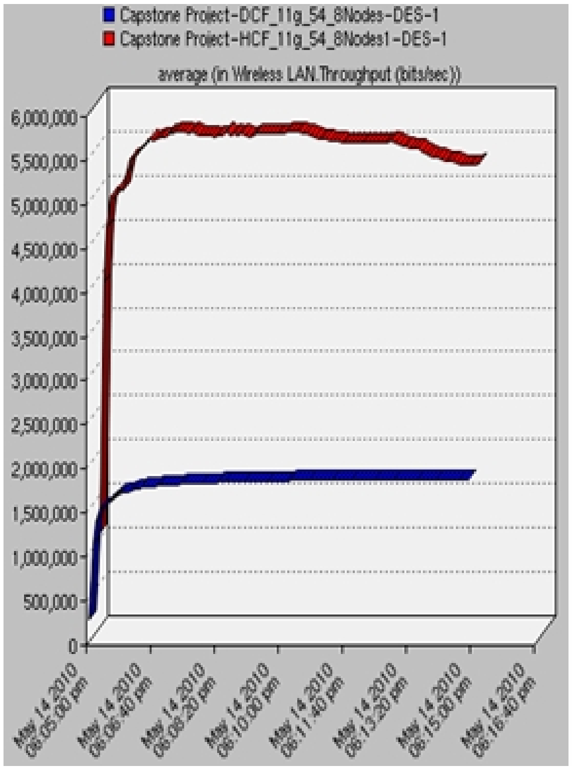


Fig 4.3 Avg. MAC delay for DCF vs. EDCF **Fig4.4 Avg. MAC delay/AC for HCF**

In fig 4.3, for the first 1 minute of the simulation, MAC delay for both DCF and EDCF were high as all the STAs are generating traffic simultaneously which will lead to queuing delay at MAC. After sometime, HCF suffers higher MAC delay because MAC frames generated will have to wait for their access to medium which has been granted first to higher ACs. The avg. MAC delay is *0.26s*.In fig 4.4, there is an improvement in MAC delay for voice and video and even best-effort traffic suffers less.

Throughput



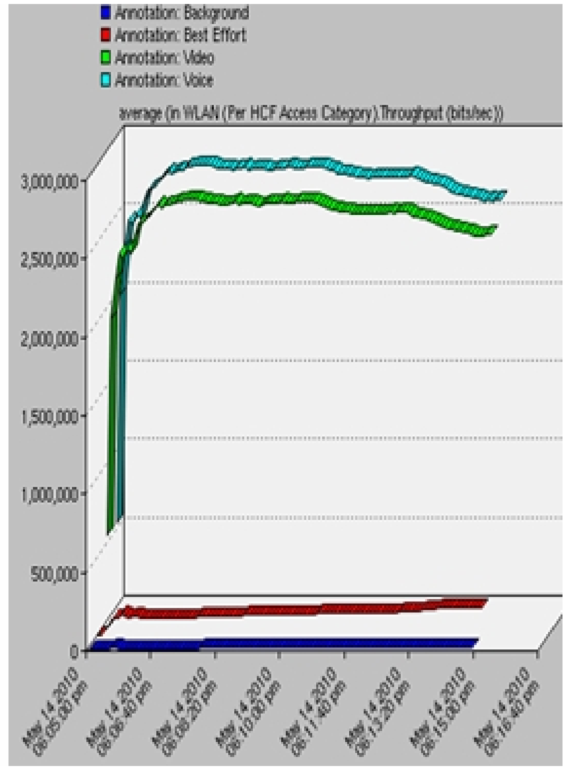


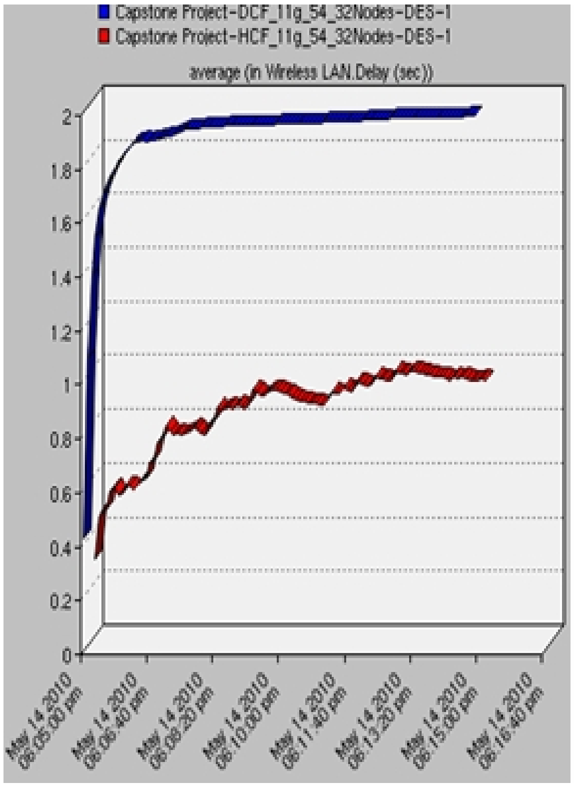
Fig4.5 Avg. Throughput for DCF vs. EDCF **Fig4.6 Avg. Throughput/AC for HCF**

There is a significant improvement in overall throughput shown in fig4.5. During starting time of the simulation, throughput for both DCF and HCF are going up, this is due to less re-transmission attempts in the beginning. But as the simulation progresses, DCF throughput stabilizes with slight drop in HCF at the end. This is caused by increase in number of backoff timers by other STAs. By the use of HCF, there is nearly 3 times improvement than DCF. The avg. throughput for DCF is *18, 71,920 bits/s* while avg. throughput achieved with HCF is *52, 91,947 bits/s*.

While in fig 4.6, voice category has the highest throughput followed by video which ensures maximum frames got transferred from end to end for both.

Scenario 4: No. of nodes = 32

Delay



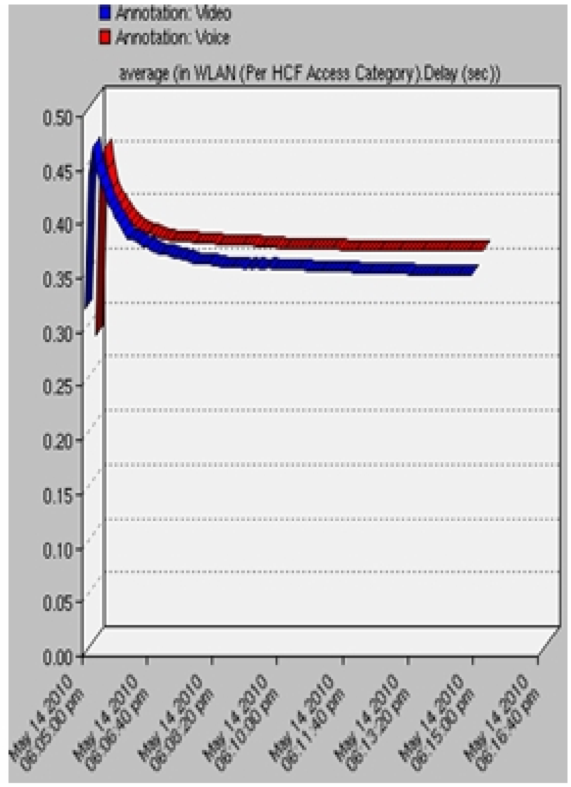


Fig4.7 Avg. delay for DCF vs. EDCF **Fig4.8 Avg. delay/AC for HCF**

As the number of nodes increased from 8 to 32 nodes, delay for DCF mode increased more than two times. This is due to more number of nodes competing to gain medium access leading to congestion and delay is caused for frames to travel to their destinations. As we can conclude from fig 4.7, HCF can still provide avg. delay close to 1s due to improved service levels for voice and video traffic. The avg. delay for DCF is 2s while HCF shows avg. delay of 1.95s. Fig. 4.8 witness lesser delay for voice and video category because of assigning low number of AIFSN causing less number of collisions. Also variable CW values helps in the deficit of re-transmission attempts.

MAC Delay

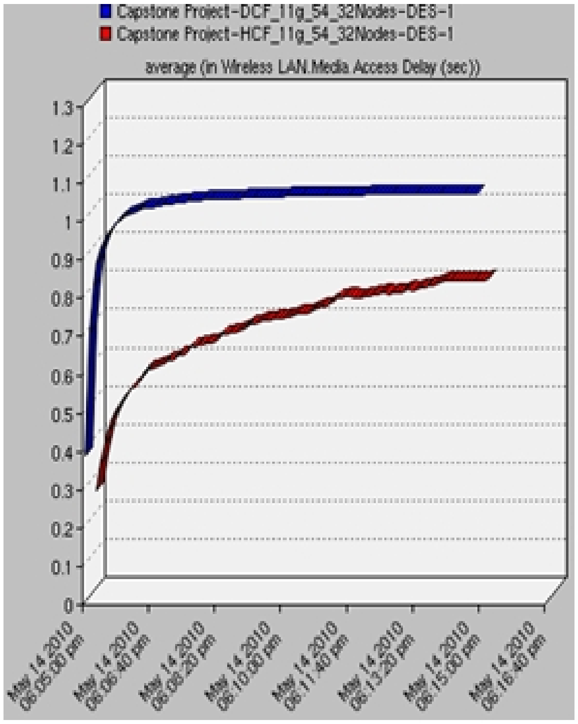


Fig4.9 Avg. MAC delay for DCF vs. EDCF

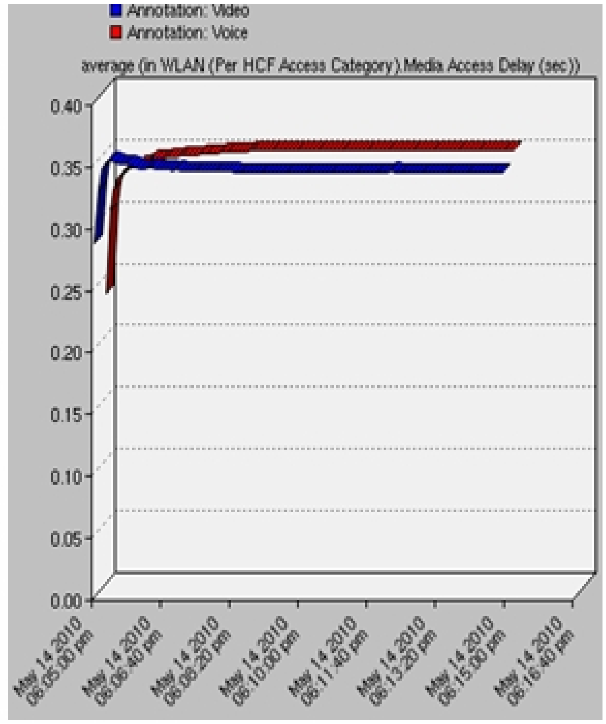
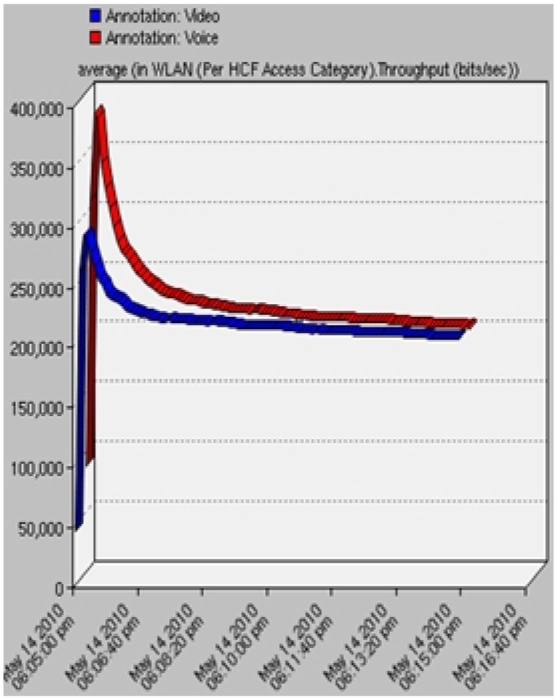


Fig4.10 Avg. MAC delay/AC for HCF

The MAC delay in fig 4.9 is initially high for both modes and then later stages, HCF shows slight gain but it is till under DCF. This slight increase in HCF is caused by longer transmission queues for the ACs with lower priorities. There is an avg. difference of 0.27s between DCF and HCF overall which is not much considering the number of nodes contending for medium access are now 32.

In fig. 4.10, the avg. MAC delay from both top categories is about 0.35s which is acceptable for real-time applications. During the beginning of simulation both video and voice have shown raise in graph, then it is consistent throughout which is due to smaller number of CW for both categories.

Throughput



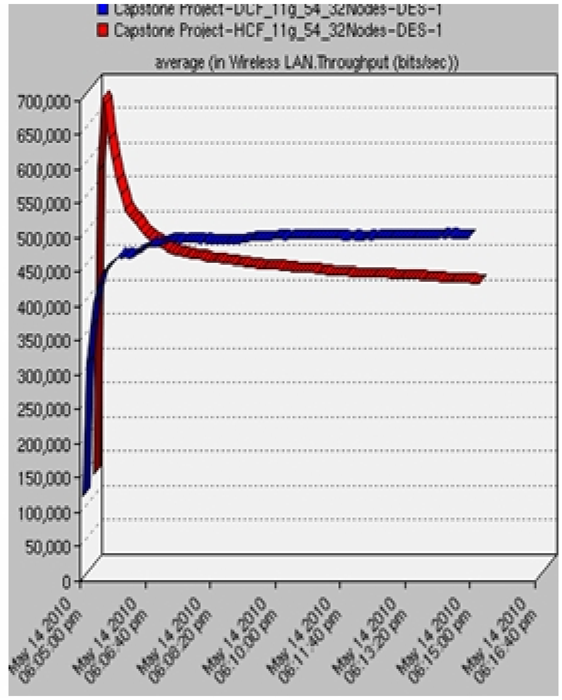


Fig4.11 Avg. Throughput/AC for HCF **Fig4.12 Avg. Throughput for DCF vs. EDCF**

Since both applications starting to generate traffic at similar time, throughput for Voice initially in HCF is much higher than the video in fig. 4.11 because it has its CW is lesser than the value assigned to video giving both more priority over other applications. Shortly after the peak, throughput for voice falls down rapidly as compared to video because of their similar AIFSN and stabilizes thereafter.

From the fig. 4.12, it is evident that the beginning trends of the simulation show that the throughput for HCF mode is way higher than DCF because of its variable CW sizes. After sometime, HCF throughput goes down and stabilizes for both access modes. This can be explained by lesser number of backoff timers assigned to STAs in the starting period of simulation but as time progresses more and more devices contending for medium which will increase re-transmission attempts and eventually decreases throughput.

Conclusion

The simulation results obtained from 4 different set of configurations each with and without QoS proves that EDCA is effective in providing better level of service to time-sensitive applications by providing varying level of services. EDCA is more effective in limiting number of collision when numbers of nodes are less (8 nodes) but as the number increases (to 32 nodes), the throughput for EDCA goes down. Fig 4.13 shows a table that contains the average values obtained from the simulation result of Scenarios 1, 2 and 4.

		Scenario 1 8 Nodes			Scenario 2 16 Nodes			Scenario4 32 Nodes		
		Delay (s)	MAC delay(s)	Throughput (bits/s)	Delay (s)	MAC delay(s)	Throughput (bits/s)	Delay (s)	MAC delay(s)	Throughput (bits/s)
DCF		0.48	0.26	18,71,920	1.07	0.58	9,31,447	1.99	1.07	4,99,606
HCF		0.49	0.27	52,91,947	0.82	0.42	9,31,308	0.95	0.81	4,14,024
Per HCF Category	Vo	0.008	0.003	26,08,387	0.09	0.08	4,89,295	0.36	0.35	2,04,786
	Vi	0.017	0.008	24,76,578	0.10	0.09	4,32,650	0.35	0.34	2,06,520
	BE	2.72	1.68	1,85,392	25.5	13.3	10,124	40.6	34.11	2631.73
	BG	27.5	16.2	21,589	130.3	146.4	238.9	83.34	84.84	85.32

Fig4.13 Results obtained from the simulation

The ITU-T has recommended 2-way voice delay of *300ms = 0.3s*. Here, I am assuming that the average delay value of *250ms = .25s* is acceptable for video traffic. Thus scenario 1, 2 and 3 can qualify to provide better voice and video service. In scenario 4, the average delay per HCF category for voice is 0.36s and for video 0.35s which is higher than the recommended level.

The varying level of services provisioned through lower CW values given to voice, video and different AIFSN will make help in enhancing the experiences of real-time application users in BSS. This advantage can be used for smaller BSSs where lesser number of users requesting for QoS for their real-time applications can be accommodated.

However, there is a limit to which 802.11e protocol can provide QoS. The obtained values from simulation in the table above depicts that the throughput keeps on decreasing as more and more nodes contending for medium access. Also, too many users can deteriorate the performance of network with higher number of collisions leading to increases in re-transmission attempts. Thus IEEE 802.11e suitable for smaller environments by providing suitable standards for benefiting services with higher priority.

5. Future Scope

In my simulation scenario, i took 802.11g PHY mode which is susceptible to interference from other devices since it works on orthogonal frequency division multiplexing (OFDM) which also a modulation scheme used in 802.11a. There are 3 separate non-overlapping channels for 802.11g. This means covering a large area where there is a high density of users is an issue since 802.11g works in 2.4GHz frequency so it may have RF interferences from devices which use similar frequency. Hence this project can tested with 802.11a mode which operates in 5GHz frequency range with 12 separate non-overlapping channels.

Further extending the scope, HCF can be coupled with another mechanism apart from EDCA (which is used as primary mechanism for QoS in this project) called *HCCA (HCF Controlled Channel Access).*

6. References

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