Performance evaluation of IEEE 802.11 MAC layer in supporting delay sensitive services

Dr. Jyotsna Sengupta[1] and Er. Gurpreet Singh Grewal[2]

[1]Reader & Head, Department of Computer Science, Punjabi University, Patiala
jyotsnasengupta@gmail.com

[2]Lecturer, Department of Information Technology, GNDEC, Ludhiana
gsgrewal01@gmail.com

ABSTRACT

Providing QoS requirements like good throughput and minimum access delay are challenging tasks with regard to 802.11 WLAN protocols and Medium Access Control (MAC) functions. IEEE 802.11 MAC layer supports two main protocols: DCF (Distributed Coordination Function) and EDCF (Enhanced Distributed Coordination Function). During the evaluation of EDCF, the performance of various access categories was the determining factor. Two scenarios, with same Physical and MAC parameters, one implementing the DCF and other EDCF, were created in the network simulation tool (OPNET MODELER [5]) to obtain the results. The results showed that the performance of EDCF was better in providing QoS for real-time interactive services (like video conferencing) as compared to DCF, because of its ability to differentiate and prioritize various services. Whereas the DCF's overall performance was marginally better for all kinds of services taken together.

KEYWORDS

QoS, wireless local area network, MAC, PCF, EDCF, Video Conferencing, Voice Over IP (VOIP).

1. INTRODUCTION

With the increasing demand and penetration of wireless services, users of wireless network now expect quality of service and performance comparable to what is available from fixed networks. Media Access Control (MAC) protocol in wireless networks controls and manages the access and packet transmission through the shared channel in a distributed manner, with minimum possible overhead involved [9]. A MAC protocol should provide an efficient use of the available bandwidth while satisfying the Quality of Service (QoS) requirements of both data and real-time applications. Real-time services such as streaming voice and video require a certain quality of service such as low packet loss and low delay to perform well [7]. To provide QoS for such kind of application, service differentiation is must.

The IEEE 802.11 standard specifies two access mechanisms, the contention based Distributed Coordinator Function (DCF), and the centralized solution known as the Point Coordination Function (PCF). Presently, however, in most available products, only DCF is implemented. As both the medium access control (MAC) layer and the physical (PHY) layer of 802.11 [1] are designed for best effort data transmissions, the original 802.11 standard does not take QoS into account. Hence to provide QoS support IEEE 802.11 standard group has specified a new IEEE 802.11e standard [3].

This paper is organized as follows: Section II describes the 802.11 DCF and the 802.11e EDCF. In section III we analyses the performance of EDCA in supporting Real-time traffic and compare DCF and EDCF. Finally section IV concludes the paper.

2. MAC PROTOCOLS

Distributed Coordination Function (DCF) is the currently used protocol that comes with an optional Point coordination Function (PCF) Protocol. Enhanced Distributed Coordination Function (EDCF) is the future protocol that promises to provide the QoS. The explanation of these protocols is as follows:

2.1 Distributed Coordination Function (DCF)

DCF is the basic and mandatory MAC mechanism of legacy IEEE 802.11 [1] WLANs. It is based on carrier sense multiple access with collision avoidance (CSMA/CA). Working of DCF is explained in this section as it is the basis for the Enhanced Distributed Channel Access (EDCA), which we discuss in this paper.

The 802.11 MAC works with a single first-in-first-out (FIFO) transmission queue [10]. 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 (or BC).For each slot time interval, during which the medium stays idle, the random BC is decremented. If a certain station does not get access to the medium in the first cycle, it stops its back-off counter, waits for the channel to be idle again for DIFS and starts the counter again. As soon as the counter expires, the station accesses the medium. Hence the deferred stations don't choose a randomized back-off counter again, but continue to count down. Stations that have waited longer have the advantage over stations that have just entered, in that they only have to wait for the remainder of their back-off counter from the previous cycle(s).

Each station maintains a contention window (CW), which is used to select the random back-off counter. The BC is determined as a random integer drawn from a uniform distribution over the interval [0, CW].The larger the contention window is the greater is the resolution power of the randomized scheme. It is less likely to choose the same random BC using a large CW .However, under a light load; a small CW ensures shorter access delays .The timing of DCF channel access is illustrated in Fig. 1.

An acknowledgement (ACK) frame is sent by the receiver to the sender for every successful reception of a frame. The ACK frame is transmitted after a 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 station's contention. The CW size is initially assigned CWmin 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 CWmax and another attempt with back-off is performed. After each successful transmission, the CW value is reset to CWmin.

All of the MAC parameters including SIFS, DIFS, Slot Time, CWmin, and CWmax are dependent on the underlying physical layer (PHY) [6]. DIFS is determined by SIFS+2*SlotTime, irrespective of the PHY.

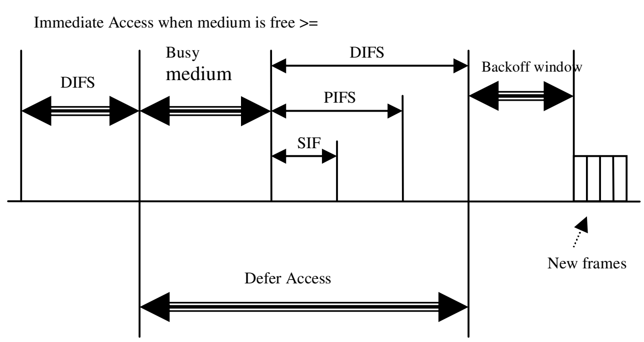

Fig.1. Timing relationship for DCF

2.2 Enhanced Distributed Coordination Function (EDCF)

EDCF is designed to provide prioritized QoS by enhancing the contention-based DCF. It provides differentiated, distributed access to the wireless medium for QoS stations (QSTAs) using 8 different user priorities (UPs).Before entering the MAC layer, each data packet received from the higher layer is assigned a specific user priority value. How to tag a priority value for each packet is an implementation issue. The EDCA mechanism defines four different first-in first-out (FIFO) queues, called access categories (ACs) that provide support for the delivery of traffic with UPs at the QSTAs. Each data packet from the higher layer along with a specific user priority value should be mapped into a corresponding AC according to table II. Note the relative priority of 0 is placed between 2 and 3.This relative prioritization is rooted from IEEE 802.1d bridge specification [4]. Different kinds of applications (e.g., background traffic, best effort traffic, video traffic, and voice traffic) can be directed into different ACs. For each AC, an enhanced variant of the DCF, called an enhanced distributed coordination function (EDCF), contends for TXOPs using a set of EDCF parameters from the EDCF Parameter Set element or from the default values for the parameters when no EDCF Parameter Set element is received from the QAP of the QBSS with which the QSTA is associated.

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

Table II. Details of Access Classes

Fig. 2 shows the implementation model with four transmission queues, where each AC behaves like a virtual station: it contends for access to the medium and independently starts its back-off after sensing the medium idle for at least AIFS period. In EDCA a new type of IFS is introduced, the arbitrary IFS (AIFS), in place of DIFS in DCF. Each AIFS is an IFS interval with arbitrary length as follows:

$$AIFS[AC] = SIFS + AIFSN[AC] \times \text{slot time}$$

Where AIFSN[AC] is called the arbitration IFS number and determined by the AC and the physical settings, and the slot time is the duration of a time slot. The timing relationship of EDCA is shown in Fig 3. The AC with the smallest AIFS has the highest priority. The values of AIFS[AC], CWmin[AC], and CWmax[AC], which are referred to as the EDCA parameters, are announced by the AP via beacon frames. The purpose of using different contention parameters for different queues is to give a low-priority class a longer waiting time than a high-priority class, so the high-priority class is likely to access the medium earlier than the low-priority class. An internal collision occurs when more than one AC finishes the back-off at the same time. In such a case, a virtual collision handler in every QSTA allows only the highest-priority AC to transmit frames, and the others perform a back-off with increased CW values.

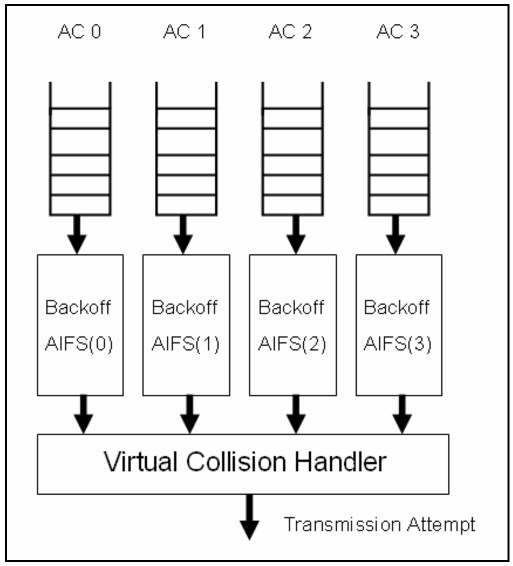

Fig.2. Implementation model

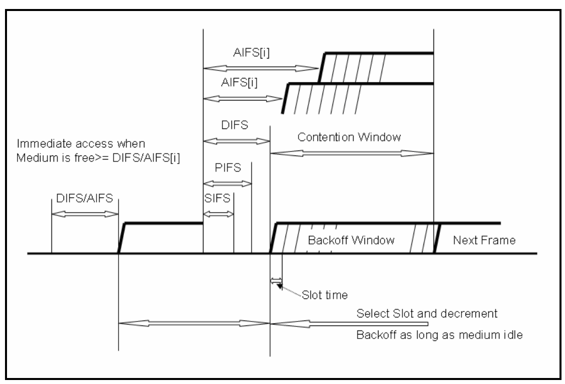

Fig.3. Timing relationship for EDCF

TXOP-Transmission opportunity is defined in IEEE 802.11e as the interval of time when a particular QSTA has the right to initiate transmissions. There are two modes of EDCA TXOP defined, the initiation of the EDCA TXOP and the multiple frame transmission within an EDCA TXOP. An initiation of the TXOP occurs when the EDCA rules permit access to the medium. A multiple frame transmission within the TXOP occurs when an EDCAF retains the right to access the medium following the completion of a frame exchange sequence, such as on receipt of an ACK frame. The TXOP limit duration values are advertised by the QAP in the EDCA Parameter Set Information Element in Beacon frames. 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. This is also referred to as contention free burst (CFB). In this paper, we only investigate the situation where a station transmits one data frame per TXOP transmission round.

3. SIMULATION EVALUATION

3.1 Simulation Setup

In this section we use network simulator (OPNET modular) to evaluate the performance of IEEE 802.11e EDCA mechanism [8]. We choose 802.11b as the PHY layer, and the PHY data rate is set to 11 Mb/s. The simulation parameters are shown in the table III.

AC	CWmin	CWmax
0	31	1023
1	31	1023
2	$(CW_{min}+1)/2 -1)$ Comes out to be 15	CW_{min} i.e. 15
3	$(CW_{min}+1)/4 -1$ Comes out to be 7	$(CW_{min}+1)/2 -1$ Comes out to be 15

Table III Simulation parameters

3.2 Simulation Analysis of EDCF

In case of EDCF, all four traffic classes were fed into the MAC layer from higher layer, which are corresponding to AC(0), AC(1), AC(2) and AC(3) respectively to check how efficient the new protocol is to provide service differentiation required for real time application. (Note that DCF does not support service differentiation, so no provision of Access category). For this, in the application profile of scenario (for EDCF protocol) different application was configured for different access category. Details are shown in the Table IV.

ACCESS CATEGORY	APPLICATION CONFIGURED	DESIGNATION
AC(0)	HTTP (LIGHT)	BACKGROUND
AC(1)	REMOTE LOGIN (HEAVY)	EXCELLENT EFFORT

AC(2)	VIDEO CONFERENCING	INTERACTIVE MULTIMEDIA
AC(3)	VOIP	INTERACTIVE VOICE

Table IV Access Category corresponding to an application

In the profile configuration, a profile for clients was configured that uses all the four applications. In simulation scenario, 15 stations were configured to use these services randomly. In the simulation, we assumed that each traffic class has the equal portion of the total data traffic in terms of the average number of packets generated per unit time. The results obtained are as follows:

3.2.1 Throughput of Different Access Categories

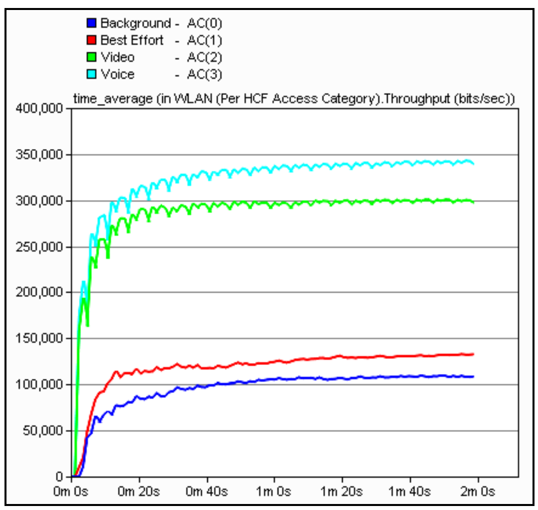

Figure 4 Throughput of Different Access Categories

In Figure 4, we can see Throughput of Access category 3 is way high than the Access category 0 and 1. Throughput for Access category 2 lies in between 3 and 1. It means that Throughput for applications like Voice over IP and Video conferencing, EDCF provides maximum Throughput by providing them more priority over the other services like simple HTTP.

3.2.2 Media Access Delay for Different Access Categories

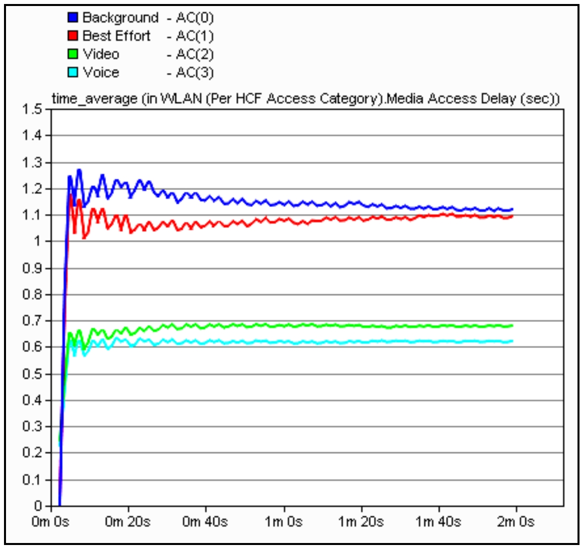

Figure 5. Wireless LAN - Media Access Delay

In Figure 5, we can see Media Access Delay for Access category 3 is less among all Access categories. Delay for Access category 1 lies in between AC(0) and AC(2), which is round about 0.1 seconds less than AC(0). It means that the medium is assigned to the application according to the priority. Thus, EDCF provides lesser Medium Access Delay for delay sensitive applications.

3.3 Comparative Analysis of DCF and EDCF

Next step is to check the performance of both protocols in terms of Throughput, Media Access Delay, Retransmission Attempts and Data Dropped. These four metrics are determining factors in terms of overall performance of both the protocols.

3.3.1 THROUGHPUT

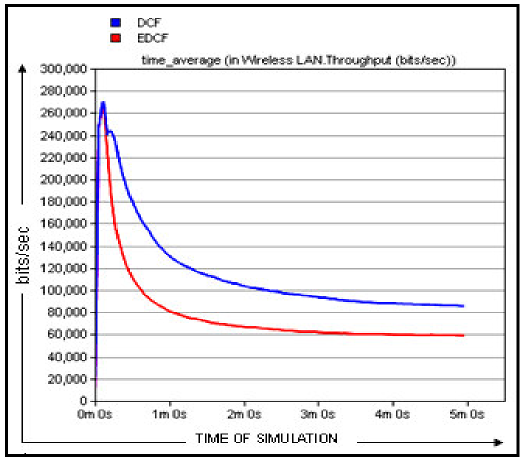

Figure 6. Throughput of DCF vs. EDCF

In Figure 6, we can see in first 30 seconds of simulation, Throughput of both DCF and EDCF is high, but then after that, it decreases with time and stabilizes for both protocols. Throughput in first 30 seconds is high due to less number of Retransmission Attempts (less number of backoff's). From Graph analysis, one fact is clearly visible, that curve of DCF is marginally higher than that of EDCF. We can conclude that DCF's overall Throughput is somewhat more than the EDCF.

3.3.2 Retransmission Attempts

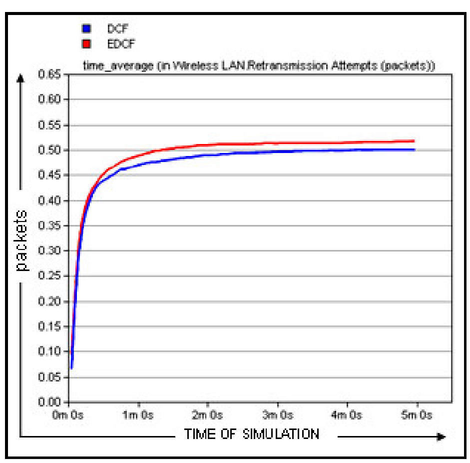

Figure 7. Retransmission Attempts of DCF vs. EDCF

In the Figure 7, we can see in first 30 seconds of simulation, Retransmission Attempts for both DCF and EDCF are less, but then after that, it decreases with time and stabilizes for both protocols. Retransmission Attempts in first 30 seconds are less due to less number of backoff's assigned to wireless stations. There is a small noticeable difference between curves of Retransmission Attempts of DCF and EDCF protocol. That small difference implies that the overall Retransmission Attempts made in DCF protocols are a bit lesser than EDCF protocol.

3.3.3 Media Access Delay

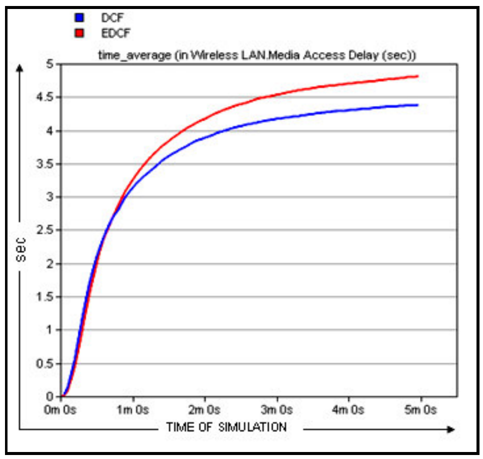

Figure 8. Media Access Delay of DCF vs. EDCF

In Figure 8, for the first minute of simulation the Medium Access Delay for both protocols increases at equal pace, and then after that, DCF suffers somewhat lesser Access Delay than EDCF. The increase in the Medium Access Delay for both protocols is due to increase in the number of nodes competing to gain access of medium.

3.3.4 Data Dropped

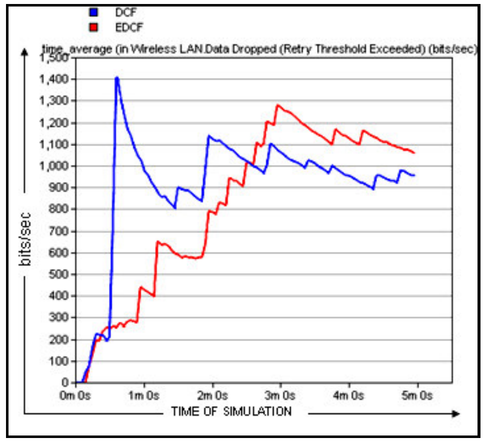

Figure 9. Amount of Data Dropped of DCF vs. EDCF

In Figure 9, after first 30 seconds of simulation, DCF suffers a sudden high Data Drop, but Data Drop in EDCF increases gradually. The reason of varying Data Drop gradually in EDCF is the service differentiation which provides priority based scheme to handle different kind of data. After 2.5 minutes of simulation, curves of Data Dropped of DCF and EDCF intersects each other, EDCF finishes at somewhat more Data Dropped than DCF.

4. CONCLUSION

The results obtained from simulation shows that Enhanced Distribution Coordination Function provides efficient mechanism for service differentiation and hence provides quality of service to the Wireless LAN. However, this improvement comes at a cost of a decrease in quality of the lower priority traffic up to the point of starvation. The acquisition of the radio channel by the higher priority traffic is much more aggressive than for the lower priority. Higher priority traffic benefited, while lower priority traffic suffered. In terms of overall performance (under the used simulation conditions in this particular study of QoS of Wireless LAN), DCF performs marginally well than EDCF. This happens due to reason that in EDCF mechanism, each AC function acts like a virtual station for medium access, so more collision will be expected for EDCF scenario. But in terms of Quality of Service for delay sensitive applications (like Video conferencing) EDCF outperforms DCF. EDCF has been purposed as the medium access control protocol for IEEE's upcoming standard IEEE 802.11e.

ACKNOWLEDGEMENTS

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