

QoS Issues of Media Access Delay and Throughput in WLAN

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Abstract

To analyze the performance of various MAC protocols in providing QoS to users of WLAN, the metrics used were Throughput, Data Drop, Retransmission and Medium Access Delay. 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) 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. In a network environment, where support for realtime interactive services is required, EDCF protocol should be used.

1. Introduction

Wireless refers to the transmission of voice and data over radio waves. It allows its users to communicate with each other without requiring a physical connection to the network. Wireless devices include anything that uses a wireless network to either send or receive data [Ivan Stajmenovic, 2002].

Wireless communication has become the most promising way to connect people. Cellular systems have experienced exponential growth over the last decade and there are currently around two billion users worldwide. In 1895, a few decades after the telephone was invented, Marconi demonstrated the first radio transmission. Early radio systems transmitted analog signals. The first digital network based on packet radio, ALOHANET, was developed at the University of Hawaii in 1971. The Defense Advanced Research Projects Agency (DARPA) invested significant resources to develop it. In 1990, the first digital communication based cellular system was introduced. Since then, Radio technology advanced rapidly to enable transmissions over larger distances with better quality and less power. It enabled mobile communications and wireless networking [Ivan Stajmenovic, 2002].

Existing models of wireless transmission errors are generally simple two-state Markov models, e.g. the

Gilbert-Elliott model developed in 1960s; these models have questionable relevance to modern networks. In particular, the parameters for these models have largely persisted substantiated by actual measurements from real modern networks. These models also often fail to accurately characterize the distribution tail, which is critical when attempting to establish network coverage across whole environments.

Wireless Technologies	Standard	Data Rate	Frequency Band	Range
Personal Area Networks	Bluetooth	1 – 22.4 Mbps	5 GHz	10 m
	IR	1 – 15 Mbps	0.76 – 1.33 MHz	5 m
Local Area Networks	WLAN	11/54 Mbps	2.4/5 GHz	50 - 150m
	Hiperlan	20 Mbps		
Wide Area Networks	GSM	9.6 Kbps		30 Km
	GPRS	170 Kbps		

Fig. 1 Wireless Technologies Summary

Medium Access Control (MAC) Sublayer

The Media Access Control (MAC) data communication protocol sub-layer, also known as the Medium Access Control, is a sublayer of the Data Link Layer specified in the seven-layer OSI model (layer 2). It provides addressing and channel access control mechanisms that make it possible for several terminals or network nodes to communicate within a multipoint network, typically a local area network (LAN) or metropolitan area network (MAN).

The MAC sub-layer acts as an interface between the Logical Link Control (LLC) sublayer and the network's physical layer. The MAC layer emulates a full-duplex logical communication channel in a multipoint network. This channel may provide unicast, multicast or broadcast communication service.

The MAC layer addressing mechanism is called physical address or MAC address. This is a unique serial number assigned to each network adapter, making it possible to deliver data packets to a destination within a subnetwork, i.e. a physical network consisting of one or several network segments interconnected by repeaters, hubs, bridges and switches, but not by IP routers. An IP router may interconnect several subnets.

Physical Layer

The Physical layer provides the transmission of bits through a communication channel by defining electrical,

mechanical, and procedural specifications. Modulation, which is a Physical layer function, is a process in which the radio transceiver prepares the digital signal within the network interface card (NIC) for transmission over the airwaves. Spread spectrum “spreads” a signal’s power over a wider band of frequencies, sacrificing bandwidth in order to gain signal-to-noise performance [Ivan Stajmenovic, 2002]. Main layer to be analyzed is MAC layer.

Perspectives of QoS Problem

Quality of services problem has two major perspectives: Network and Application/user.

Network Perspective

From Network Perspective, QoS refers to the service quality or service level that the network offers to applications or users in terms of network QoS parameters, including: latency or delay of packets traveling across the network, reliability of packet transmission, and throughput.

Application/User Perspective

From Application/User Perspective QoS generally refers to the application quality as perceived by the user. That is, the presentation quality of the video, the responsiveness of interactive voice, and the sound quality of streaming audio. We group applications and users in the same category because of their common way they perceive quality.

Layered QoS

The layered QoS approaches (philosophies) separate QoS aspects on each layer. In layered QoS approach each layer’s functions are considered important and determining to improve the quality of service of network. The performance of Transport, Network and data link layer is the most crucial factor among the other layers of OSI model.

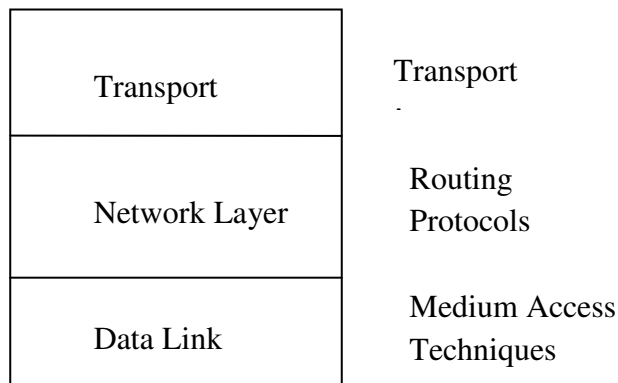


Fig. 2 Layered QoS Approaches

As there has been lot of work done in Transport and Network layer, the performance of both layers in supporting QoS of WLAN is at acceptable level. But the data link layer is still lagging behind. IEEE 802.11, the official body that sets the standards for WLANs is continuously making efforts to improve it. In year 2005, IEEE passed a new standard 802.11e to provide QoS in WLANs [Curtis A. Schwaderer]. A new protocol, EDCF in place of existing DCF has been purposed.

Distributed Coordination Function (DCF)

Distributed Coordination Function is the basic access mechanism used in IEEE 802.11.

It uses a Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) algorithm to mediate the access to the shared medium. Before discussing DCF, there is terminology used in technicalities of the algorithm that one needs to know; that are as follows:

IFS (Inter Frame Space) is the time a station waits when the medium is idle before attempting to access it.

IEEE 802.11 defines several IFSs, and by using shorter IFS, the medium is accessed prior to stations using longer IFS. The standard defines four IFS in ascending order of time, in other words, descending order of priority.

SIFS (Shortest IFS) – control packets such as acknowledgements use SIFS

PIFS (Priority Coordination Function IFS) – used if PCF mode.

DIFS (Distributed Coordination Function IFS) – used in case of sending data packets and management packets (such as beacons).

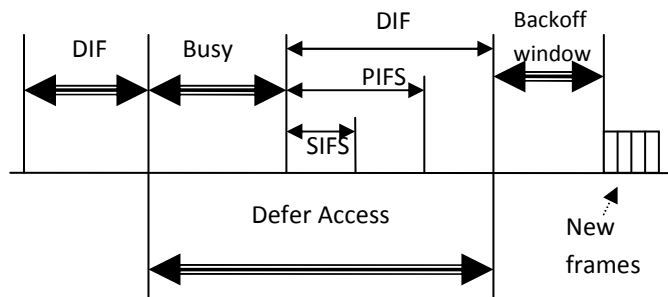
EIFS (Extended IFS)

Therefore, in an event of contention, acknowledgment will have higher priority than data and management packets. The algorithm is explained as follows:

Whenever a data frame is to be sent, the station senses the medium. If it is free for at least a DCF interframe space (DIFS) period of time, the frame is transmitted. Otherwise, if the medium is busy, a backoff time B (measured in time slots which depends upon the characteristic of physical layer) is chosen randomly in the interval [0, CW], where CW is the contention window. After the medium has been detected idle for at least a DIFS, the backoff timer is decremented by one for each time slot the medium remains idle. If the medium becomes busy during the backoff process, the backoff timer is paused, and is restarted when the medium has been sensed idle for a DIFS again. When the backoff timer reaches zero, the frame is transmitted. Upon detection of a collision (which is detected by the absence of an acknowledgment frame to the data frame), the contention window is redefined according to Equation (1).

$$CW[i] = 2^{(k+i)} - 1 \quad - \quad (1)$$

Where i is the number of attempts (including the current one) to transmit the frame that has been done, and k is a constant defining the minimum contention window, $CW_{min} = 2^k - 1$. A new backoff time is then chosen and the backoff procedure starts over. The backoff mechanism is also used after a successful transmission before sending the next frame. After a successful transmission, the co



ntention window is reset to CW_{min} .

Fig. 3 Interframe Space relationships

Point Coordinator Function

PCF is a polling-based access mechanism which requires the presence of a base station that acts as Point Coordinator (PC) [Rajmohan Rajaraman, 2005]. If PCF is supported, both PCF and DCF coexist and, in this case, time is divided into superframes as shown in Figure 4 of Superframe of IEEE 802.11. Each superframe consists of a contention period where DCF is used and a contention free period (CFP) where PCF is used. The CFP is started by a special frame (a beacon) sent by the base station. Since the beacon

Details of Access Classes

is sent using ordinary DCF access method, the base station has to contend for the medium, and therefore, the CFP may be shortened.

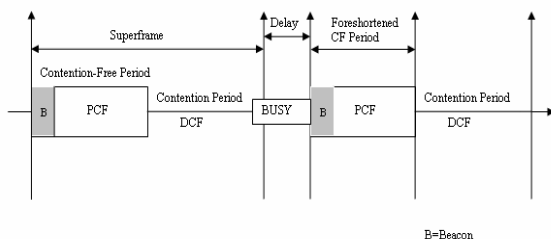


Fig. 4 Superframe of IEEE 802.11

The PC keeps a list of mobile stations that have requested to be polled to send data. During the CFP, it sends poll frames to the stations when they are clear to access the medium. Upon reception of a poll frame, the station sends

a data packet if it has any packet queued. To ensure that no DCF stations are able to interrupt this mode of operation, the IFS between PCF data frames is shorter than the usual DIFS. This space is called a PCF Interframe Space (PIFS). To prevent starvation of stations that are not allowed to send during the CFP, there must always be room for at least one maximum length frame to be sent during the contention period.

Enhanced Distributed Coordination Function

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. The EDCF 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 shown here [S. Choi, 1997].

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

Note that the relative priority of 0 is placed between 2 and 3. This relative prioritization is rooted from IEEE 802.1d bridge specification. Different kinds of applications (e.g. best effort traffic, video traffic, and voice traffic) can be directed into different Figure shows the implementation model with four transmission queues.

ACs. For each AC, an enhanced variant of the DCF, called an enhanced distributed channel access function (EDCAF), contends for TXOPs (Transmission Opportunities).

Where each AC behaves like a virtual station: it contends for access to the medium and independently starts its backoff after sensing the medium idle for at least AIFS period. In EDCF a new type of IFS is introduced, the arbitrary IFS (AIFS), in place of DIFS in DCF [Rajmohan Rajaraman, 2005]. 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 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 EDCF parameters, are announced by the AP (Access point) 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 backoff 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 backoff with increased CW values [Marko Hannikainen, 2003].

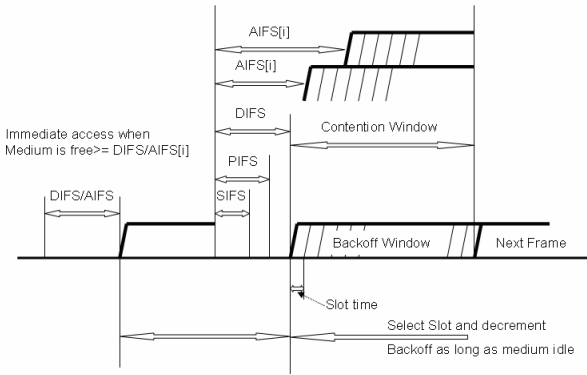


Fig. 5 The timing relationship of EDCF

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 EDCF TXOP defined, the initiation of the EDCF TXOP and the multiple frame transmission within an EDCF TXOP [Weihua Helen Xi, 2006]. An initiation of the TXOP occurs when the EDCF rules permit access to the medium. A multiple frame transmission within the TXOP occurs when an EDCF 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 (QoS station) in the EDCF Parameter Set Information Element in Beacon frames. During an EDCF 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 [Marko Hannikainen, 2003]. This is also referred to as contention free burst (CFB). In this thesis, we only investigate the

situation where a station transmits one data frame per TXOP transmission round.

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 here.

Access Category	Application Configured	Designation
AC(0)	HTTP (LIGHT)	BACK GROUND
AC(1)	REMOTE LOGIN (HEAVY)	EXCELLENT EFFORT
AC(2)	VIDEO CONFERENCING	INTERACTIVE MULTIMEDIA
AC(3)	VOIP	INTERACTIVE VOICE

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:

Throughput of Different Access Categories

In Figure 6, 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.

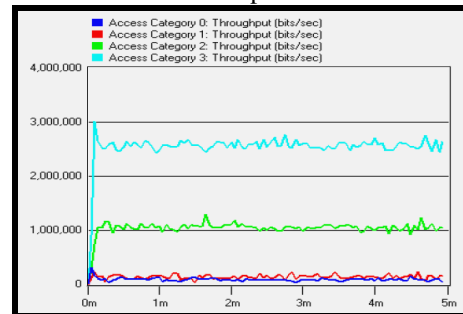


Fig. 6 Throughput of Different Access Categories

Media Access Delay for Different Access Categories

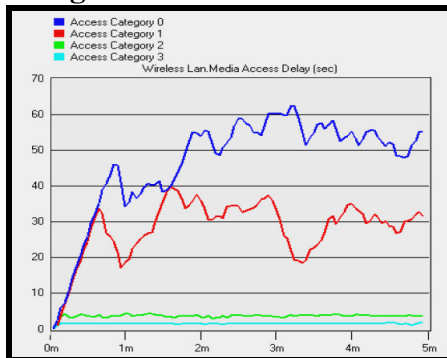


Fig. 7 Wireless LAN - Media Access Delay

In Figure 7, we can see Media Access Delay for Access category 3 is minimum among all Access categories. Throughput for Access category 2 is just 3 to 4 seconds more than AC(3). It means that the medium is assigned to the application according to the priority. Thus, EDCF provides lesser Medium Access Delay for realtime applications.

Comparative Analysis of DCF and EDCF

Next step is to check the performance of both protocols in term of Throughput. This metric is determining factors in terms of performance of both the protocols.

Throughput

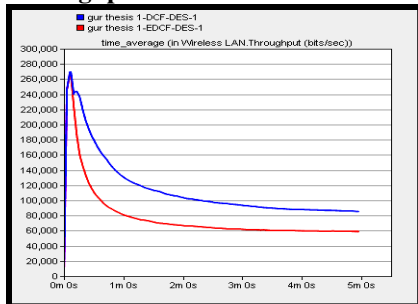


Fig. 8 Throughput of DCF vs. EDCF

In Figure 8, 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.

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