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Performance Analysis of Industrial WLAN Based on EDCA Scheme Defined in IEEE802.11e

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Abstract

In the last few years wireless local area network (WLAN) technology and products have grown unusually. This growth has encouraged many researchers to employ WLAN technology in different application Areas. Recently, using IEEE 802.11 WLAN in industrial automation applications is attractive and more interesting. However, the currently used medium access mechanism makes WLANs non-deterministic and hence not suitable for industrial real-time traffic. Legacy IEEE 802.11 WLANs were initially designed for best effort traffic only and did not provide any QoS support for this kind of traffic. The new amendment IEEE 802.11e standard was introduced and ratified in 2005. It defines the concept of a Hybrid Co-ordination Function (HCF) at the MAC layer for medium access control. HCF is a combination of HCF Controlled Channel Access (HCCA) with parameterized quality of service (QoS) and Enhanced Distribution Channel Access (EDCA) with prioritized QoS. Enhanced Distribution Channel Access (EDCA) is an enhanced version of Distributed Coordination Function (DCF) mechanism used in the original IEEE 802.11 WLAN. This paper analyze the performance of the EDCA in an industrial automation network with real-time requirements by means of a simulation with the network simulator OPNET 11.5 and compares the results with the DCF in terms of latency and throughput in various scenarios.

Keyword: Industrial WLAN, EDCA mechanism, Delay, Throughput, Real-Time Traffic

تحليل أداء شبكة لاسلكية محلية صناعية قائمة على تقنية الوصول (EDCA) المعرفة في المقياس IEEE 802.11e

الخلاصة

في السنوات القليلة الماضية تطورت تقنية الشبكة اللاسلكية المحلية بشكل كبير جدا. هذا التطور شجع الكثير من الباحثين على استخدام هذه التقنية في مجالات عديدة. استخدام تقنية الشبكة اللاسلكية المحلية في التطبيقات الصناعية في الوقت الحالي جذب الكثير من الاهتمام. على أي حال فان استخدام تقنية الشبكة اللاسلكية المحلية مع تقنية الوصول الحالية غير مناسب لتطبيقات الزمن الحقيقي الصناعية. الشبكة اللاسلكية المحلية مصممة في الأساس للتعامل مع البيانات من نوع (Best effort) وغير مجهزة بأي جودة خدمة. المقياس المحسن IEEE 802.11e قدم لأول مرة عام 2005. هذا المقياس يعرف مفهوم دالة التنسيق المختلط (HCF) في طبقة أل MAC لسيطرة الوصول للوسط. دالة أل HCF مركبة من دالة الوصول المسيطر للقنوات (HCCA) المجهزة بعاملية جودة الخدمة ودالة تعزيز الوصول إلى قنوات التوزيع (EDCA) المجهزة بأولوية جودة الخدمة. دالة أل EDCA هي عبارة عن نسخة محسنة من دالة الوصول الموزعة للوسط DCF. في هذا البحث يتم تحليل أداء تقنية الوصول أل EDCA عند استخدامها في البيئات الصناعية باستخدام حزمة المحاكاة ألـOPNET ومقارنة النتائج مع دالة DCF بمفهوم زمن التأخير والعطاء من خلال بناء عدة سيناريوهات تحاكي التطبيقات الصناعية.

الكلمات الدالة: الشبكة اللاسلكية المحلية الصناعية، تقنية أل EDCA ، التأخير، العطاء، بيانات زمن– حقيقي

Introduction

Wireless technologies acquire more important place in market every day. Their utilization is being investigated not only in telecommunication, but also in industry. At present, wireless communications are used in industrial environments mainly to enable simpler and more cost-effective maintenance and diagnostics functions [1].

Wireless solutions and products today available on the market are generally considered unsuitable for implementing distributed control applications and systems, in particular for real time applications. This is due to a number of reasons: for instance, because of radio interferences, it is not possible to grant fully deterministic behavior. Wireless transmissions are quite sensitive to electromagnetic noise, and this can significantly affect the robustness of the control system, while this problem is far less serious for "wired" communications[1].

IEEE 802.11 WLAN is one of the most deployed wireless technologies all over the world and is likely to play a major role in next-generation wireless communication networks. The main characteristics of the 802.11 WLAN technology are simplicity, flexibility and cost effectiveness [2] [3].

Higher degrees for flexibility, throughput and extension are usually demanded in such industrial applications. Keeping power consumption low is not a key issue in these cases. This implies that when the need arises for wireless communication at industrial environments, WLANs are probably the most suitable choice. In addition, commercial off-the-shelf equipment is already widely available at low cost and can be readily embedded in workstations and controllers that rely on standard platforms [1].

The IEEE 802.11 is a standard that defines the specifications of both Physical (PHY) and Media Access Control (MAC) layers of WLAN. According to that standard mandatory distributed coordination function (DCF) and an optional point coordination function (PCF) are the two medium access coordination functions at MAC layer. The IEEE 802.11 based WLAN is initially designed only for the best effort data traffic and have proven their ability to send data at higher rates and robust in so many environments. But it does not provide any support for real-time traffic. If we want to use wireless components in industrial automation, where reliable and time conscious communication is a demanded factor, the real-time behavior must be considered because whether it is Ethernet or wireless, industrial automation system has rigorous requirements on quality of service (QoS) such as jitter and delay.

This implies that, unless suitable mechanisms are adopted (e.g., the point coordination-based access scheme to avoid collisions), WLANs are not suitable to connect field devices in industrial applications. In addition, the lack of support for prioritized data exchanges in legacy 802.11 networks has made very difficult so far to obtain a quasi-real-time (or soft-real-time) behavior, as demanded by lots of industrial applications, in particular in the automation field [4].

Even the contention-free PCF channel access mechanism, which has been specifically designed to support time-bounded services, can provide only some limited QoS support. This is primarily due to its unpredictable beacon delays that may introduce unpredictable time delays in the Contention-Free Period (CFP). Furthermore, the unknown transmission durations of each polled station that is not under the control of the point coordinator may reduce the QoS provided to the other polled stations. PCF is also rarely implemented in commercial products due to its complexity and inefficiency concerning normal data transmission [3].

However, without doing any modifications to the MAC layer of IEEE 802.11 standard make it not suitable for many industrial applications as QoS cannot be guaranteed. The upcoming IEEE 802.11e standard faces this problem and might therefore be a potential technology to be used in wireless industrial application [4].

IEEE 802.11e is supposed to eliminate the lack of predictability of communication delays, which was a major problem in the legacy version. The performance and applicability of the upcoming standard IEEE 802.11e in industrial applications is of high interest for the automation industry and will therefore be analyzed in this paper.

The current work is investigating performance analysis of EDCA scheme defined in IEEE 802.11e WLAN standard in industrial environments. The main target of this paper is to investigate the effect of non real-time traffic upon the behavior of real-time traffic (by real-time traffic we mean small sized packets, generated in periodic intervals). We studied end-to-end delay and throughput by means of OPNET modeler.

This paper is organized as follows: Section II includes a survey of related works; Section III briefly explores DCF and EDCA mechanism and explains the differences between them. Section IV illustrates the simulation framework, section V describes the simulation topology with a discussion of simulation results and finally section VI provided conclusions.

Literature Review

In recent years, the performance of EDCA has been explored by means of not only simulation but also analytical evaluations. Most of the EDCA analytical studies are based on the modifications of DCF analysis [5].

Sh. Tariq[6] evaluated the performance of IEEE 802.11e MAC layer with different Access Categories (ACs). They compared between different values of 802.11e legacies to show that EDCA provides differentiated channel access for different traffic types and is better equipped to handle real-time applications with stringent QoS requirements.

Kong et. al.[7] presented a development of an analytical model. They analyzed the throughput performance of differentiated service traffic and proposed a recursive method capable of calculating the mean access delay. Service differentiation functionality and effectiveness of the EDCA are investigated through extensive numerical and simulation results.

Xiong and Mao[8] proposed a novel Markov chain model with a simple architecture for EDCA performance analysis under the saturated traffic load. The effect of using different Arbitration InterFrame Spaces (AIFSs) is analyzed and the possibility that a station's back off procedure may be suspended due to transmission from other stations is considered.

Liu and Niu [9], proposed a traffic models for different kinds of applications to convert the unsaturated system into an equivalent saturated system and calculated out the queuing delay in the sender buffer. They presented a new analysis model to analyze the backoff delay and packet loss rate of all kinds of applications under the IEEE 802.11e Enhanced Distributed Channel Access (EDCA).

Moraes et al [10] evaluated the limitations of the highest priority level of the EDCA mechanism (voice category) when supporting real-time communication. A realistic error-prone model channel was used to measure the impact of interferences against an error-free channel.

Moraes et al[11] analyzed the timing behavior of the EDCA function, when it is used to support real-time traffic. They assess the behavior of the voice category in open communication environments (i.e., a communication environment subject to external disturbances) when this access category is used to transfer real-time traffic.

Cena et al [12] presented a number of experiments, aimed at measuring the statistical distribution of response times in real 802.11g and 802.11e WLANs when the traffic patterns they support resemble those effectively found in industrial communication systems. Results have been validated both by means of a simple computational model, and by using a network simulator.

On the other hand performance of IEEE 802.11e based HCCA mechanism has also evaluated in industrial wireless networks [13-15]. HCCA provides traffic parameterization and enables contention-free access to the shared medium. Despite this mechanism seems to be very interesting and suitable for industrial systems [1], the implementation of HCCA still contains many unresolved issues [3]. A further drawback of HCCA lies in the difficulties (in terms of both costs and complexity) associated with its actual implementation. This is why, actually, WLAN interfaces that are implementing it are still difficult to find on the market.

IEEE 802.11e Contention-Based Channel Access

Many researchers have shown much interest in developing new medium access schemes to support QoS. Accordingly the IEEE 802.11 working group developed a new standard called IEEE802.11e to enhance the original IEEE802.11 medium access control (MAC) sublayer to support QoS. The original IEEE802.11 WLAN MAC sublayer employs a distributed coordination function (DCF) based on CSMA/CA for medium access, and it is best known for its asynchronous best effort data transfer [16].

DCF is a distributed medium access scheme. It works according to the “listen before talking” principle [1]. In this mode, a station must sense the medium before initiating a packet transmission by PHY and MAC layer virtual carrier sensing. If the medium is found idle for a time interval longer than Distributed InterFrame Space (DIFS), then the station can transmit the packet directly. Otherwise, the transmission is deferred and the backoff process is started. Specifically, the station computes a random time interval named Backoff time, uniformly distributed between zero and the current Contention Window size (CW):

$$\text{Backoff Time} = \text{rand}\,[0; CW] \times a\,\text{SlotTime} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where CWmin < CW < CWmax and Slot time depends on the PHY layer type. The backoff timer is decreased only when the medium is idle, whereas it is frozen when another station is transmitting. Each time the medium becomes idle, the station waits for a DIFS and then continuously decrements the backoff timer. As soon as the backoff timer expires, the station is authorized to access the medium. Obviously, a collision occurs if two or more stations start transmission simultaneously.

Unlike wired networks (e.g. CSMA/CD), in wireless environment collision detection is impossible due to the significant difference between transmitted and received power levels. Hence, a positive acknowledgement is used to notify the sender that the transmitted frame has been successfully received, see Figure (1). The transmission of the acknowledgement is initiated at a time interval equal to the Short InterFrame Space (SIFS) after the end of the reception of the previous frame. Since the SIFS is smaller than the DIFS, the receiving station does not need to sense the medium before transmitting an acknowledgement. If the acknowledgement is not received, the sender assumes that the transmitted frame was lost and schedules a retransmission and then enters the backoff process again. To reduce the probability of collisions, after each unsuccessful transmission attempt, the contention window is doubled until a predefined maximum value CWmax is reached. To improve the channel utilization, after each successful transmission, the contention window is reset to a fixed minimum value CWmin. The Network Allocation Vector (NAV) is used for MAC virtual carrier sensing, by updating the local NAV with the value of other stations' transmission duration. By using NAV, a station can know when the current transmission ends and channel is idle.

In order to solve the so-called hidden terminal problem, an optional RTS/CTS (RequestToSend and ClearToSend) scheme is introduced, see Figure (2). The transmitter sends a short RTS frame (20 octets) before each data frame transmission. Note that a collision of the short RTS frames is less severe and probable than a collision of data frames (up to 2346 octets). The receiver replies with a CTS frame if it is ready to receive and the channel is reserved for the duration of packet transmission. When the source receives the CTS, it starts transmitting its frame, being sure that the channel has been reserved for it during the entire frame transmission duration. All other stations in the Basic Service Set (BSS) update their Network Allocation Vectors (NAVs) whenever they hear a RTS, a CTS or a data frame. The overhead of sending RTS/CTS frames becomes considerable when data frame sizes are small, thus the channel is used suboptimally. Moreover, very large frames may reduce transmission reliability, e.g. an uncorrectable error in a large frame wastes more bandwidth and transmission time than an error in a shorter frame. So another optimization parameter of fragmentation_threshold is used. That means, when data frame size is larger than this threshold, the data frame will be partitioned into several smaller MAC level frames [2].

To optimize DCF performance, a number of parameters can be tuned (beacon interval, use of request/clear to send [RTS/CTS] frames, frame fragmentation threshold, etc.). These parameters are basically station-based and therefore cannot effectively differentiate multiple flows within a station. In addition, unsolved problems of PCF led to fervent activities within the IEEE 802.11 working group to enhance the MAC protocol [3].

Therefore QoS enhancement have been carefully investigated and evaluated in the past years. In 2005 a new standard was developed, the IEEE 802.11e, which is an amendment to the original IEEE 802.11. The amendment IEEE 802.11e adds QoS to the MAC layer in the IEEE 802.11 standard and is independent of what physical layer in use. IEEE802.11e introduces the new Hybrid Coordination Function (HCF) for the medium access, which consists of the contention based Enhanced Distributed Channel Access (EDCA) for prioritized QoS along with contention free HCF Controlled Channel Access (HCCA). These new functions are built on DCF defined in the 802.11 legacy model as shown in Figure (3).

IEEE 802.11e EDCA extends the DCF mechanism by introducing priority-based differentiated medium access for several traffic categories. The EDCA mechanism defines four access categories (ACs) that provide support for the delivery of traffic with user priorities (UPs) (defined by IEEE 802.11D) at the stations. An AC is assigned to each frame before it enters the MAC layer based on its user priority (UP) or its frame type according to the Table(1) [9]:

Traffic arriving on the eight Ups is mapped onto 4 different access categories (ACs), conceived for voice *(AC_VO)*, video *(AC_VI)*, best-effort *(AC_BE)*, and background *(AC_BK)* traffic, respectively. Each access categories equipped with a single transmit queue as shown in Figure (4)[1].

Different levels of service are provided to each of the ACs, based on three independent mechanisms: the Arbitration Interframe Space (AIFS), the Transmission Opportunity time interval (TXOP), and the Contention Window (CW) size. For a station operating under EDCA, each frame will wait that the medium remains idle during an AIFS [AC] interval. The duration of the AIFS [AC] interval is given by:

$$AIFS\ [AC] = AIFSN\ [AC] \times a\ SlotTime + a\ SIFSTime \quad \ldots (2)$$

Where the AIFSN [AC] is a positive integer that must be greater than or equal to 2 for all stations, except for the QoS Access Points (QAPs), where it will be greater than or equal to 1.

The default parameters defined for the EDCA mechanism are presented in Table (2). The aCWmin and aCWmax parameters depends on the characteristics of the physical (PHY) layer, for example, in the IEEE 802.11a PHY mode aCWmin = 15 and aCWmax = 1023. Figure (5) shows the relationships between the multiple AIFSs in the DCF and EDCA mechanisms. It is worth mentioning that default AIFSN value for the voice category is 2. Thus, AIFS [VO] = AIFS [VI] = DIFS.

Traditionally, the performance analysis of IEEE 802.11e communications is carried out considering typical multimedia traffic requirements. That is, requirements usually applied for transferring voice and video streams together with background traffic. However, when the communication services are used to support factory floor industrial applications, specific communication requirements must also be considered, including specific hard real-time and reliability constraints [10].

Simulation Framework

A simple way to exploit EDCA in distributed industrial applications is to reserve the higher access categories (video and, mostly, voice-grade traffic) for real-time data exchanges, whereas the lowest ones (best effort and background) are left for non real-time activities (e.g., device parameterization or software updates) [1][9][10].

In this paper OPNET is used as a simulation tool. OPNET does not offer data acquisition as a standardized application so we depend on the procedure adopted in [17], which developed an efficient way to simulate field devices. As depicted in [17], videoconference is a most suitable application that can be used to simulate industrial real-time applications using OPNET network simulator.

By real-time communication, we mean small-sized packets generated in periodic intervals that must be delivered before the end of the message stream period. So a videoconference application is modified to simulate real-time traffic (i.e. small-sized packet in periodic intervals) for real-time stations. These real-time periodic data exchanges are intended to model both sensor messages sent to plant controllers, and output messages sent from plant controllers to the actuators.

For non real-time traffic, FTP application is used to represent interfering traffic from nearby IEEE 802.11 stations, which transmit on the same radio channel as WLAN real- time stations. These stations are modeled as source of best effort traffic.

Simulation Topology

For such type of application domains, the support of reliable communication is one of the major requirements. For instance, in automation systems, real-time control data must be periodically transferred between sensors, controllers and actuators according to strict transfer deadlines.

In this paper, we are interested in the packet end_to_end delay of IEEE 802.11e based EDCA when it is used to support communications in industrial environments in saturation state (before reaching dropping threshold). Packet end_to_end delay can be calculated theoretically using equations (3) & (4):

Packet end_to_end delay= WLAN delay + node delay ………………………….. (3)

Where:

Node delay= (1/packet processing speed) + (queuing delay inside node's buffer) ..... (4)

The simulation scenarios were built considering two modes of operation: an *ad hoc* network topology, and *infrastructure* network topology where multiple non real-time stations and real-time stations are operating in the same frequency band. It is assumed that all stations are within the range of transmission of each other and there is neither node mobility nor hidden stations and there is no channel error. Real-time stations only transfer real-time messages, using the default set of parameters defined by the EDCA mechanism (Table 1) for video (VI) access category. Non real-time stations (stations that are out of the sphere-of-control of the real-time architecture) are intended to model external traffic sources that are sharing the communication medium with the real-time traffic sources. These stations transmit best effort traffic using the default set of parameters defined by the EDCA mechanism (Table 1).

IEEE 802.11e can be based on any physical layer specified for IEEE 802.11. First of all we start our simulation by test the suitable standard to be used as a physical layer to implement IEEE 802.11e standard. For simplicity we create a network contains two nodes, one act as sensor node and the other as controller-actuator node. The network was examined by setting two parameters: packet size (in byte) and packet production rate (in packet/sec). We assumed two states as the boundaries of the system:

a. Short packet size (which assumed to be 100 byte [17]) with maximum packet production rate.
b. Long packet size (which assumed to be 500 byte [17]) with maximum packet production rate.

The effect of packet production rate on the throughput of the system in each case was examined by varying packet production rate until reaching saturated throughput (before reaching dropping threshold). The packet processing speed of sensor node is assumed to be 5000 packet/sec which reflects CPU speed of ≈250 MHz [17]. The area over which the sensor and controller-actuator nodes are place extend for 100 × 100m which supposed to be reasonable area in factory floor. For controller-actuator node, the packet processing speed is chosen to be 20000 packet/sec(≈ 2 GHz) in order to serve more requests from the different sensor nodes. Each network operates at maximum allowed speed. The simulation results are listed in Tables (3) and (4).

It can be noted from the results that a network woks with IEEE 802.11a can achieve maximum throughput and minimum time delay in ad hoc mode and infrastructure mode. So the physical parameters of IEEE 802.11e will be based on the IEEE 802.11a PHY mode where aCWmin = 15 and aCWmax = 1023 with a network speed of 54Mbps.

For better analysis a different network loads were examined. Two different scenarios were considered: The first scenario is small population scenario with 5 real-time stations and 5 non real-time stations, while the second scenario is large population scenario with 25 real-time stations and 25 non real-time stations.

The real-time traffic generator generates packets according to the distribution of packet interarrival time (packet production rate) and packet size. The distribution of packet interarrival time can be any distribution. In this paper we study the network under saturation traffic, so we use constant packet interarrival time.

Before starting the scenarios, the saturated throughput must be fixed for each network. We find the maximum packet production rate for each number of stations using the same procedure explained above. The packet size is assumed to be 100 byte (small packet size). The results are listed in the Table (5) and (6).

The Max. packet rate will be used as the packet production rate in the two scenarios which represent a network load about 8% of the total network load in ad hoc mode and about 4% of the total network load in infrastructure mode.

First scenario

In this scenario, we study the packet end-to-end delay and throughput for real-time traffic which is supposed to be the high access category (AC_VI). The network contains 5 real-time stations and 5 non real-time stations modeled as low access category (AC_BE). The results are shown in Figures (6) and (7) for ad hoc mode and infrastructure mode. As we can from Figure (6) that the average time delay (packet end_to_end delay) for the network based DCF mechanism is about 50 ms while in EDCA it is about 0.45 ms in ad hoc mode. Figure (2) shows that the average time delay (packet end_to_end delay) for the network based DCF mechanism is about 84 ms while in EDCA it is about 0.7 ms in BSS mode. By contrast, factory automation systems usually require shorter cycle times, in the typical range between 1 and 10 ms, that may also shrink below 1 ms in some particular condition (e.g., motion control) [1]. So the results show that using EDCA access mechanism greatly enhances the time behavior of WLAN in industrial applications.

The throughput in terms of OPNET is the number of packets that are successfully received at the receiving end calculated as bits/s. The resulted throughput for DCF mechanism and EDCA mechanism is listed in Table (7) and (8). The results shows that the throughput for EDCA mechanism remains constant and it didn’t suffer any dropping, while DCF mechanism suffered a packet dropping as listed in the tables.

Second scenario

In this scenario the network contains 25 real-time stations with 25 non real-time stations. The results are shown in Figures (8) and (9). Figure (8) shows that the average time delay (packet end_to_end delay) for the network based DCF mechanism is about 1.08 sec while in EDCA it is about 0.38 ms in ad hoc mode. Figure (9) shows that the average time delay (packet end_to_end delay) for the network based DCF mechanism is about 60 ms while in EDCA it is about 1.3 ms in BSS mode. Again, using EDCA access mechanism greatly enhances the time behavior of WLAN in this scenario.

The resulted throughput of the network based EDCA mechanisms and DCF mechanism is listed in Tables (9) and (10). It can be seen that the throughput in the network based EDCA decreased (but without any dropping) when the number of real-time stations increased. The throughput decreases significantly because of more stations contending for bandwidth. It is worth remembering that responsiveness, rather than throughput, is the key factor in many industrial applications.

Conclusions

In this paper the applicability of using EDCA as access mechanism when supporting real-time traffic similar to the real-time traffic usually found in the factory floor and comparing the results with those obtained by using DCF mechanism has been studied by mean of simulation.

The simulation scenario considers the existence of an external disturbance (best effort traffic generated by nearby standard IEEE 802.11 stations), and its effect upon the transfer of real-time traffic. The highest access category (video) is modified to represent a real-time traffic (small-sized packets in periodic intervals). The simulation analysis shows that EDCA mechanism is more suitable for industrial applications than DCF access mechanism in the term of time delay and packets lose especially when the number of real-time stations is small (5 stations in our analysis). But when the number of real-time stations increased to 25 stations this led to decrease the throughput. Although, the throughput has been decreased but there was no packet dropping and the time delay was in the range of real-time delay constrains in industrial applications (this is an important requirement in industrial applications to deliver messages without any errors).

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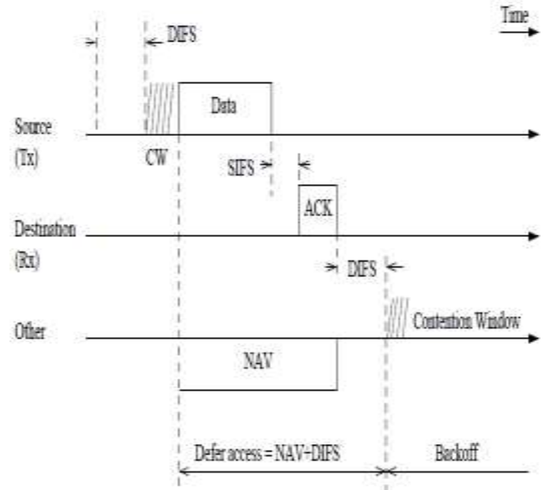

Fig.(1) Basic DCF CSMA/CA

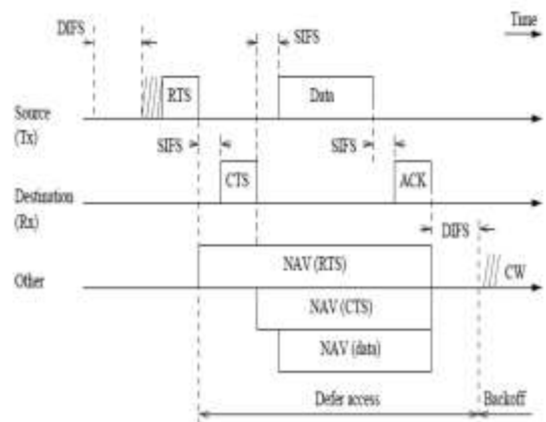

Fig.(2) RTS/CTS Access Scheme

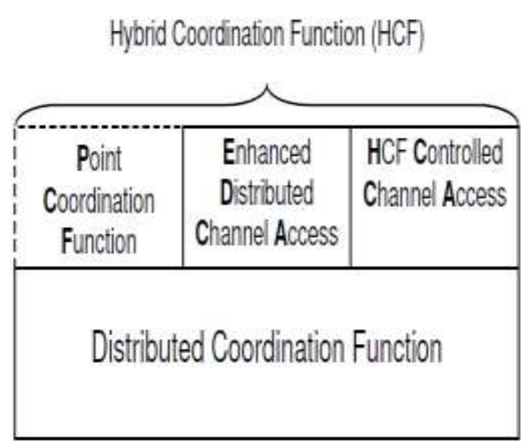

Fig.(3) IEEE 802.11e MAC architecture

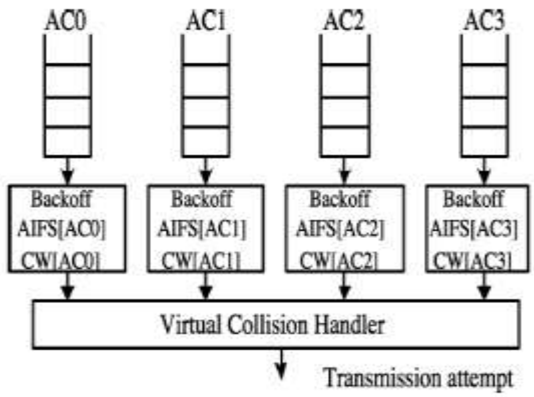

Fig.(4) Four Access Categories for EDCA

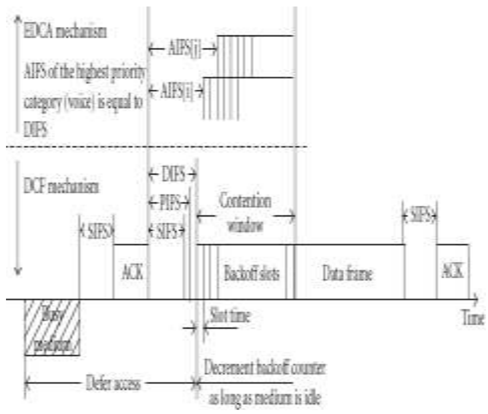

Fig.(5) Interframe spaces in the DCF and EDCA mechanisms.

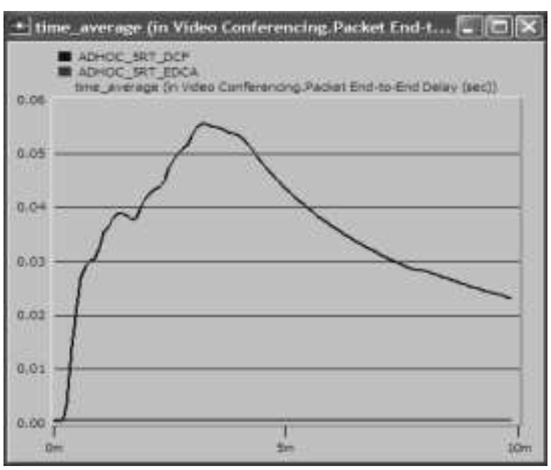

Fig.(6) End to end delay for Scenario1 (Ad hoc network)

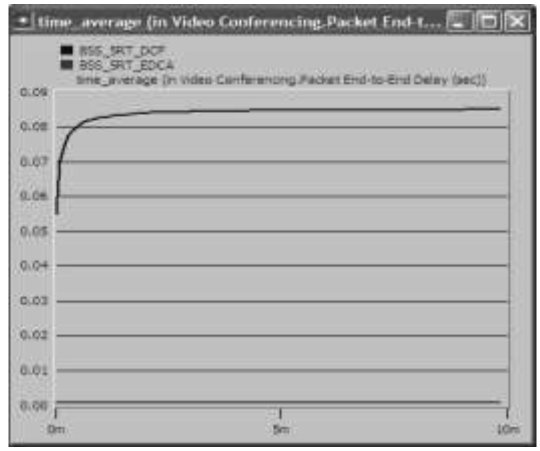

Fig.(7) End_to_end delay for Sceanario1 (BSS network)

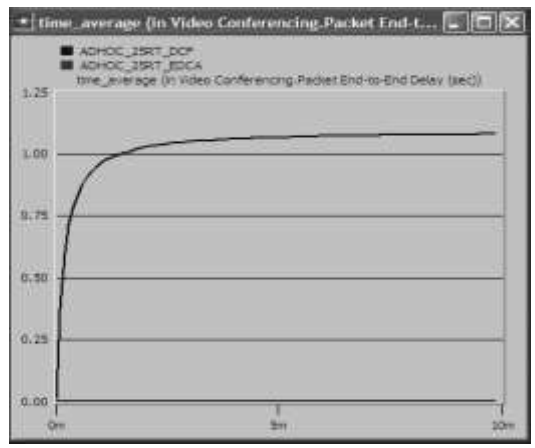

Fig.(8)End to end delay for Scenario2 (Ad hoc network)

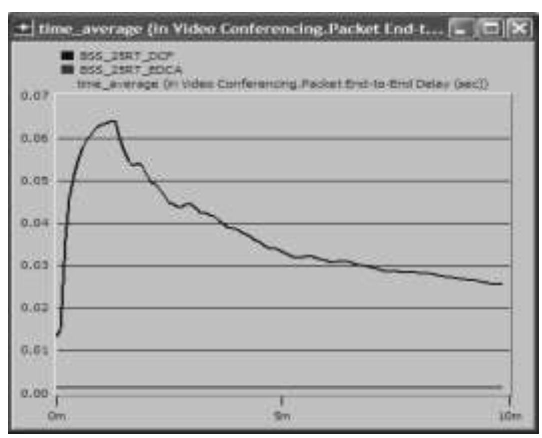

Fig.(9)End to end delay for Scenario2 (BSS network)

Table(1)User Priority to Access Category mapping

Priority	User Priority (UP)	Access Category (AC)	designation
Lowest	1	AC_BK	Background
	2	AC_BK	Background
	0	AC_BE	Best effort
	3	AC_BE	Best effort
	4	AC_VI	Video
Highest	5	AC_VI	Video
	6	AC_VO	Voice
	7	AC_VO	Voice

Table(2) Default EDCA Parameters Set.

AC	CWmin	CWmax	AIFSN	TXOP limit IEEE 802.11b	TXOP limit IEEE 802.11a/g
AC_VO	*(aCWmin+1)/4*	*(aCWmin+1)/2-1*	2	3.264 ms	1.504 ms
AC_VI	*(aCWmin+1)/2-1*	*aCWmin*	2	6.016 ms	3.008 ms
AC_BE	*aCWmin*	*aCWmax*	3	0 ms	0 ms
AC_BK	*aCWmin*	*aCWmax*	7	0 ms	0 ms

Table(3) Standard Performance Measures (Ad hoc

Standard	Packet length (byte)	Packet production rate (packet/sec)	Packet end_to_end Delay (sec)	Throughput (Mbps)
11b	100	1020	0.03457	1,044
11b	500	785	0.00574	3,316
54g	100	3392	0.01429	3,473
54g	500	2808	0.00288	11,861
54a	100	5000	0.03121	5,119
54a	500	3988	0.00153	16,845

Table(4) Standard Performance Measures (BSS mode)

Standard	Packet length (byte)	Packet production rate (packet/sec)	Packet end_to_end Delay (sec)	Throughput (Mbps)
11b	100	575	0.04002	0.589
11b	500	426	0.01705	1,799
54g	100	2633	0.00344	2,696
54g	500	1974	0.00063	8,338
54a	100	2864	0.01218	2,932
54a	500	2087	0.00170	8,815

Table(5)Ad hoc mode saturated Throughput

Number of stations	Max. packet rate (packet/sec)	Saturated throughput (Mbps)
5	1140	5,843
25	213	5,432

Table(6) BSS mode saturated Throughput

Number of stations	Max. packet rate (packet/sec)	Saturated throughput (Mbps)
5	583	2,984
25	115	2,949

Table(7) Scenario 1 (Ad hoc mode) Measurements

Mechanism	Throughput (Mbps)	Packet lose %
DCF	5,829	0.23
EDCA	5,843	0

Table(8) Scenario 1(BSS mode) Measurements

Mechanism	Throughput (Mbps)	Packet lose %
DCF	2,925	1.9
EDCA	2,984	0

Table(9)Scenario 2(Ad hoc mode) Measurements

Mechanism	Throughput (Mbps)	Packet lose %
DCF	5,252	3.3
EDCA	3,053	0

Table(10) Scenario 2 (BSS mode) Measurements

Mechanism	Throughput (Mbps)	Packet lose %
DCF	2,939	0.3
EDCA	1,766	0