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Abstract

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***Abstract* – With fast deployment of wireless local area networks (WLANs), the ability of WLAN to support real time services with stringent quality of service (QoS) requirements has come into fore. In this paper, we evaluate the capability of QoS support in the IEEE 802.11e standard, which is the medium access control (MAC) enhancements for QoS support in 802.11. Both the enhanced distributed channel access (EDCA) and the polling based channel access modes are evaluated, and their performance under real time audio and video traffic is shown through simulations. We find that EDCA provides satisfactory service differentiation among its four access categories. However, in the presence of heavy load traffic such as a high definition television (HDTV) signal transmission, it is more desirable to place such load under HCF polling mode to avoid the adverse impact of other traffic on this class of traffic. With a hybrid polling and EDCA protocol, network capacity is effectively increased to better support real-time audio and video transmissions in future home networks.**

***Index Terms*— Wireless local area networks, quality of service, 802.11**

I. Introduction

Wireless data networks based on IEEE 802.11b standard [1], known also by the commercial trademark *Wi-Fi*, is evolving into the fastest-growing wireless data network applications. Selling at an estimated number of 1-1.5 million network interface cards per month, 802.11 networks are springing up not only in businesses and hot-spot public spaces, but also in residence homes. This trend has drummed up the interest of big home electronic appliance manufacturers in developing cableless home networking products and weave together home electronic appliances and wireless data networks. For example, next generation entertainment electronic devices such as TV, VCR, DVD player, etc. may be equipped with wireless network adaptors and connected with each other through wireless networks. Then, video and audio streams from a VCR or computer can be easily delivered to TV receivers or speakers anywhere in a household without the need of re-wiring the cables. In such applications, 802.11 is becoming a very promising network standard of choice due to its high data transmission rate and non-negligible market dominance.

Recent advances in IEEE 802.11 family, especially the expected finalization of IEEE 802.11e standard [3], have further sealed the role of 802.11 in home networking applications. 802.11e is an extension to the legacy 802.11a/b standard to provide quality of service (QoS) support to time-sensitive applications, such as voice and video – which are typical applications in home networks. The IEEE 802.11e standard introduces the hybrid coordination function (HCF) as the medium access control(MAC) scheme. While backward compatible with DCF and PCF, HCF provides stations with prioritized and parameterized QoS access to the wireless medium. HCF combines aspects of both the contention-based and the contention free access methods, where the contention-based channel access mechanism in HCF is known as the enhanced distributed channel access (EDCA) and its contention-free counterpart is known as the HCF polling based channel access. EDCA mode can be regarded as a “soft” QoS assurance mechanism in the sense that a traffic class can *statistically* reduce its transmission delay by categorizing itself into a higher priority traffic class and use an access category (AC) that has higher priority in its contention for the channel. Though this mechanism is easier to implement, QoS requirement of a connection cannot be always met, especially under heavy load conditions [4] [5]. Compared with EDCA, polling based schemes inherently provides hard QoS guarantees with its centralized control [6], where a hybrid coordinator (HC) is used to allocate transmission opportunities (TXOPs) to wireless stations by polling.

As real time video and audio transmission are supposed to be the prevailing applications in typical home networks, in this paper we are interested in evaluating the capability of HCF to support video and audio traffic, with co-existing background and best effort data traffic. Among the class of audio/video applications, we are particularly interested in the capability of 802.11e to satisfy the stringent QoS requirements of High Definition Television (HDTV) signal transmission, which typically possess a high data rate of 20Mbps and would be a critical application in home networks. For this purpose, we consider and compare EDCA high priority AC and HCF polling as vehicles carrying QoS traffic, while the best effort and background connections are carried in EDCA low priority AC. Our simulation evaluates network delay and throughput performance under a variety of traffic scenarios.

This paper is organized as follows: Section II briefly introduces the operation of HCF in an 802.11e WLAN, Section III describes the simulation setup, in Section IV we evaluate the performance of EDCA in supporting QoS traffic, and in Section V we evaluate the performance of HCF polling. Finally,

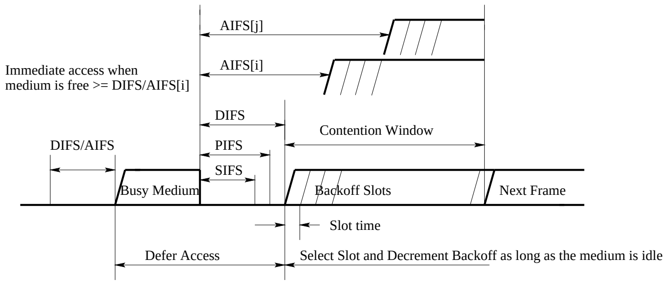

Fig. 1. IFS relationships and EDCA channel access

Section VI concludes the paper.

II. 802.11E HCF MECHANISM

HCF in 802.11e consists of two enhanced functions of DCF and PCF, namely, EDCA and HCF polling. EDCA provides differentiated and distributed access to the wireless medium with 4 access categories (AC), each corresponding to an individual prioritized output queue. With HCF polling channel access method, a hybrid coordinator (HC) is needed, which uses the highest channel access priority to contend the channel and allocate TXOPs to stations. The TXOP acts like a form of channel reservation mechanism, where all other stations back off upon receiving it and the destination station of the TXOP uses the reserved time interval to send its data. TXOPs are sent to a station in such a manner that the predefined delivery priority, service rate, delay and jitter requirements desired by the station could be met.

Channel access priority of various types of packets is assured by both the *Inter-Frame Space (IFS)*, which is the time a packet needs to defer before initiating its transmission or backoff procedure, as well as the amount of backoff time it takes before transmission. There are five different kinds of IFS: Short IFS (SIFS), Distributed coordination function IFS (DIFS), Point coordination function IFS (PIFS), Extended IFS (EIFS), and Arbitration IFS (AIFS). The various IFS's and the basic deference and backoff procedure of EDCA is sketched in Figure 1. Various ACs use different AIFS value and contention window size to contend for the channel, where the the value of AIFS is determined by the following equation:

$$\text{AIFS} = \text{SIFS} + \text{AIFS}_n \cdot \text{aSlotTime}$$

with the value of AIFS_n dependent on the AC and aSlotTime/SIFS value dependent on the PHY layer used.

The number of backoff slots of each AC is a uniformly distributed random number drawn from $[0, CW-1]$, where CW is the contention window in the range of $[CW_{min}, CW_{max}]$. Upon each successful transmission, CW is reset to CW_{min}, and upon each errorneously transmitted packet it doubles its length until reaching CW_{max}. Again under EDCA, the value of CW_{min} and CW_{max} are different for each AC. Table I shows the default EDCA parameters for each AC, where the value of aCW_{min} and aCW_{max} are dependent on the physical layer.

AC	CW_{min}	CW_{max}	$AIFS_n$
0	aCW_{min}	aCW_{max}	3
1	aCW_{min}	aCW_{max}	7
2	$\frac{aCW_{min}+1}{2}-1$	aCW_{min}	2
3	$\frac{aCW_{min}+1}{4}-1$	$\frac{aCW_{min}+1}{2}-1$	2

TABLE I

DEFAULT EDCA PARAMETERS

In HCF polling mode, a hybrid coordinator (HC) is needed to act as the major control station to poll each station. Though the HC may be any station in the network, in an infrastructure network the AP normally takes up the responsibility to act as the HC. The HC gains control of the channel after sensing the channel idle for a time period equivalent to PIFS. After grabbing the channel, the HC polls a station on its polling list. Upon receiving a poll, the polled station either responds with an QoS-Null packet, if it has no data to send; or responds with a QoS-Data+QoS-ACK packet, if it has data to send. The polled station may perform several packet exchange sequences during one TXOP. At the end of a TXOP, the HC either sends a QoS-Poll to the next station on its polling list after a PIFS interval, or releases the channel if there is no more station to poll.

III. SIMULATION SETUP

We use discrete event simulation based on OPNET to evaluate the performance of 802.11e HCF, where the physical layer is chosen as IEEE 802.11a [2] at 5GHz that allows up to 54Mbps data transmission rate. Table II shows a summary of MAC and PHY layer parameters for 802.11a, as well as the packet overhead.

For the voice traffic, we assume the G711 codec is used, which generates voice packets at a constant bit rate of 64 kbit/s, with packet size of 160 bytes and packet interarrival time of 20ms. With RTP/UDP/IP header overhead of 40 bytes and MAC/PHY layer overhead of 60 bytes, the overall packet size transmitted reaches 260 bytes.

The high quality video traffic, simulating HDTV application between antenna/Digital VCR and TV, has a constant bit rate of 20 Mbit/s and packet size of 1024 bytes. Again, TCP/IP/MAC/PHY headers need to be taken into consideration.

The best effort data is modeled as sources generating packets whose size is exponentially distributed with Poisson arrivals. The average packet size is 501 bytes plus TCP/IP/MAC/PHY overhead, with interarrival time being 25ms. We characterize the background traffic as constant bit rate traffic with bit rate 250 kbit/s and packet size 750 bytes.

IV. SUPPORTING QOS TRAFFIC WITH EDCA MODE

First consider a baseline traffic scenario which consists of one pair of VoIP connection, a one-directional high quality video (HDTV) traffic, a two directional best effort (BE) data

TCP header size	20 bytes
UDP header size	8 bytes
IP header size	20 bytes
MAC header size	36 bytes
Physical header size	24 bytes
PHY layer specification	DSSS
Transmission rate	54Mbits/sec
SIFS interval	$16\mu s$
A slot time	$9\mu s$
aCW_{min}	15
aCW_{max}	1023

TABLE II

PACKET OVERHEAD AND MAC PARAMETERS

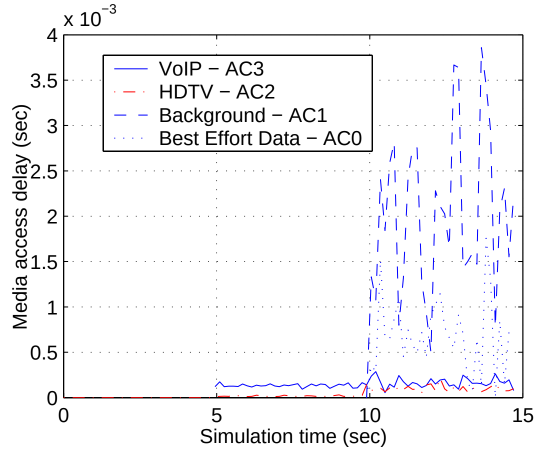

Fig. 2. Media access delay for the baseline EDCA traffic scenario

transmission and a two directional background (BK) traffic. Consistent with 802.11e specifications, VoIP traffic is carried under AC3, HDTV under AC2, background traffic under AC1 and best effort data under AC0.

To better illustrate the impact of additional traffic streams on existing load, applications are started at different times. For example, the HDTV application starts from the very beginning of simulation, while the VoIP application starts at simulation time 5s and the BK and BE traffic start at 10s into simulation. Figure 2 shows the delay performance of these traffic streams. The media access delay of HDTV traffic is almost negligible from time 0s to 5s, as it is the only traffic in the network so that it does not need to contend the channel with other sources. With the introduction of VoIP traffic at time 5s, HDTV media access delay increases slightly while the delay for VoIP traffic is around 0.2ms. It is interesting to note that although VoIP traffic uses a higher AC to contend the channel against the video traffic, the advantage is not reflected from its delay performance. This is due to the fact that the HDTV traffic possesses a shorter packet arrival interval and larger packet size, while VoIP traffic is comparatively much lighter with shorter packet size and longer packet inter-arrival time. Therefore, it is more common for a VoIP packet, upon its arrival at MAC layer, to find channel busy and to wait till the end of transmission of a large video packet. On the other hand, even if a HDTV packet finds channel being in use, the waiting time for the channel to be cleared is much shorter.

Though the low priority densely loaded traffic gains advantage over high priority light load traffic when the two traffic are the only loads in the network, such favor over heavy load traffic diminishes with advention of more traffic streams, while the virtue of using higher priority AC becomes more obvious. For example, Figure 2 shows that from time 10s (starting time of BE and BK traffic), the media access delay of HDTV traffic creeps up while the delay of VoIP traffic is almost un-affected by such increase in low priority traffic load. Also, the media access delay of connections using lower AC is significantly higher than that of the connections using higher AC to access the channel, where the background traffic suffers the largest delay that could reach as high as 3.8ms compared with a maximal delay of only 0.3ms for VoIP traffic.

In the next experiment, we evaluate the impact of increasing the volume of VoIP traffic and BK/BE data traffic on system performance. Firstly, we increase the number of VoIP connections from 1 to 4, all of which start from time 5s while the other traffic loads remain unchanged. Then, we also added to the *baseline* model two more background and best effort data traffic connections starting at 10s. Figure 3 and Figure 4 show the delay performance of these two scenarios respectively. As illustrated in Figure 3, increasing the highest priority VoIP connections has a very significant impact on both the delay and throughput of lower priority traffic streams. Especially, the media access delay of HDTV traffic soars to around 60ms and the delay of background traffic could reach as high as several seconds. Comparing to VoIP load increases, increases in BK and BE load does not affect HDTV media access delay in Figure 4 as much as that in Figure 3, largely due to the higher AC used by HDTV traffic than BE and BK traffic. However, the delay of background traffic again goes up to more than one second, indicating that the additional traffic connections to the baseline scenario has driven the network out of its capacity to support the background traffic.

Figure 5 and Figure 6 show the throughput performance of VoIP and HDTV traffic in the above scenarios respectively. With more VoIP traffic, the throughput of each VoIP connection decreases as a result of contentions among the VoIP connections (see Figure 5). It is worthwhile to note that due to the small CW_{max} value of 7, the total number of VoIP connections in a BSS should be small to keep the network stable. Otherwise, if the VoIP connection number is larger than CW_{max}, there may be infinite number of collisions between VoIP connections since at least two VoIP station will have the same backoff timer. We find that adding more BE and BK connections does not affect VoIP throughput. Therefore, the curve for baseline scenario is combined with the curve for *More BE/BK* scenario in Figure 5.

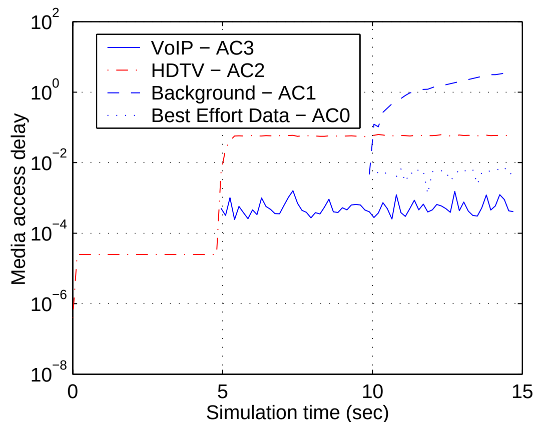

Fig. 3. Media access delay for EDCA scenario with more VoIP connections

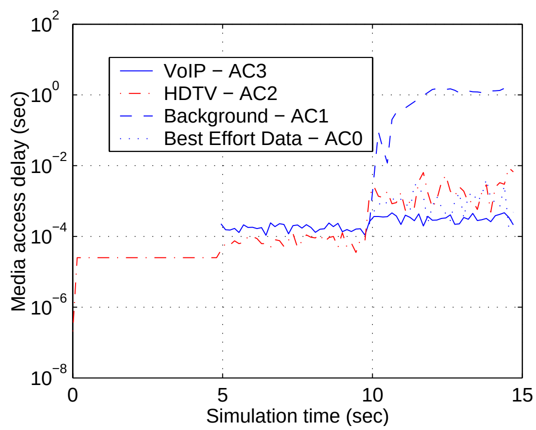

Fig. 4. Media access delay for EDCA scenario with more BK and BE connections

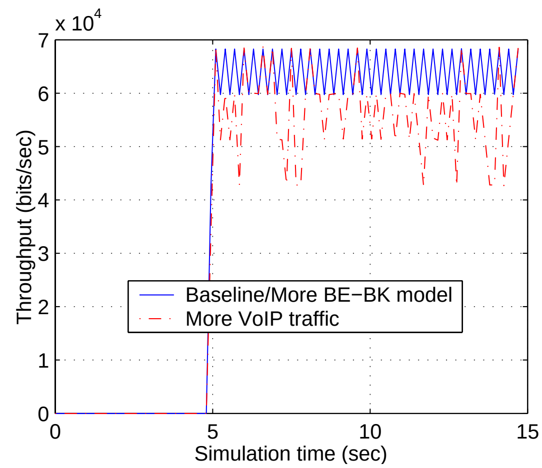

Fig. 5. Throughput for VoIP connection

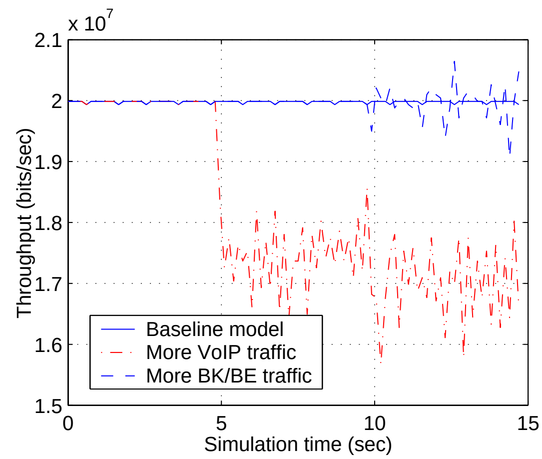

Fig. 6. Throughput for HDTV connection

As illustrated in Figure 6, HDTV throughput is severely affected by additional VoIP connections, which drops to around 17Mbps in the scenario with more VoIP connections. In such case, since the throughput is always smaller than the load (20Mbps), queues will build up at the transmitter end. This ultimately leads to packet drops and result in an average data loss rate of approximately 3Mbps. Adding BE and BK traffic has a less significant impact. However, fluctuations in HDTV throughput are still observed after the BE and BK traffic kick in at time 10s.

V. Supporting QoS Traffic with hybrid EDCA and HCF polling

From the previous section, we find the heavily loaded traffic streams are particularly vulnerable to network load variations. To "protect" such traffic, here we investigate the possibility of bringing the QoS traffic under the care of HCF polling while the other traffic remain in EDCA mode. Polling provides a more secure way of supporting QoS, and hopefully carrying the heavy load traffic under polling mode could also reduce its interference with other traffic.

We start with the baseline scenario, with addition of an AP to poll the HDTV and VoIP traffic periodically. Upon being polled, the station will transmit the packets in its buffer. The number of packets that could be transmitted in one polling cycle is bounded by the assigned TXOP. In this simulation the polling interval to each station equals the packet inter-arrival time of the QoS traffic generated by the station. We assume stations in the BSS could communicate with each other directly without the need to route all packets through the AP. Otherwise, network load will be doubled by this routing and forwarding process. This feature is not available in legacy standard but has been added in 802.11e. The mere purpose of this assumption here is to make sure that the traffic load is the same as that in last section so that the results are also comparable.

Figure 7 shows the media access delay for the baseline model. HDTV and VoIP traffic have gained very stable performance, with the impact of adding VoIP traffic streams almost negligable. Furthermore, due to reduced channel contention, the media access delay of BE and BK traffic are also smaller than the EDCA configuration.

The most significant advantage of adopting HCF configuration is observed when more traffic loads are added. Figure 8 shows the media access delay for the scenario with the number of VoIP connections increased to 4. The impact of adding other traffic streams on the media access delay of QoS traffic is almost negligible, while the delays of BK and BE traffic are only slightly increased. This advantage may become more clear when we compare Figure 8 with Figure 3, where HDTV traffic experiences significant performance degradations such as long media access delay, buffer overflow and throughput loss, and BK data could hardly go through the network. Therefore, HCF configuration provides much better QoS guarantee to QoS traffic and improves performance to traffic carried in EDCA mode. We do not show the throughput performance here since, for all the scenarios in HCF configuration, the throughput of QoS traffic equals its offered load.

Similar result is observed with increased BE and BK traffic. Figure 9 shows the media access delay for the traffic scenario with the number of BE and BK connections increased to 3. When these traffics kick in at time 10s, the increase in media access delay of QoS traffic is again negligible. Most of the performance losses are absorbed by best effort and background traffic themselves, whose maximal delay shoot up to 7ms compared to 4ms in the baseline scenario.

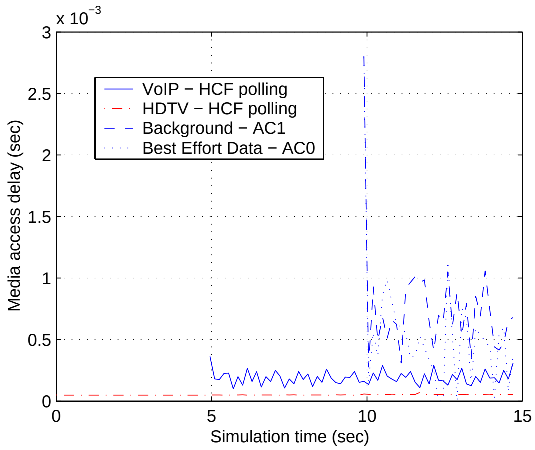

Fig. 7. Media access delay for the baseline HCF scenario

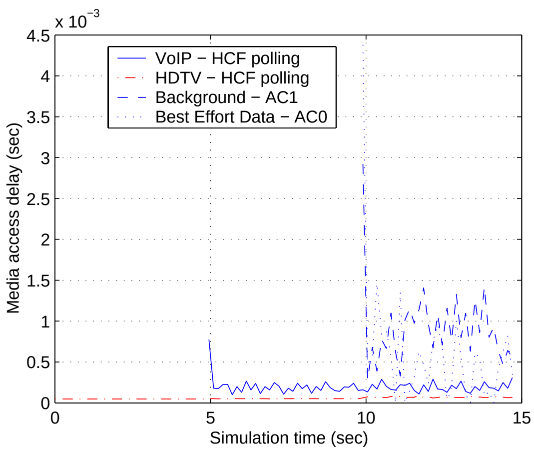

Fig. 8. Media access delay for the HCF scenario with more VoIP traffic

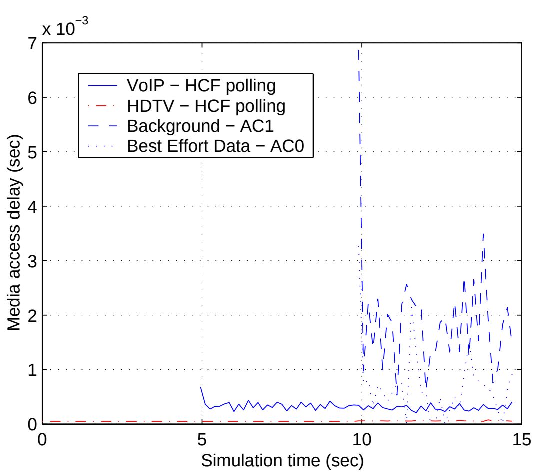

Fig. 9. Media access delay for the HCF scenario with more BE and BK traffic

VI. Conclusion

In this paper, we have evaluated the performance of enhanced MAC protocols for QoS in IEEE 802.11 WLAN, in carrying QoS applications. Through our simulations, we find that although EDCA could provide a certain level of service differentiation among various access categories, its lack of QoS guarantee still impairs the performance of heavily loaded traffic connections under non-negligible background traffic. In such case, we find that by placing the QoS traffic under HCF polling control, QoS requirements from both heavy load traffic in HCF polling and light load traffic in EDCA mode could be better satisfied. Therefore, more centralized control at the AP is desired when heavy traffic load is expected in the network.

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