QoS Enhancement in IEEE802.11 Wireless Local Area Networks

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Abstract

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Introduction

IEEE802.11 wireless local area network (WLAN) is a shared-medium communication network that transmits information over wireless links for all IEEE802.11 stations in its transmission range to receive. It is one of the most deployed wireless networks in the world and is high likely to play a major role in multimedia home networks and next-generation wireless communications. The main characteristic of the IEEE 802.11 WLANs is its simplicity, scalability and robustness against failures due to its distributed nature. IEEE802.11 wireless networks can be configured into two different modes: ad hoc and infrastructure modes. In ad hoc mode, all wireless stations within the communication range can communicate directly with each other, whereas in infrastructure mode, an Access Point (AP) is needed to connect all stations to a Distribution System (DS), and each station can communicate with others through the AP. IEEE802.11 standards actually include a family of standards. Among them, the original standard called IEEE802.11 provides the data rates up to 2 Mbps at 2.4 GHz ISM band [1]. Later, IEEE802.11 working group published its enhanced version named IEEE802.11b that extends the data rate up to 11 Mbps at this ISM band [2]. Its high-speed version at 5 GHz UNII band, i.e. IEEE802.11a, was also defined later [3]. IEEE802.11a standard can achieve data rate of up to 54Mbps by using OFDM (Orthogonal Frequency Division Multiplexing) modulation technique at physical layer. Today, IEEE802.11 wireless networks are widely installed at homes, corporate buildings and hot spots.

With the applications over 802.11 WLAN increasing, the customers demand more and more new features and functions of IEEE802.11 WLAN. One very important feature is the support of applications with Quality of Service (QoS) in 802.11 wireless networks. So, the support of video, audio, real-time voice over IP and other multimedia applications over 802.11 WLAN with QoS requirements is the key for 802.11 WLAN to be successful in multimedia home networking and future wireless communications. Many researchers have shown much interest in developing new medium access schemes to support QoS [4, 5]. Accordingly, IEEE 802.11 working group is currently working on a new standard called 802.11e to enhance the original 802.11 MAC (Medium Access Control) sublayer to support QoS [6]. The original 802.11 WLAN MAC sublayer employs a DCF (Distributed Coordination Function), which is based on CSMA/CA (Carrier Sense Multiple Access/Collision Avoidance), for medium access, and is best known for its asynchronous best-effort data transfer. In order to support QoS in 802.11 WLAN, the upcoming IEEE802.11e standard adds a new function called HCF (Hybrid Coordination Function) which includes both controlled contention-free and contention-based channel access methods in a single channel access protocol. The HCF uses a contention-based channel access method called the enhanced DCF (EDCF) that operates concurrently with a controlled channel access mechanism that is based on a central polling

mechanism. HCF supports both prioritized and parameterized medium access.

This article will briefly review the main features and functions of the upcoming 802.11e standard. The detailed discussion will be focusing on EDCF functions. The comparison between DCF and EDCF are also given.

Original 802.11 Medium Access Mechanisms

The architecture of IEEE802.11 standard includes the definitions of MAC sublayer and Physical (PHY) Layer. The original 802.11 MAC sublayer has two access mechanisms: DCF (Distributed Coordination Function) and PCF (Point Coordination Function). DCF uses CSMA/CA protocol, and it is best known for asynchronous data transmission (or best-effort service). PCF uses a central-controlled polling method to support synchronous data transmission. Unlike DCF, the implementation of PCF is optional as stated in the standard [1]. DCF is the basic medium access mechanism for both ad hoc and infrastructure modes. In DCF mode, each station checks whether the medium is idle before attempting to transmit. If the medium has been sensed idle for a DIFS (Distributed InterFrame Space) period, which is 50 μs for 802.11b, the transmission can begin immediately. If the medium is determined to be busy, the station shall defer until the end of the current transmission. After deferral, the station will select a random backoff interval and shall decrement the backoff interval counter while the medium is idle. Once the backoff interval has expired, the station begins the transmission. More specifically, the station selects a random number called backoff time, in the range of 0 and CW (Contention Window). The backoff timer decrements the backoff time each time the medium is detected to be idle for an interval of one slot time. As soon as the backoff timer expires, the station can begin to transmit. If the transmission is not successful, a collision is considered to have occurred. In this case, the contention window is doubled, and a new backoff procedure starts again.

The process will continue until the transmission is successful or discarded.

The backoff time, which is used to determine the time interval that a station has to wait before transmission after deferral, is a random number that lies between 0 and CW. The backoff time is computed as follows [1]:

$$\text{Backoff Time} = \text{Random()} * \text{SlotTime} \qquad (1)$$

Where Random() is a pseudorandom integer drawn from a uniform distribution over the interval [0,CW]. CW is an integer within the range of values of the PHY characteristics CWmin and CWmax, that is CWmin ≤ CW ≤ CWmax. For 802.11b, CWmin=31 and CWmax=1203. SlotTime equals the value of the corresponding PHY characteristics, which is 20 μs for 802.11b. CW parameter shall take an initial value of CWmin. The CW will take the next value in the series after each unsuccessful transmission until the CW reaches the value of CWmax. Once it reaches CWmax, the CW shall remain at the value of CWmax until it is reset. This improves the stability of the access protocol under high-load conditions. The CW shall be reset to CWmin after each successful attempt to transmit a packet. The set of CW values shall be sequentially ascending integer powers of 2, minus 1, beginning with a PHY specific CWmin value, and continuing up to CWmax value. The back off procedure is used to reduce the possibility of collision by selecting a different random backoff time for different stations. The backoff procedure is shown in Figure 1 [1]. The effect of this backoff procedure is that multiple stations are deferring and go into random backoff, and then the station having the smallest backoff time will win the contention. It is seen that CWmin and CWmax are fixed for a given PHY. So, DCF doesn't differentiate the data traffic and stations. All stations and traffic classes have the same priority to access the wireless medium (WM). Thus, different delay and bandwidth requirements of applications are not supported with the use of DCF.
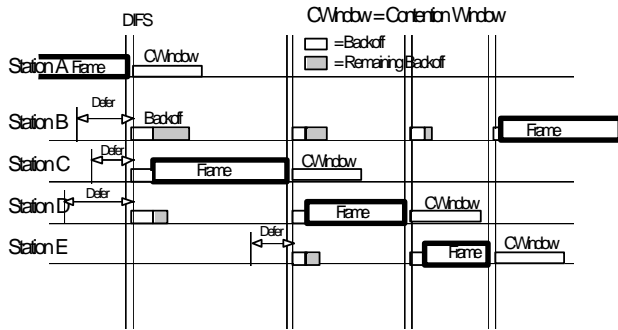
Figure 1: Backoff Procedure

PCF provides contention-free medium access method. It is actually a polling medium access method with the Point Coordinator (PC) performing the role of the polling master. PC resides in AP. So, PCF is only available and usable on the infrastructure network configuration. PCF has higher priority than DCF since it may start transmission after a shorter waiting time than DIFS. The waiting time interval used for PCF is called PIFS (PCF Interframe Space), which is 30 μs for 802.11b. Once the AP gains the control of the WM, it polls the associated stations on a polling list. The polling list is the list of privileged stations solicited for data frames during the contention free period. During the contention free period, a station may transmit only if it gets polled. With PCF, a contention free period (CFP) and contention period (CP) alternate over the time. During the CFP, PCF is used for medium access, while the DCF is used during the CP. PCF supports time-bounded applications with some limitations.

EDCF and HCF

Some high layer applications such as data, video, audio have different requirements in bandwidth, delay, jitter, and packet loss. However, in DCF mechanism of IEEE802.11, all the stations and data flows have the same priority to access medium. There is no differentiation mechanism to support the transmission of data streams with different QoS requirements. To support applications with QoS over 802.11 WLAN, IEEE 802.11 working group is currently developing a standard called IEEE802.11e, which enhances the original 802.11 MAC to support applications with QoS requirements. The upcoming IEEE802.11e standard adds a new medium access mechanism called HCF, which concurrently exists with basic DCF/PCF for backward compatibility. HCF has both contention-based and controlled contention-free channel access methods in a single channel access protocol. The HCF combines functions from the DCF and PCF with some enhanced, QoS-specific mechanisms and frame subtypes to allow a uniform set of frame exchange sequences to be used for QoS transfers during both the CP and CFP. The HCF uses a contention-based channel access method, called the enhanced DCF (EDCF) that operates concurrently with a controlled channel access mechanism based on a polling mechanism.

EDCF in 802.11e is the contention-based medium access method for HCF. The QoS support is realized with the introduction of traffic categories (TCs). EDCF provides differentiated, distributed access to the wireless medium for 8 priorities for stations. EDCF channel access defines the access category (AC) mechanism that provides support for the priorities at the stations. Each station may have up to 4 ACs to support 8 user priorities (UPs). One or more UPs are assigned to one AC. A station accesses the medium based on the access category of the frame that is to be transmitted. The mapping from priorities to access categories is defined in Table 1 [6].

Priority (Same as 802.1D Priority)	Access Category (AC)	Designation
1	0	Best Effort
2	0	Best Effort
0	0	Best Effort
3	1	Video Probe
4	2	Video
5	2	Video
6	3	Voice
7	3	Voice

Table 1 – Priority to Access Category Mappings

Each AC is an enhanced variant of the DCF. It contends for TXOPs (Transmission Opportunities) using a set of EDCF channel access parameters. TXOP is a time interval when a particular station has the right to initiate transmissions onto WM. An AC with higher priority is assigned a shorter CW in order to ensure that in most cases, higher-priority AC will be able to transmit before the lower-priority ones. This is done by setting the contention window limits CWmin[AC] and CWmax[AC], from which the contention window CW[AC] is computed, to different values for different ACs. For further differentiation, different IFS (Inter Frame Space) is introduced according to ACs. Instead of DIFS, an arbitration IFS [AIFS] is used. The AIFS is at least DIFS, and can be enlarged individually for each AC. Similar to DCF, if the medium is sensed to be idle in EDCF mechanism, a transmission can begin immediately. Otherwise, the station defer until the end of current transmission on the WM. After deferral, the station waits for a period of AIFS(AC) to start a backoff procedure. The backoff interval is now a random number drawn from the interval [1, CW(AC)+1]. Each AC within a single station behaves like a virtual station. It contends for access to the wireless medium and independently starts its backoff time after sensing the medium is idle for at least AIFS. Collision between ACs within a single station are resolved within the station such that the data frames from higher-valued AC receive the TXOP and the data frames from lower-valued colliding ACs behave as if there were an external collision on the WM. The timing relationship for EDCF is shown in Figure 2 [6].
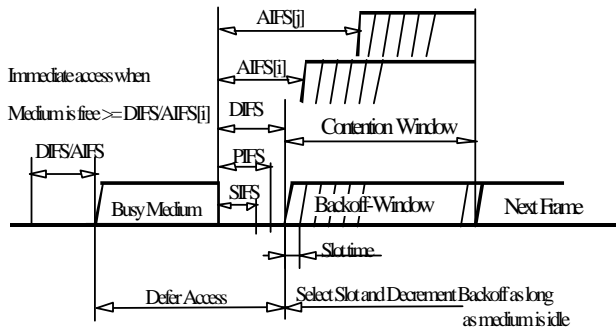

Figure 2: Timing Relationship for EDCF

The prioritized medium access of EDCF in 802.11e is realized by assigning different contention windows and different AIFS to different ACs. Data units are now delivered through multiple backoff instances within one station. Each backoff instance is parameterized with TC-specific parameters. The typical values of CW limits and AIFS for different ACs the in QoS parameters set is shown in Table 2. A model of the reference implementation is shown in Figure 3 [6]. It illustrates a mapping from frame type or priority to access categories, the four queues and four independent channel access functions, one for each queue.

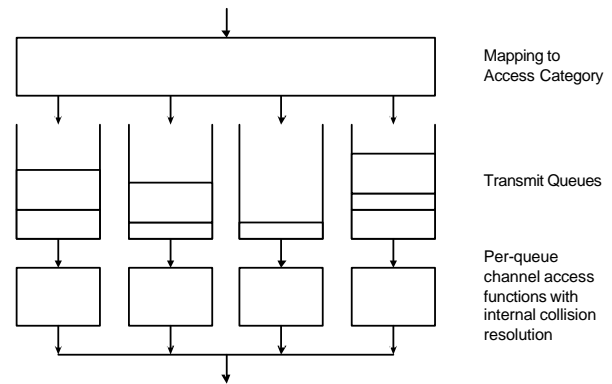| AC	CWmin	CWmax	AIFS
0	CWmin	CWmax	2
1	CWmin	CWmax	1
2	(CWmin+1)/2 - 1	CWmin	1
3	(CWmin+1)/4 - 1	(CWmin+1)/2 - 1	1

Table 2: Typical QoS Parameters

Figure 3: Reference Implementation Model

HCF controlled channel access channel access mechanism manages access to WM using HC that has higher medium access priority than EDCF. This allows it to transfer traffic from itself and to allocate TXOPs to stations. The HC is a type of PC, but operates at different rules with PC. HC traffic delivery and TXOP allocation may be scheduled during both CFP and CP. The HCF transfer

protocol is based on a polling scheme controlled by an HC operating at AP. The HC gains control of the WM as needed to send QoS traffic to stations and to issue QoS (+) CF-polls to stations by waiting a shorter time between transmissions than the stations using EDCF or DCF. The duration values used in QoS frame exchange sequences reserve the medium for an slot time period longer than the end of the sequence to permit continuation of a NAV (Network Allocation Vector)-protected CF transfer by concatenation of contention free bursts. This extra WM reservation allows the HC to initiate a subsequent TXOP with reduced risk of collision because all stations other than the TXOP holder and the HC will not be able to begin contending until a DIFS interval later than end of the last transfer within the TXOP.

Simulation Evaluation

A simulation model was constructed using OPNET. In the simulation, four IEEE802.11 wireless stations with EDCF mechanism were configured into ad-hoc mode shown in Figure 4. Four stations remain stationary during the simulations. The simulation uses standard OPNET 802.11b PHY module with maximum data rate up to 11 Mbps to simulate the wireless medium. While, the original 802.11 MAC was modified to support EDCF mechanism. For simplicity, we just simulated the EDCF access function and didn't consider other traffic parameters such as TXOPs in simulation. Any AC get an access to the medium, it transmits one packet and then release the channel for the next access contention. All PHY characteristics was according to 802.11b DSSS PHY parameters, in which CWmin= 31, CWmax=1023 and SlotTime=20 µs.
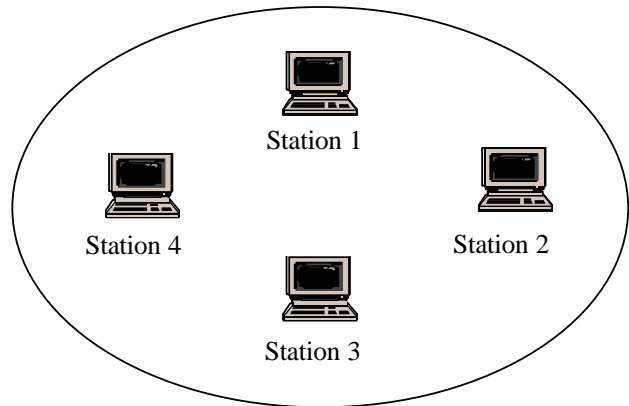

Figure 4. Simulation Scenario

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. In the simulation, we assumed that each traffic class has the equal portion of the total data traffic in terms of the average number packets generated per unit time. The packets had the same size of 1024 bytes and remained constant during the simulation. The packets of AC(0), AC(1) and AC(2) were generated according to Poisson Process with a mean interarrival time equal to 0.0001 second, while AC(3) packets were generated at a constant rate to simulate a voice source.

Figure 5 shows the average medium access delays for different access categories in EDCF mechanism. As shown, access category (3) has the smallest average medium access delay, and access category (0) has the largest medium access delay. The horizontal coordinate represents the simulation time (minutes). In Figure 6, the throughputs for different ACs over the WLAN are shown. We can see that AC(3) has the highest value of throughput, while the throughput of AC(0) is lowest. These results are as expected since EDCF differentiates the traffic classes and supports priority access. So, the higher priority traffic categories have a smaller medium access delay and more bandwidth.
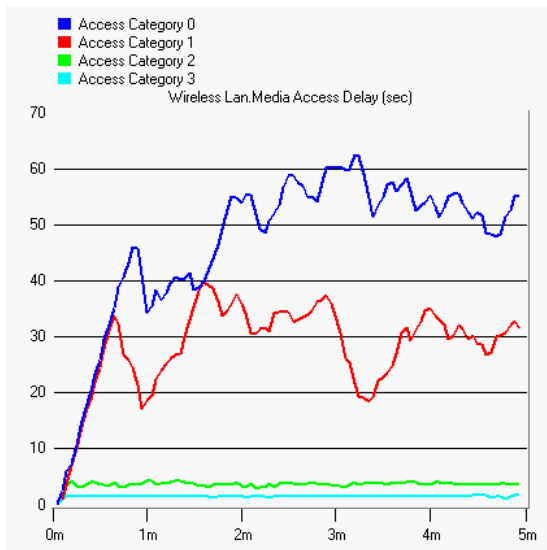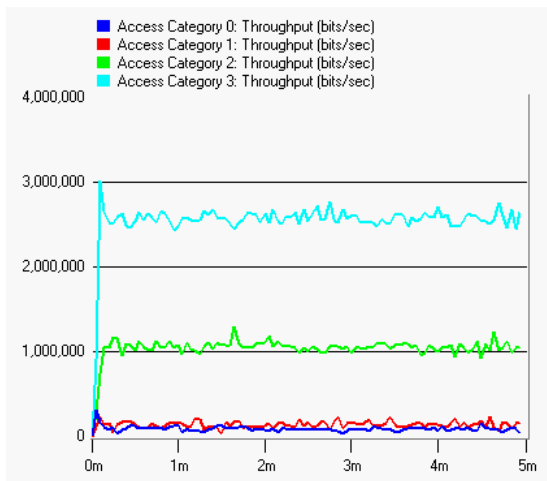
Figure 5. Medium Access Delay for Different ACs

Figure 6. Throughputs for Different ACs

Conclusions

A detailed EDCF and HCF medium access mechanism of the upcoming standard IEEE802.11e was presented in this article. EDCF for QoS support was evaluated. The simulation results show that EDCF works well for differentiated data services and priority access to the medium.

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BIOGRAPHIES

Daqing Gu [M] (dgu@merl.com) received his BE degree from Tsinghua University, Beijing, China in 1987; the MS and Ph.D. degrees in electrical engineering from the State University of New York at Stony Brook, Stony Brook, NY in 1996 and 1999, respectively. He is currently a principal technical staff in Mitsubishi Electric

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