QoS Enhancement in IEEE802.11 Wireless Local Area Networks

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ABSTRACT

In this article a distributed medium access scheme called EDCF, which is adopted in an upcoming standard IEEE802.11e to allow prioritized medium access for applications with QoS requirements, is described and discussed. Its performance is also evaluated via simulations.

INTRODUCTION

The 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 highly likely to play a major role in multimedia home networks and next-generation wireless communications. The main characteristic of the IEEE 802.11 WLAN 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. 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, IEEE802.11, provides data rates up to 2 Mb/s at 2.4 GHz industrial, scientific, and medical (ISM) band [1]. Later, the IEEE802.11 working group published its enhanced version, IEEE802.11b, that extends the data rate up to 11 Mb/s in the ISM band [2]. Its high-speed version at 5 GHz unlicensed national information infrastructure (UNII) band, IEEE802.11a, was also defined later [3]. The IEEE802.11a standard can achieve a data rate up to 54 Mb/s using orthogonal frequency-division multiplexing (OFDM) at the physical layer. Today, IEEE802.11 wireless networks are widely installed in homes, corporate buildings, and hot spots.

With applications over 802.11 WLANs increasing, customers demand more and more new features and functions. One very important feature is the support of applications with quality of service (QoS). Thus, 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, the IEEE 802.11 working group is currently working on a new standard called 802.11e to enhance the original 802.11 medium access control (MAC) sublayer to support QoS [6]. The original 802.11 WLAN MAC sublayer employs a distributed coordination function (DCF) based on carrier sense multiple access with collision avoidance (CSMA/CA) 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 a hybrid coordination function (HCF) that 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 enhanced DCF (EDCF) that operates concurrently with a controlled channel access mechanism 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 function. A comparison between DCF and EDCF is also given.

ORIGINAL 802.11 MEDIUM ACCESS MECHANISMS

The architecture of IEEE802.11 standard includes the definitions of the MAC sublayer and physical (PHY) layer. The original 802.11 MAC sublayer has two access mechanisms: the DCF and point coordination function (PCF). DCF uses CSMA/CA, and it is best known for asynchronous data transmission (or best effort service). PCF uses a centrally controlled polling method to support synchronous data transmis-

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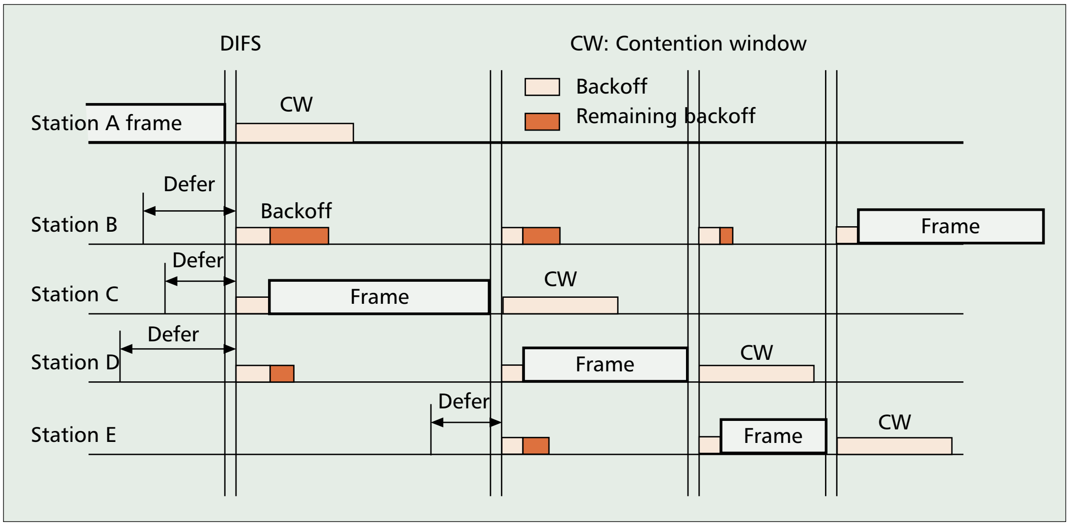


Figure 1. *Backoff procedure.*

DCF does not differentiate the data traffic and stations. All stations and traffic classes have the same priority to access the wireless medium. Thus, different delay and bandwidth requirements of applications are not supported with the use of DCF.

sion. 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 distributed interframe space (DIFS) 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 transmission. More specifically, the station selects a random number called backoff time, in the range of 0 to contention window (CW). 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 becomes zero, 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. The process will continue until the transmission is successful or discarded.

The backoff time, which is used to determine the time interval 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]:

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

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 (i.e., 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 backoff 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 Fig. 1 [1]. The effect of this backoff procedure is that multiple stations defer and go into random backoff, and the station with the smallest backoff time will win the contention. It is seen that CWmin and CWmax are fixed for a given PHY. Thus, DCF does not 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 by the use of DCF.

PCF provides a 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. The PC resides in the AP. Thus, 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 PCF interframe space (PIFS), which is 30 µs for 802.11b. Once the AP gains 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, the PCF is used for medium access, while the DCF is used during the CP. The PCF supports time-bounded applications with some limitations.

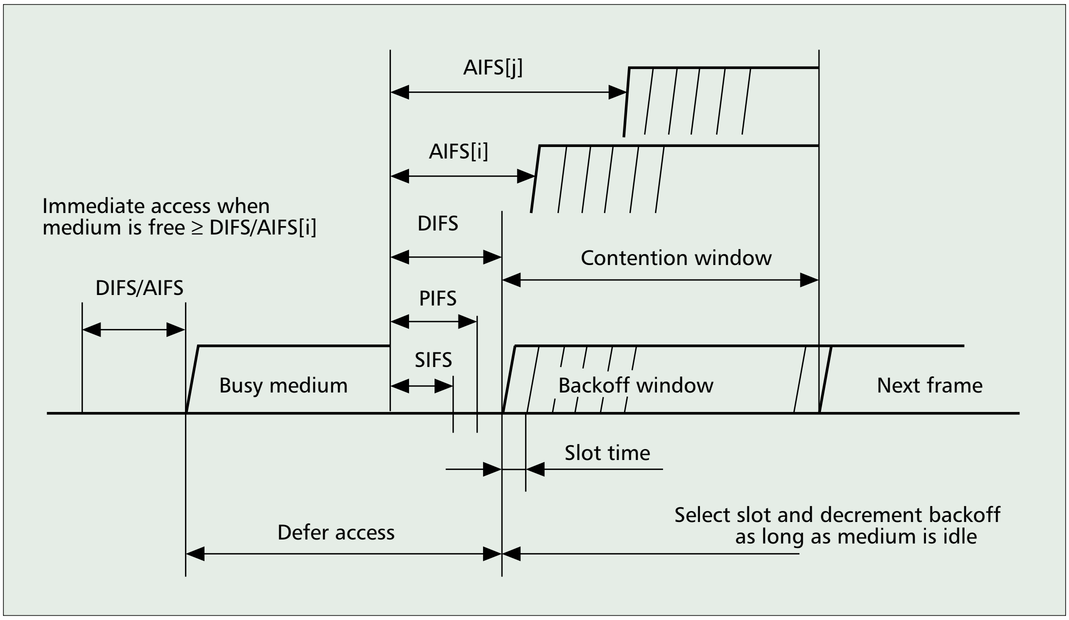


Figure 2. *The timing relationship for EDCF.*

EDCF AND HCF

Some high-layer applications such as data, video, and audio have different requirements in bandwidth, delay, jitter, and packet loss. However, in the DCF mechanism of IEEE802.11, all the stations and data flows have the same priority to access the 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 WLANs, 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, 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.

The EDCF in 802.11e is the contention-based medium access method for HCF. QoS support is realized with the introduction of traffic categories (TCs). The EDCF provides differentiated distributed access to the wireless medium for eight priorities of 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 four ACs to support eight user priorities (UPs). One or more UPs are assigned to one AC. A station accesses the medium based on the AC of the frame to be transmitted. The mapping from priorities to ACs is defined in Table 1 [6].

Each AC is an enhanced variant of the DCF.

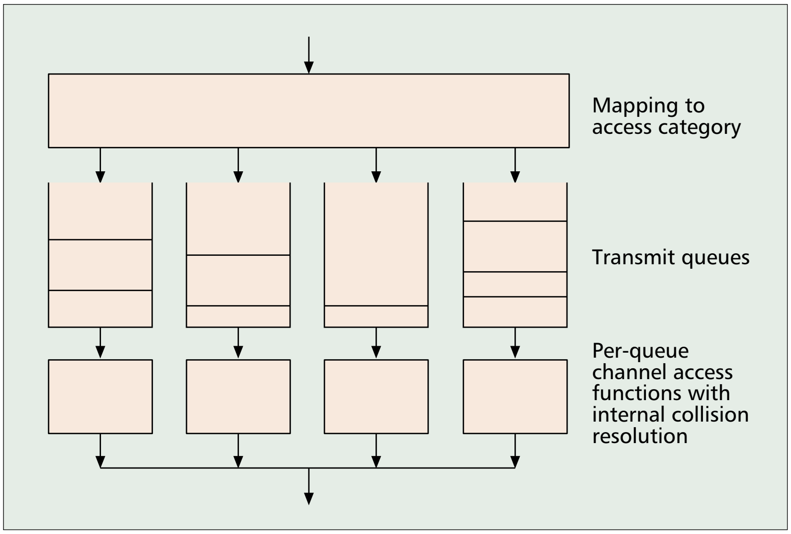


Figure 3. *The reference implementation model.*

Priority (same as 802.1D priority)	Access category	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.*

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.*

It contends for transmission opportunities (TXOPs) using a set of EDCF channel access parameters. TXOP is a time interval when a particular station has the right to initiate transmissions onto the WM. An AC with higher priority is assigned a shorter CW in order to ensure that, in most cases, a higher-priority AC will be able to transmit before lower-priority ones. This is done by setting the CW limits CWmin[AC] and CWmax[AC], from which CW[AC] is computed, to different values for different ACs. For further differentiation, different interframe space (IFS) 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 the EDCF mechanism, a transmission can begin immediately. Otherwise, the station defers 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 an EDCF is shown in Fig. 2 [6].

The prioritized medium access of the EDCF in 802.11e is realized by assigning different CWs 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 AIFSs for different ACs in the QoS parameters set is shown in Table 2. A model of the reference implementation is shown in Fig. 3 [6]. It illustrates a mapping from frame type or priority to ACs, the four queues, and four independent channel access functions, one for each queue.

The HCF controlled channel access mechanism manages access to the WM using an HC that has higher medium access priority than the EDCF. This allows it to transfer data from itself and to allocate TXOPs to stations. The HC is a type of PC, but operates on different rules than a 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 an EDCF or a DCF. The duration values used in QoS frame exchange sequences reserve the medium for a slot time period longer than the end of the sequence to permit continuation of a network allocation vector (NAV)-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 the end of the last transfer within the TXOP.

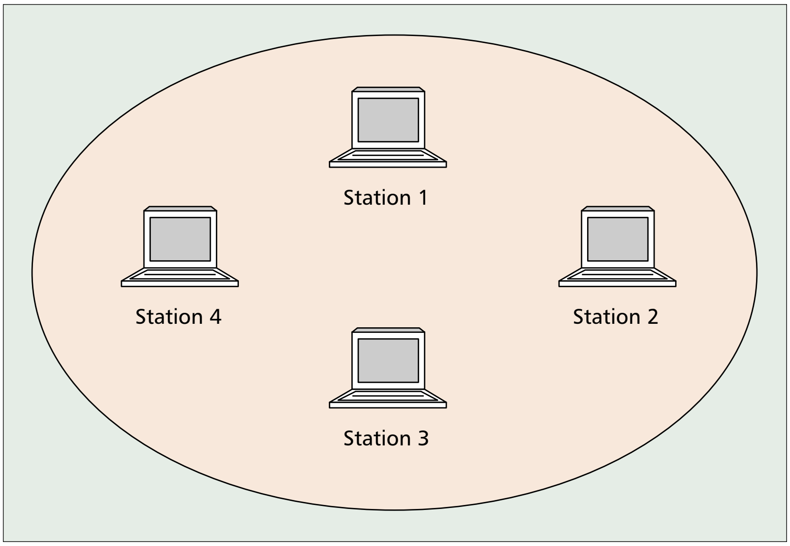
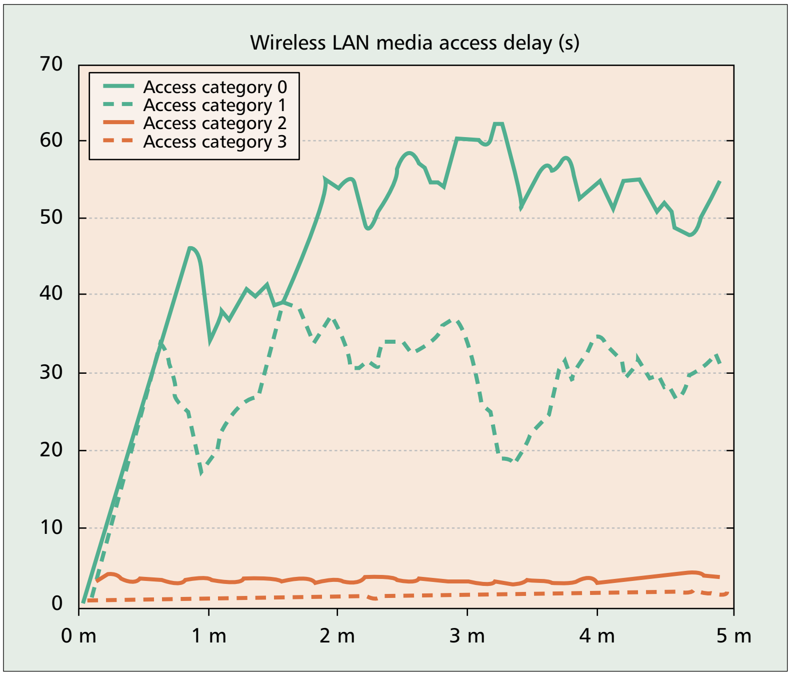


Figure 4. *The simulation scenario.*

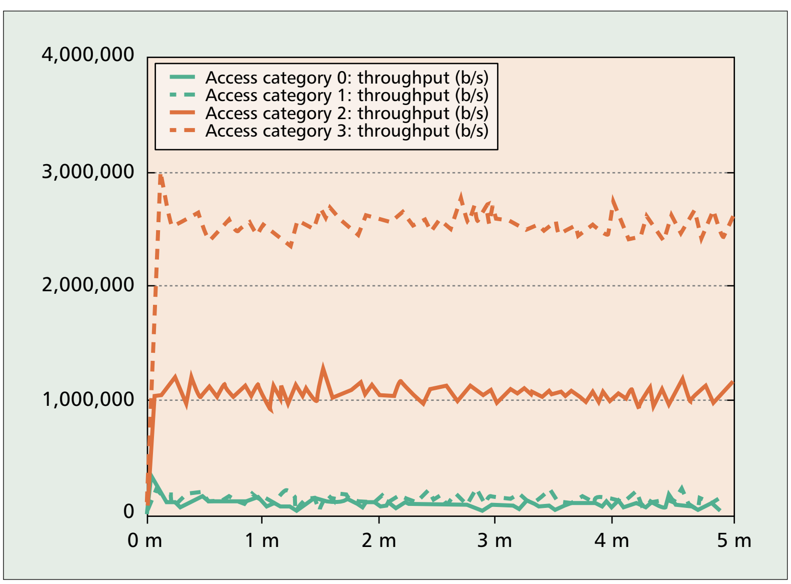
Simulation Evaluation

A simulation model was constructed using OPNET. In the simulation, four IEEE802.11 wireless stations with EDCF mechanisms were configured in ad hoc mode (Fig. 4). Four stations remain stationary during the simulations. The simulation uses a standard OPNET 802.11b PHY module with maximum data rate up to 11 Mb/s to simulate the wireless medium. While the original 802.11 MAC was modified to support the EDCF mechanism, for simplicity we just simulated the EDCF access function and did not consider other traffic parameters such as TXOPs in simulation. Any AC getting access to the medium transmits one packet and then releases the channel for the next AC. All PHY characteristics was according to 802.11b direct sequence spread spectrum (DSSS) PHY parameters, in which CWmin = 31, CWmax = 1023, and SlotTime = 20 µs.

All four traffic classes were fed into the MAC layer from the higher layer; these corresponded to AC(0), AC(1), AC(2) and AC(3), respectively. In the simulation we assumed that each traffic class has an equal portion of the total data traffic in terms of average number



■ **Figure 5.** *Medium access delay for different ACs.*



■ **Figure 6.** *Throughputs for different ACs.*

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 inter-arrival time equal to 0.0001 s, 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 ACs in the EDCF mechanism. As shown, AC(3) has the smallest average medium access delay, AC(0) the largest. The horizontal coordinate represents the simulation time in minutes. In Fig. 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 the EDCF differentiates the traffic classes and supports priority access. Thus, the higher-priority traffic categories have a smaller medium access delay and more bandwidth.

Conclusions

A detailed EDCF and HCF medium access mechanism of the upcoming IEEE802.11e standard is presented in this article. The 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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