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PAPER

A Priority Scheme for IEEE 802.11 DCF Access Method*

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SUMMARY IEEE 802.11 is a standard for wireless LANs. The basic access method in its MAC layer protocol is the distributed coordination function (DCF) for the ad hoc networks. It is based on the mechanism of carrier sense multiple access with collision avoidance (CSMA/CA). DCF is used to support asynchronous data transmission. However, frames in DCF do not have priorities, making it unsuitable for real-time applications. With a little bad luck, a station might have to wait arbitrarily long to send a frame. In this paper, we propose a method to modify the CSMA/CA protocol such that station priorities can be supported. The method is simple, efficient and easy to implement in comparison to point coordination function (PCF), another access method in IEEE 802.11 based on access points (base stations). Simulations are conducted to analyze the proposed scheme. The results show that DCF is able to carry the prioritized traffic with the proposed scheme.
key words: *wireless LAN, CSMA/CA, multimedia applications, priority*

1. Introduction

Wireless Local Area Network (WLAN) is a rapidly emerging field of activity in computer networks. It provides user connectivity without being tethered off by wired networks. WLAN can be used in many places. A common one is the wireless office. Other examples include conference registrations, campus classrooms, emergency relief centers, tactical military communications, and so on [1]–[3].

Currently, there are two emerging WLAN standards: the European Telecommunications Standards Institute (ETSI) HIgh Performance European Radio LAN (HIPERLAN) [4] and the IEEE 802.11 WLAN [5]. There are also several other proposals under study [6], [7]. Most draft standards cover the physical layer and medium access control (MAC) sublayer of the open systems interconnection (OSI) seven-layer reference model.

The IEEE standard for WLANs was initiated in 1988 as IEEE 802.4L, a part of the IEEE 802.4 token bus wired LAN standard. In 1990 the IEEE 802.4L changed its name to IEEE 802.11 to form a WLAN standard in the IEEE 802 LAN standards organization. The scope of the standard is "to develop a MAC sublayer and Physical Layer (PHY) specification for wireless connectivity for fixed, portable and moving stations within a local area." After an unexpectedly long endeavor and several draft standards, the technical aspects of this standard were completed in 1997. The standard defines the basic media and configuration issues, throughput requirements, transmission procedure, and range characteristics for WLAN technology.

Neither the HIPERLAN nor IEEE 802.11 standard is perfect. Quite a bit of criticism has been directed at both of them. To begin with, the relatively low bit rate is too slow for the future B-ISDN using the ATM standard. Besides, the low available frequency bandwidth will limit the use of such a system for image transmission. It requires the design of a new higher-performance wireless network.

Furthermore, frames in DCF, the basic access method in IEEE 802.11 MAC layer protocol, do not have priorities, and there is no other mechanism to guarantee an access delay bound to the stations. To put it another way, real-time applications like voice or live video transmission may suffer with this protocol. Since the demand for transferring delay-sensitive data in wireless environment is evident from the evolution of new data communication applications, we propose a method to modify the DCF protocol such that station priorities can be supported along with the real time applications in an ad hoc network.

MAC protocols that aim to carry multimedia traffic must be able to meet the differing requirements of each of the different traffic classes. Time-bounded data are useless unless arrived in time. Examples of such traffic include voice and video. On the other hand, asynchronous data, such as email or file transfer, can be delayed without causing any inconvenience. In general, there are two methods in wireless MAC protocols to facilitate the transmission of time-bounded data, reservation schemes and priority schemes. Reservation schemes, like DQRUMA [8], IEEE 802.11 PCF [4] and PRMA-DA [9], allow time-bounded traffic to reserve a periodic time slot on the channel that they alone can access. These approaches need a central agent, typically the Base Station that acts as a slot scheduler. Conse-

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quently, these approaches are not suitable for ad-hoc networks. Another approach is to solve the resource reservation problem in protocols above network layer. The resource ReSerVation Protocol (RSVP) [10] is one of the examples. RSVP is not a MAC layer protocol. It is a flow setup protocol that needs the support from network routers. All reservation schemes suffer from one drawback. When reserved and unused, the resource is simply wasted. This is where priority schemes come in. Priority schemes share resources and at the same time allow some stations to have a larger share of the pie. They assign higher priority to the time-bounded traffic and high priority traffic has precedence for using network resources. However, depending on the protocol design (for example, whether the resource usage is preemptive), performance can not be absolutely guaranteed.

A simple priority scheme for IEEE 802.11 has been proposed in [18]. A high priority station has a shorter waiting time when accessing the medium. Performance for transporting voice traffic is also examined. In this paper, we propose a more flexible priority scheme for IEEE 802.11 DCF access method. A high priority station also has a shorter waiting time when accessing the medium. Furthermore, when collision occurs, a high priority station can have advantage in accessing the medium too. Many levels of priorities can be designed. In this paper, we use four classes of priority to demonstrate the idea. Performance for audio/video traffic is examined in detail. The results show good performance improvements over the original DCF protocol. Moreover, this mechanism is designed with a view of simple, efficient, and easy of implementation.

The remainder of this paper is organized as follows. In Sect. 2, we explain some terminology in IEEE 802.11 standard and the way CSMA/CA works. Section 3 presents a method to modify the CSMA/CA protocol such that station priorities can be supported. It is simple to implement. Simulation and its results are shown in Sect. 4. Section 5 concludes this paper.

2. Preliminaries

The IEEE 802.11 standard considers two network topologies: ad hoc and infrastructure-based. In an ad hoc configuration (see Fig. 1), the mobile terminals communicate with each other in an independent basic service set (BSS) without connectivity to the wired backbone network. In an infrastructure network (see Fig. 2), mobile terminals communicate with the backbone network through an access point (AP). The AP is a bridge supporting range extension by providing the integration points necessary for network connectivity between multiple BSSs, thus forming an extended service set (ESS). In other words, the ESS consists of multiple BSSs that are integrated together using a common distribution system (DS). A mobile terminal can roam among different BSS in one ESS without losing connectivity to the backbone.

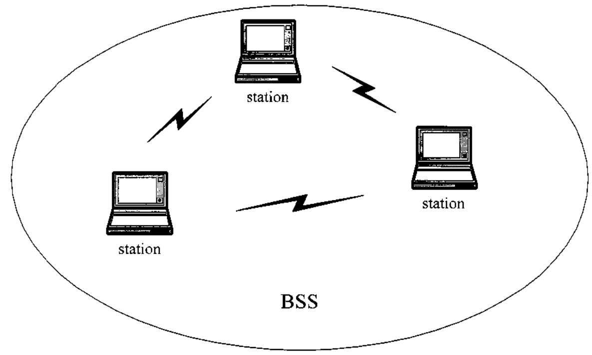

Fig. 1 Ad hoc network.

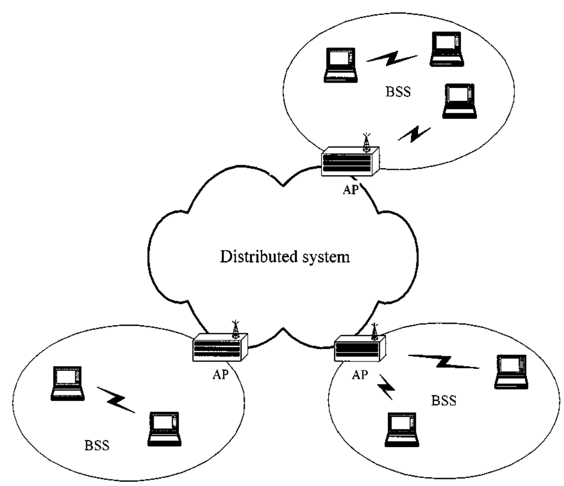

Fig. 2 Infrastructure network.

IEEE 802.11 standard supports three different types of frame: management, control, and data frames, which are illustrated in Fig. 3. The IEEE standard 48-bits MAC addressing is used to identify a station. In Fig. 3, the 2 duration octets indicate the time for stations in the BSS to adjust their network allocation vector (NAV). When one station transfers frames, all stations in the BSS hear these frames, read the duration field, and register the duration field to their NAVs accordingly. Therefore, the NAV records the time for other station to transfer frames, and indicates the amount of time that must elapse before the current transmission session is complete and the channel can be sampled again for idle status.

The basic access method of the IEEE 802.11 MAC protocol for ad hoc networks is the distributed coordination function (DCF), also known as carrier sense multiple access with collision avoidance (CSMA/CA). DCF is used to support asynchronous data transmission. The protocol also incorporates an alternative access method, the point coordination function (PCF), in infrastructure networks. PCF is used to support both asynchronous and time-bound isochronous appli-

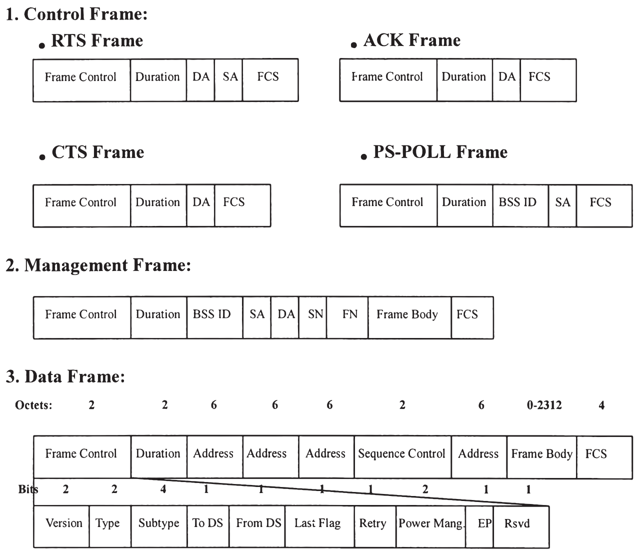

Fig. 3 IEEE 802.11 frame format.

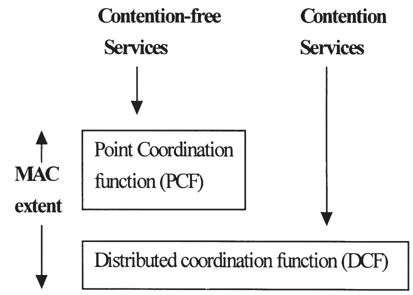

Fig. 4 MAC architecture.

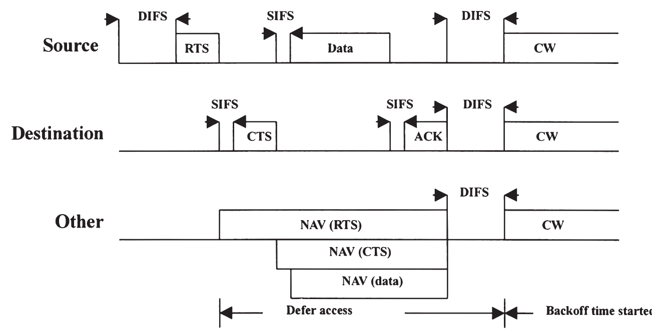

Fig. 5 Transmission data using RTS/CTS mechanism.

cations. The MAC architecture is depicted in Fig. 4.

CSMA/CA works by a "listen before talk" scheme. To transmit a station must sense the medium to determine if another station is transmitting and must ensure that the medium is idle for the specified distributed coordination function interframe space (DIFS) duration before transmitting. The PCF requires the existence of a centralized entity, AP, to poll the mobile terminal that has the right to transmit. The AP uses a shorter interframe space value, defined as a point coordination function interframe space (PIFS), to decide whether the medium is busy or idle. Three interframe space (IFS) intervals are specified in the IEEE 802.11 standard: short IFS (SIFS), PCF-IFS (PIFS), and DCF-IFS (DIFS). The SIFS interval is the smallest IFS, followed by PIFS and DIFS respectively. As a result, PCF traffic has high priority over DCF traffic. Control frames, which wait SIFS before transmission, have the highest-priority access to the communication media. Request-to-send (RTS) and Clear-to-send (CTS) are used by stations to reserve channel bandwidth before transmission to solve the "hidden terminal" [11] and "exposed terminal" [11] problems. This mechanism can also minimize the amount of bandwidth wasted when collision occurs.

Despite these precautions, collision can still occur. The collision avoidance portion of CSMA/CA is performed by a random backoff procedure. If a station with a frame to transmit initially senses the channel to be busy; then the station waits until the channel become idle for DIFS period, and then computes a random backoff time to wait before sensing again to verify a clear channel on which to transmit. If the channel becomes busy before time out, the station freezes its timer. This process is repeated until the waiting time approaches zero and the station is allowed to transmit. The idle period after a DIFS period is referred to as the contention window (CW). Figure 5 is a timing diagram illustrating the transmission of data frame using the RTS/CTS mechanism. For more information about IEEE 802.11 standard, see [12]–[14].

3. Enforce Priorities for DCF Access

In this section, we will introduce a method to support station priorities. The method is simple, efficient, and easy to implement in comparison to PCF (The PCF protocol is extremely complex and has substantial delay at low load, i.e., stations must always wait for the polling, even in an otherwise idle system).

Our method can be divided into two parts: shorter IFS and shorter random backoff time for higher priority stations. Each part has two classes of priority. Thus, there are four classes of priority by combining these two parts.

3.1 Shorter IFS

The basic idea of this part is that priority access to the wireless medium is controlled through the use of different interframe space (IFS) time intervals between the transmission frames. The shorter IFS a station uses, the higher priority this station will get. Since only two kinds of IFSs, SIFS and DIFS, are used in DCF protocol and the other IFS, PIFS, is shorter than DIFS but longer than SIFS. We can use the mechanism which IEEE 802.11 standard already had to implement our

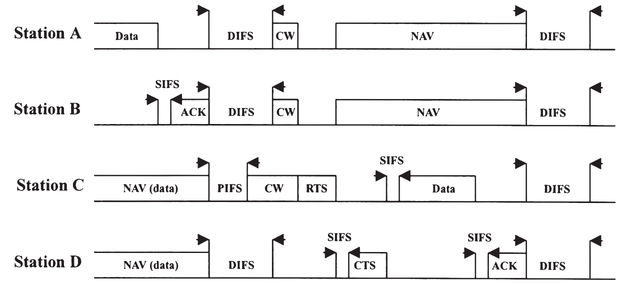

Fig. 6 Transmission data by station C using shorter interframe space.

IFS / Priority / Backoff algorithm	PIFS	DIFS
$\left\lfloor ranf()\cdot\frac{2^{2+i}}{2}\right\rfloor$	3	1
$\frac{2^{2+i}}{2}+\left\lfloor ranf()\cdot\frac{2^{2+i}}{2}\right\rfloor$	2	0

Fig. 7 Combinations of shorter IFS and shorter random backoff time.

priority scheme. Figure 6 shows how it works. Initially, station A, which has normal priority, sends its data to station B. Upon receipt of the correct packet, station B waits a SIFS interval and transmits a positive acknowledgment frame (ACK) back to station A, indicating that the transmission was successful. After successful detection of the ACK frame, all stations wait for a DIFS period and sample the channel again except station C. Assume station C has higher priority. It waits for a shorter IFS, PIFS, to decide whether the medium is busy or idle. As a result, station C will seize the channel by waiting only PIFS period. By "seize," we mean that all other stations knew C was transmitting and would not interfere.

An issue is how much time a station must wait before it actually seizes the channel. In effect, the total time a station waits is the sum of the IFS and the random backoff time. This means that no matter how short IFS a station uses, it can still lose in the contention if the total time is longer than the other stations. In the next, we will determine the appropriate backoff Slot_Time to ensure this priority scheme works effectively.

3.2 Shorter Random Backoff Time

As mentioned earlier, the collision avoidance portion of CSMA/CA is performed through a random backoff procedure. If a station with a frame to transmit initially senses the channel to be busy, then it waits until the channel becomes idle. After that, it waits for a DIFS period, and then waits for a random backoff time.

For IEEE 802.11 standard, time is slotted. The unit is called a Slot_Time. The random backoff time is an integer value that corresponds to a number of time slots. Initially, a station computes a backoff time in the range 0–7. If the medium is still idle after a DIFS period, the station decrements its backoff timer until the medium becomes busy again or the timer reaches zero. If the timer has not reached zero and the medium becomes busy, the station freezes its timer. When the timer finally decrements to zero, the station transmits its frame. If two or more stations decrement to zero at the same time, a collision will occur, and each station will have to generate a new backoff time in the range 0–15. For each retransmission attempt, the backoff time grows as $\lfloor ranf()\cdot 2^{2+i}\rfloor \bullet$ Slot_Time, where i is the number of consecutive times a station attempts to send a frame, $ranf()$ is a uniform variate in (0,1), and $\lfloor x\rfloor$ represents the largest integer less than or equal to x.

To support priority, we change the backoff time generation function to $\lfloor ranf()\cdot 2^{2+i}/2\rfloor$ for high priority stations and $2^{2+i}/2+\lfloor ranf()\cdot 2^{2+i}/2\rfloor$ for low priority stations. This technique divides the random backoff time into two parts: $0 \sim 2^{2+i}/2-1$ and $2^{2+i}/2 \sim 2^{2+i}-1$. The high priority stations use the former and the low priority stations usethe latter. Please note that dividing the backoff time in more detail can support more levels of priorities. For example, initially, the high priority stations generate a backoff time in the range 0–3, and the low priority stations generate a backoff time in the range 4–7. Thus, the former will have higher priority in contending the channel. Unfortunately, there is no such thing as a free lunch. Low priority stations still have to generate a longer backoff time even when no high priority stations want to transmit. In other words, additional delay is imposed by the longer backoff time. Fortunately, the Slot_Time used in IEEE 802.11 standard is relatively small when compared to the other frame formats, so delay is tolerable.

It is worth mentioning that when a station decrements its backoff timer and the medium becomes busy, the station freezes its timer. This means that a station will raise its priority automatically after several times of transmission failure. Besides, more priority levels can be obtained by modifying the backoff algorithms in a similar way. However, the probability of collisions in the same priority level will increase.

If the backoff time is divided into two parts, four priority classes can be supported by combining the shorter IFS scheme, as shown in Fig. 7.

4. Simulation and Performance Evaluation

In this section, we evaluate the performance of the proposed scheme.

4.1 Simulation Model

The simulation models are built using the Simscript tool [15]. The model represents an ad hoc network, where all stations in the BSS (Basic Service Set) are capable of directly communicating with all other stations in the BSS. Several assumptions have been made to reduce the complexity of the model. First, the "hidden terminal" and "exposed terminal" problems are not addressed in the simulation model. Second, no stations operate in the "power-saving" mode. Third, no interference is considered from nearby BSSs. Finally, the probability that the frame is transmitted successfully is calculated as: $p_r\{\text{success}\} = (1-BER)^n$, where n is the number of bits transmitted in the frame and BER denotes bit error rate.

Three types of traffic are considered in the simulation.

1. Pure data
   The arrival of data frames from a station's higher-layer to MAC sublayer is Possion. Frame length is assumed to be exponentially distributed with mean length 1024 octets.
2. Voice traffic
   Voice stream is characterize by two parameters (γ, δ), where γ is the rate of the source and δ is the maximum tolerable jitter (packet delay variation) for this stream. Frames of voice traffic that are not successfully transmitted within its maximum jitter constraint is assumed to be lost. The voice stream is modeled as an two state Markov on/off process, where stations are either transmitting (on) or listening (off). The amount of time in the off or on state is exponentially distributed, where the mean value of the silence (off) period is 1.5 s, and the mean value of the talk spurt (on) period is 1.35 s.
3. Video traffic
   We use a Source Model in [16]. The bit rate of a single source for the nth frame, $\lambda(n)$, is defined by the recursive relation: $\lambda(n) = a\lambda(n-1) + bw(n)$ [bit/pixel], where $a = 0.8781$, $b = 0.1108$, and $w(n)$ is a sequence of independent Gaussian random variables which have mean 0.572 and variance 1. Like voice frames, video frames that are not successfully transmitted within its maximum tolerable delay, d, is assumed to be lost.

Assume video, voice and data are integrated in the ratio of 1 : 1 : 2. The priority levels of video, voice and data frames are 3, 2 and 0 respectively. Performance is measured in terms of average access delay and loss probability. Since fluctuation of delay among frames is important for the audio/video applications. We also evaluate the variance of the delay as well as the average access delay. The default values used in the simulation are listed in Table 1.

Table 1 Default attribute values used in the simulation.

Attribute	Value
Channel rate	2Mb/s
Stations	10
Slot_Time	10 μ s
SIFS_Time	10 μ s
PIFS_Time	30 μ s
DIFS_Time	100 μ s
RTS frame length	25 octets
CTS frame length	25 octets
BER	10^{-6}
γ	32Kb/s
δ	32ms
d	50ms

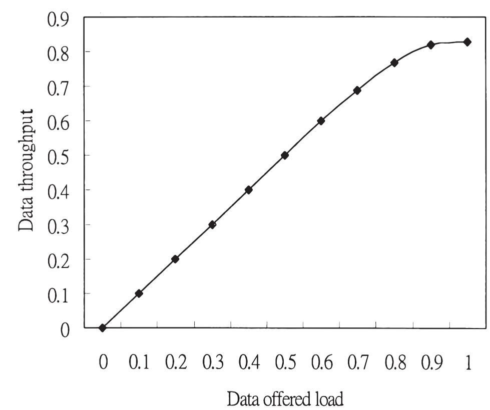

Fig. 8 Throughtput versus offered traffic for DCF protocol.

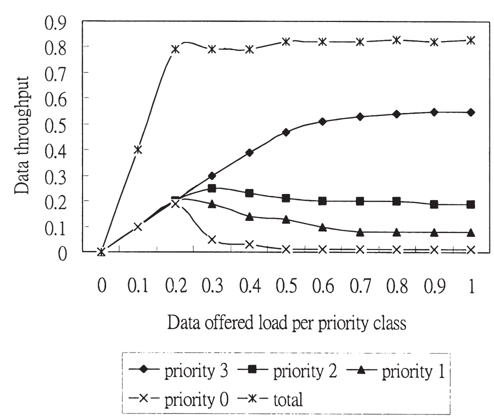

Fig. 9 Priority effects on data throughput.

4.2 Simulation Results

Simulation results are shown below in the form of plots. Figure 8 shows the aggregate throughput in megabits per second versus the offered load in megabits per second for the original DCF protocol. Figure 9 shows the aggregate throughput in megabits per second versus the offered load for each priority class under the proposed scheme.

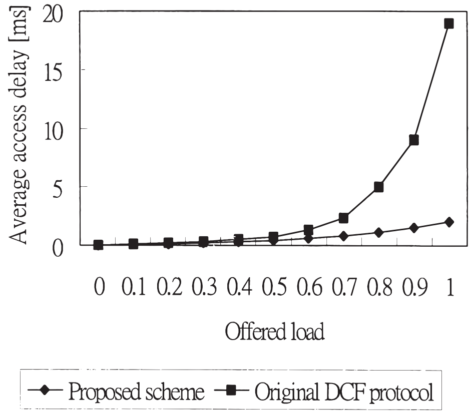

Fig. 10 Average access delay of video traffic, variance = 0.45 (proposed scheme) and 34.06 (original protocol).

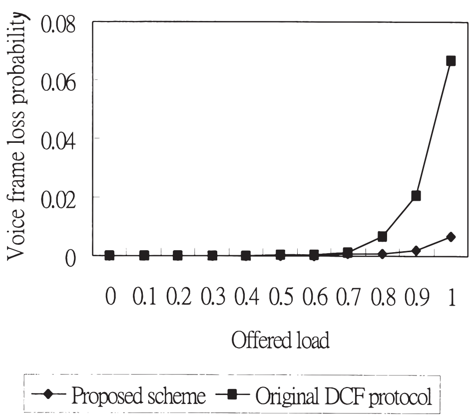

Fig. 11 Frame loss probability of video traffic.

As shown in the figure, we can see that approximately 55 percent of bandwidth is allocated to the highest priority traffic under heavy load. The low priority traffic gets to transmit with the left bandwidth. In light load, the lower priority traffic can have the bandwidth it needs, so it is not wasted.

Figures 10 and 11 show average access delay and loss probability of video traffic under multimedia traffic condition. Note that the average access delay of the proposed scheme increases a little as the load increases, but the average access delay of the original DCF protocol increases significantly as the load increases. Frame loss probability of the original DCF protocol degrades severely when the offered load become larger than 0.7 in contrast to the smoothness of the priority method. For video traffic, allowable loss probability is about [17]. With this criterion, the proposed scheme can tolerate an offered load of 0.9. The simulation results indicate that our priority scheme can be used to transmit high priority real-time applications such as video traffic.

Figures 12 and 13 show the average access delay and frame loss probability of voice traffic under multimedia traffic condition. When the offered load is high, average access delay and loss probability of the proposed scheme remain low but the original DCF protocol shows sharp rise just after the offered load becomes larger than 0.7. For voice traffic, the allowable loss probability is about [19]. Therefore, when the offered load is smaller than 0.9, the proposed scheme works very well for voice traffic.

Figure 14 shows the average access delay of data traffic under multimedia traffic condition. As expected,

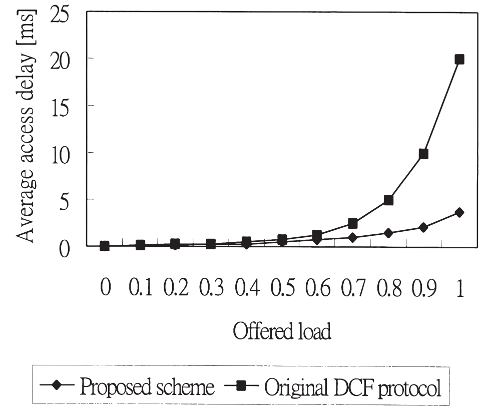

Fig. 12 Average access delay of voice traffic, variance = 1.27 (proposed scheme) and 38.39 (original DCF protocol).

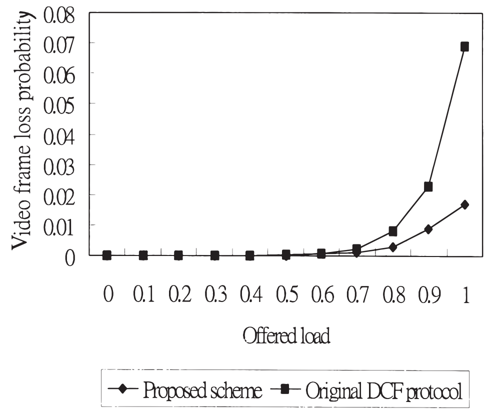

Fig. 13 Frame loss probability of voice traffic.

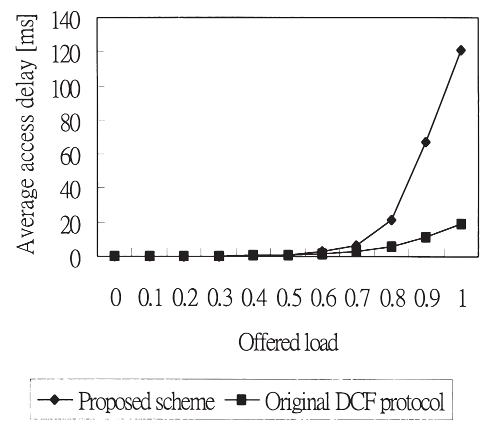

Fig. 14 Average access delay of data traffic, variance = 1521.82 (proposed scheme) and 36.95 (original DCF protocol).

the average access delay of data traffic in the proposed scheme become worse than the original DCF protocol since it is of low priority.

5. Conclusions

It is widely acknowledged that the support of multi-priority level is required to provide a variable quality of service to the user. In this paper, a multi-priority scheme for IEEE 802.11 DCF access method is proposed. By modifying the CSMA/CA protocol, four classes of priority are available to support real-time applications. Our method is simple, efficient, and easy to implement. We also analyze the proposed scheme via simulation. The results show that DCF is able to carry the prioritized traffic with the proposed scheme.

The success of WLANs depends on the availability of corresponding backbone wired infrastructure and the evolution of the software applications. The new generation wireless technologies should support universal wide-band access to a variety of services such as cordless telephony, Internet access, multimedia conference, remote audio, and flexible positioning of audio system. This means that widely varying QoS requirements are needed in the future. Supporting prioritized traffic is only the beginning. Bandwidth allocation, connection admission control, and traffic policing all need to be considered together to satisfy various QoS flows in the future networks.

Acknowledgement

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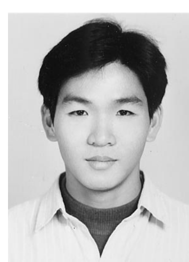

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