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IEEE 802.11 무선 랜에서 성능 향상을 위한 채널 예약 기반 DCF MAC 프로토콜

Channel Reservation based DCF MAC Protocol for Improving Performance in IEEE 802.11 WLANs

현 종 욱[*] · 김 선 명[†]
(Jong-Uk Hyun · Sunmyeng Kim)

Abstract - In the IEEE 802.11 DCF (Distributed Coordination Function) protocol, the binary exponential backoff algorithm is used to avoid data collisions. However, as the number of stations increases of, the collision probability tends to grow and the overall network performance is reduced. To solve this problem, this paper proposes a data transmission scheme based on the channel reservation method. In the proposed scheme, channel time is divided into reservation period and contention period. During the reservation period, stations succeeded in channel reservation transmit their own data packets in sequence without contention. During the contention period, each station sends its data packets through contentions as in DCF. During both the reservation period and the contention period, each station sends a request for channel reservation for the next reservation period to an AP (Access Point). After receiving such a channel reservation request from each station, the AP decides whether the reservation is succeeded and sends the result via a beacon frame to each station. Performance of the proposed scheme is analyzed through simulations. The simulation results show that the proposed scheme tends to reduce the collision probability of DCF and to improve the overall network performance.

Key Words : Channel Access, DCF, IEEE 802.11, MAC, Reservation, WLAN

1. Introduction

The IEEE 802.11 standard for wireless local area networks (WLANs) defines a medium access control (MAC) protocol for sharing the channel among stations [1]. The MAC protocol is designed with two methods of communication for stations: 1) distributed coordination function (DCF) and 2) point coordination function (PCF). The DCF was designed for a contention-based channel access. It has two data transmission methods: the default basic access and optional RTS/CTS (request-to-send/clear-to-send) access. The basic access method uses the two-way handshaking (DATA-ACK) mechanism. The RTS/CTS access method uses the four-way handshaking (RTS-CTS-DATA- ACK) mechanism to reserve the channel before transmitting long data packets. This technique is introduced to avoid the hidden terminal problem. The DCF is best known for asynchronous data transmission (or best effort service). PCF uses a central controlled polling method to support synchronous data transmission (QoS for real-time traffic).

IEEE 802.11 DCF is essentially carrier sense multiple access with collision avoidance (CSMA/CA). Packet collisions on the medium are resolved using a binary exponential backoff algorithm. A station with a packet to transmit shall ensure that the medium is idle before attempting to transmit. It selects a random backoff counter less than the current contention window (*CW*) based on the uniform distribution, and then decreases the backoff counter by one at each slot when the medium is idle. If the medium is busy, the station defers until the end of the current transmission. A station transmits a packet when its backoff counter reaches zero. The contention window is initially assigned to the minimum contention window (*CWMin*). When there are collisions during the transmission, the contention window is doubled, with an upper bound of the maximum contention window (*CWMax*). After each successful transmission, the contention window is reset to *CWMin*.

As the number of stations increases, performance of the

[†] Corresponding Author : Dept. of Computer Software Engineering, Kumoh National Institute of Technology, Korea.
E-mail: sunmyeng@kumoh.ac.kr
[*] Dept. of Computer Software Engineering, Kumoh National Institute of Technology, Korea.

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IEEE 802.11 DCF protocol degrades significantly because of excessively high collision probability. To improve the performance of DCF, various methods have been proposed [2-10]. Misra and Khatua proposed SDB (Semi-Distributed Backoff) algorithm [2]. The SDB algorithm has two modes: S-mode and R-mode. In the S-mode, a transmitting station selects backoff counter to send data packets. In R-mode, a receiving station selects the backoff counter. When sending the first data packet, a station is operating in S-mode and if there is a collision in the transmitted data packet, then it operates in R-mode. Through this method, it is possible to avoid consecutive collisions of a data packet. I-DCF (Improved DCF) method is proposed to avoid packet collision issues by selecting same backoff value among different stations in DCF [3]. In the I-DCF method, unique initial backoff value is allocated to each station. Thus, backoff value is controlled dynamically according to the network traffic load. Shenoy, Hamilton, Kwasinski, and Xiong analyzed the impact of propagation delay and clock synchronization to backoff of the MAC protocol [4]. And in addition to slots used in DCF, smaller micro slots were added. In the DCF protocol, when the backoff counter value becomes zero, then data packets are sent immediately. However, in the Shenoy method, the backoff process is implemented one more time. The value used in the additional backoff process is selected within the number of the added micro slots randomly. CAD (Collision Alleviating DCF) method is proposed to reduce collisions and to avoid channel capture effects [5]. In the CAD method, a post backoff stage is used to provide packet delays between successive data packet transmissions. In the DCF protocol, a backoff counter value for the next packet transmission is set after sending packets, while in the EBA (Early Backoff Announcement) method, the backoff counter value for the next packet is set before the packet transmission [6]. The backoff counter value of the next packet is contained in the header of the current data packet and transmitted. With this value a relevant slot is reserved for the next data packet transmission. The destination station and other stations receiving the data packets know in advance that this station will send another data packet in which slot from now, and will not send their own data packets to the slot, so they can avoid the collision each other. In the reference [7], the SRB (Semi-Random Backoff) method was proposed. In this method, stations are not initialized to the default contention window after the success of packet transmission, and then do not set the backoff counter randomly. In other words, it is set at the predefined backoff counter value. This value is shared by every station in the network.

In this paper, we propose CR-DCF (Channel Reservation based DCF) scheme to reduce the collision probability of each station and to enhance the overall network performance. In the proposed scheme, channel time is divided into reservation period and contention period. During the reservation period, stations succeeded in channel reservation transmit their own data packets in sequence without contention. During the contention period, each station sends its data packets through contentions as in DCF. During both the reservation period and the contention period, each station sends a request for channel reservation for the next reservation period to an AP (Access Point). After receiving such a channel reservation request from each station, the AP decides whether the reservation is succeeded and sends the result via a beacon frame to each station.

The paper is organized as follows: Section 2 describes the operational principle of the proposed scheme in detail. Section 3 describes the simulation results and Section 4 reveals the conclusion.

2. Proposed CR-DCF Scheme

The basic operational principle of the proposed scheme is shown in Fig. 1. In the proposed scheme, channel time is divided into reservation period and contention period. The repetition cycle of the reservation period and the contention period is defined as reservation repetition interval. The reservation repetition interval starts with a beacon frame sent by an AP. Since the reservation repetition interval is fixed, every station knows when the next beacon frame is transmitted.

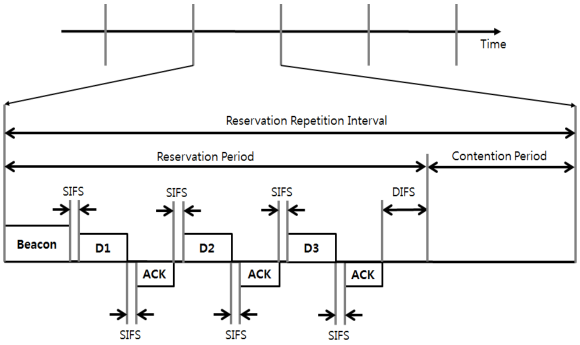


Fig. 1 Structure of Reservation Repetition Interval

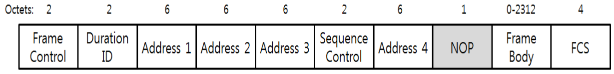
In the reservation period, stations succeeded in reservation during the previous reservation repetition interval transmit their data packets in sequence without channel contentions. The transmission sequence of stations is announced to the stations by the AP via a beacon frame. The method of sending the transmission sequence is described later. To know its turn of sending data packets, a station counts the number of transmitted data or ACK packets during the current reservation period. To do so, each station maintains variable DTS (Data Transmission Sequence). This variable value is initialized to zero when receiving a beacon frame and increased by one when receiving a data packet or an ACK packet. During the reservation period, if the DTS value is n, then nstations send data packets up to now, and n+1th station transmits its data packet next time. If the number of data packets is considered, any station in a hidden condition does not receive data packets, so it does not increase its DTS value. Thus, by taking into account the ACK packet transmitted by the AP, every station can recognize its turn of transmission, even if there occurs an issue of hidden terminal.

If the channel is idle during the DIFS (DCF Inter-Frame Spacing) without any packet transmission, then the reservation period is terminated automatically and shifted to the contention period. Thus, even if any station is not made reservation during the reservation period, it shifts to the contention period directly without any waste of channel.

In Fig. 1, let us assume that the transmission reservations are made for three stations. After receiving a beacon frame, every station initializes its own DTS variable value to zero. The first station with transmission reservation receives the beacon frame and sends its own data packet, D1, to an AP after SIFS (Short Inter-Frame Spacing). As a reply to this action, the AP sends an ACK packet. After receiving the data packets or the ACK packet, other stations increase their own DTS values by one. Through this action, they know that the next turn is the second station among the stations, which succeeded reservation. The second station sends its own data packet, D2, after the SIFS duration. Likewise, the third station sends D3 and the AP transmits an ACK packet. After that, as there is no reserved station, every station is operating in the contention period after the DIFS duration.

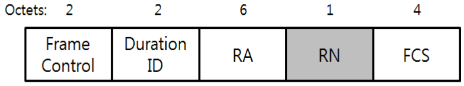
Stations are conducting channel contentions in the contention period and transmitting data packets, as in the DCF. Any station which transmits data packets in the reservation period can also transmit data packets via channel contentions during the contention period. Although only one station can send a data packet in the reservation period, it can send several data packets through channel contentions in the contention period.

Any station which has data packets in its queue to transmit can request channel reservation in the reservation period or the contention period for the reservation period in the next reservation repetition interval. To make a channel reservation request, each station sends a data packet containing the number of data packets in its queue. To do so, we slightly modify the data packet format used in the IEEE 802.11 standard. Fig. 2 shows the data packet format used in the proposed scheme. Unlike the standard format, it adds a NOP (Number of Packets) field. The length of this field is one byte. In general, the maximum length of queue in a station is less than 255, so one byte is sufficient for its purpose.



Octets:	2	2	6	6	6	2	6	1	0-2312	4
	Frame Control	Duration ID	Address 1	Address 2	Address 3	Sequence Control	Address 4	NOP	Frame Body	FCS

Fig. 2 Data Packet Format



Octets:	2	2	6	1	4
	Frame Control	Duration ID	RA	RN	FCS

Fig. 3 ACK Packet Format

A station sends the number of data packets in its queue to the AP by using the NOP field. The range of the NOP field value is 0~255. If the station does not want to make a channel reservation for the next reservation period, then it sets the NOP field value to zero and then sends the data packet. If it wants to make a channel reservation, then it sends a value of one or more.

When the AP receives a data packet of which NOP field value is one or more, it manages the station to determine the channel reservation. As mentioned above, a station can send several data packets during a repetitive reservation interval. At first, as the station needs a channel reservation, it sends a data packet of which NOP field value is one or more to request a reservation. After that, if it does not need the channel reservation any more, then it sets the NOP field value to zero and transmit it. When a station which made a reservation request previously sends a data packet of which NOP field value is zero, then the AP removes the station from the list of management.

The AP maintains a parameter of RN (Reservation Number). This parameter is initialized to zero whenever the reservation repetition interval is starting (that is, when the AP transmits a beacon frame). After receiving a data packet, of which NOP field value is one or higher, the AP increase the RN value by one. Then, it transmits an ACK packet including the RN value. Fig. 3 shows the format of an ACK packet. For a data packet, of which NOP field value is zero, the RN field value is set at zero and then an ACK packet is sending. A station receiving the ACK packet stores its own RN value.

After the contention period is terminated, the AP decides whether the final reservation is succeeded or not for the stations requesting the channel reservation in the reservation period and the contention period. At first, the AP computes the reservation priority (RP) of the stations requesting reservations. The RP of station *i* is as follows:

$$RP_i = \begin{cases} NOP_i \cdot \dfrac{NOF_i}{NOS_i + NOF_i} \cdot Q_{max}, if\ NOF_i \neq 0 \\ NOP_i, \qquad\qquad\qquad else \end{cases} \tag{1}$$

where, *NOSi* (Number of Successes) and *NOFi* (Number of Failures) is the number of success or failures for the requested channel reservations of station *i* in a given time period. *Qmax* is the largest value in the queues of stations. To endow a larger RP value to stations of which NOF is not zero than to station of which NOF is zero, we use *Qmax*. In Equation (1), the more the number of packets in the queue of a station is, or the higher failure probability of reservation is, the larger RP value endows.

Let us define that the maximum number of stations reserved in the reservation period as MRS (Maximum Reservation Station). The AP aligns the stations in a descending order of RP, and then selects MRS stations and determine them as succeeded in reservation. The NOS value of each selected station increases by one. Each remaining station not selected is deemed as a failed reservation and increases the NOF value by one.

After determining the success or failure of the reservation of stations, the AP delivers a notification via a beacon frame. Unlike the standard, the beacon frame used in the proposed scheme has an additional RC (Reservation Confirmation) field (refer to Fig. 4). This field runs in bitmap mode. If the bit value is one, then the reservation is a success; and if the value is zero, then it is a failure. The *n*th bit is a reply to a station of which RN is *n*.

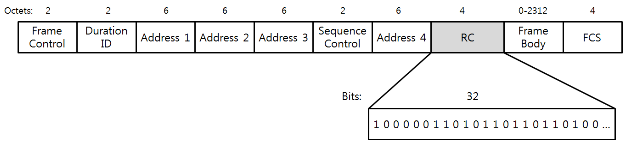


Fig. 4 Beacon Frame Format in CR-DCF Scheme

If the bit value located in the relevant RN value is one, then the station receiving a beacon frame knows that its channel reservation request is succeeded. Stations which succeed in the reservation send a data packet in sequence without contention in the reservation period. For example, RN values of the stations succeeded in reservation in Fig. 4 are 1, 7, 8, 10, 12, 13... Thus, a station of which RN value is one sends a data packet at first, and a station of which RN value is seven sends a data packet for the second time, and then a station of which RN value is eight sends a data packet for the third time. The other stations operate in the same way.

The proposed CR-DCF scheme has a possibility of occurring two types of malfunctions in the reservation period. The first is when a station succeeded in reservation receives an erroneous beacon frame. In such a case, the station cannot know whether its reservation is succeeded. Thus, the station cannot send its own data packet in its turn of transmission. If data packet is not sent, then the channel becomes idle during the DIFS duration, so every station recognizes it as the reservation period is terminated and the contention period is starting. Thus, they starts the channel contentions.

Fig. 5 shows an example of malfunction caused by a beacon frame error. For the next reservation period, the AP determines the reservation success in sequence of STA1, STA2, STA3, and STA4, and transfers the result via a beacon frame. However, since STA3 receives an erroneous beacon frame, it does not know whether the reservation is succeeded or not. STA1 and STA2 send their data packets (D1 and D2, respectively) in sequence, and the AP sends an ACK packet to each station. Since STA3 does not know whether its reservation is succeeded or not, it does not send a data packet. Accordingly, the channel becomes idle for the DIFS duration, and every station starts the contention period. At this time, the DTS value of each station is two, so STA4 does not send its data packets as well.

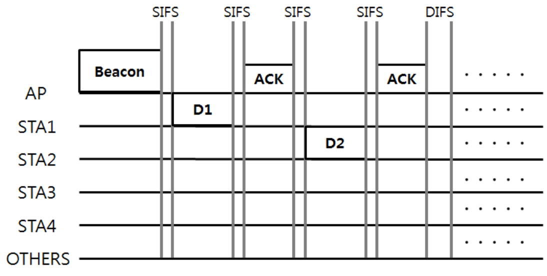


Fig. 5 Example of Malfunction Caused by Beacon Frame Error

To solve the malfunction issue caused by beacon frame errors, the proposed scheme uses a polling packet. When a data packet is not received at the designated place, then the AP waits for the PIFS (PCF Inter-Frame Spacing), and then sends a polling packet to the next station. Each station receiving the polling packet assumes that it receives a data packet or an ACK packet from the previous station already, then increases its DTS value by one. Through this action, the next station recognizes its turn, and sends its data packet. Since the PIFS value is smaller than the DIFS value, stations are not starting the contention period.

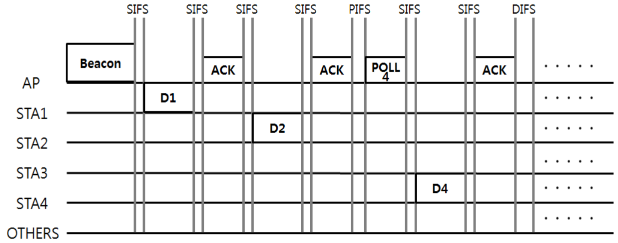


Fig. 6 Example of Solving the Malfunction Caused by Beacon Frame Error

Fig. 6 shows an example of solving a malfunction issue caused by a beacon frame error. When a malfunction is occurred as shown in Fig. 5, the AP send a POLL 4 packet to STA4 after the PIFS. Through the polling packet, STA4 recognizes that the next is its turn. In addition, after receiving the polling packet, it increase its DTS value by one to know its turn. After checking the transmission sequence, STA4 sends a data packet.

The second issue of malfunction of the proposed CR-DCF scheme is when an error occurs in data packets transmitted by a station succeeded in reservation. If an error occurs in data packets, the AP does not transmit an ACK packet. Any other stations within the transmission range of the transmitting station receive the data packet and increase the DTS value by one. However, other stations in hidden conditions do not receive the data packet and ACK packet. Therefore, they cannot increase the DTS value. Thus, each station has a different DTS value based on its condition, which may cause malfunctions.

Fig. 7 shows an example of malfunction caused by a data packet error. Let us assume that STA3 and STA4 are located in hidden condition. Every station knows its own turn of transmission as they received the beacon frame without error. Both STA1 and STA2 send the data packet normally. However, there is an error in data packet sent by STA3. As the AP receives the erroneous data packet, it does not send an ACK packet. Thus, STA4 does not increase the DTS value. Therefore, as it does not know its turn of transmission, it does not send its data packet. As a result, the channel becomes idle for the DIFS duration, and stations start the contention period.

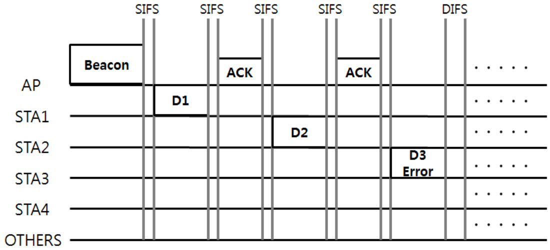


Fig. 7 Example of Malfunction Caused by Data Packet Error

A method of solving malfunction issue caused by a data packet error is to use a polling packet like the method of clearing a malfunction caused by a beacon frame error. When the AP receives an erroneous data packet, it sends a polling packet to a station, of which turn comes around. Each station receiving the polling packet assumes that it received the data packet or the ACK packet from the station with previous turn, and increases its DTS value by one. Through this action, they can work well even in hidden conditions.

Fig. 8 shows an example of solving a malfunction issue caused by a data packet error. When a malfunction occurs as shown in Fig. 7, the AP sends a POLL 4 packet to STA4 after the SIFS period. STA4 knows that the next is its turn via the polling packet. In addition, it can check its turn by increasing the DTS value by one after receiving the polling packet. After the checking the transmission order, the station transmits data packet.

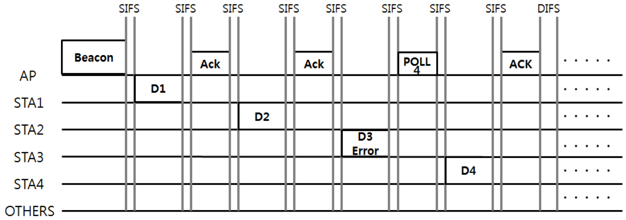


Fig. 8 Example of Solving the Malfunction Caused by Data Packet Error

3. Results of the Simulation

In this Section, we analyze simulation results of the proposed CR-DCF scheme. Performance of the CR-DCF scheme is compared with that of the DCF. The simulation was carried out based on IEEE 802.11g in which the transmission rate of data packet is 54 Mbps, and that of control packets such as RTS, CTS, and ACK is 6 Mbps. The maximum number of stations (MRS), which can be reserved in a reservation period is set to 30. The length of a data packet is 1000 bytes.

To generate data packets, we used the saturated traffic model. In this model, queues of every station are always full of data packets.

Major performance factors include normalized throughput, collision probability, and average delay. Delay is the time duration from the time at which a data packet reaches the queue head through the successful transmission to the destination station to the time of receiving an ACK packet.

Figs. 9-11 show simulation results of the basic access method using two way handshaking of DATA-ACK.

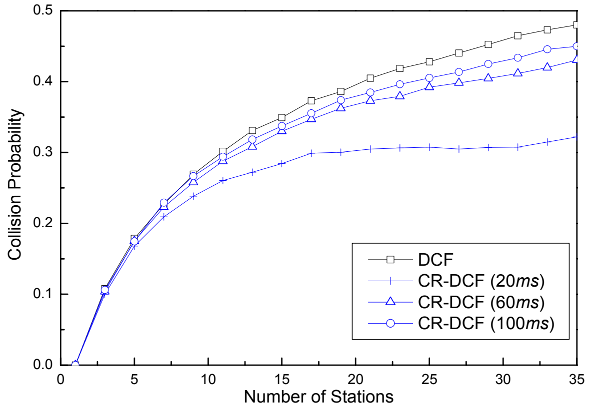


Fig. 9 Collision Probability According to the Number of Stations for Basic Method

Fig. 9 shows the result of collision probability based on the number of stations. In the figure, numbers in parentheses of the proposed CR-DCF scheme show the reservation repetition interval. In both the CR-DCF scheme and the DCF, as the number of stations increases, the collision probability grows. However, regardless of the number of stations, the proposed CR-DCF scheme is always superior to the DCF. This is because some data packets are transmitted without channel contention in the reservation period. In addition, in the proposed scheme, the shorter the reservation repetition interval is, the better the performance becomes. If the reservation repetition interval is small, then the reservation period is repeated rapidly, so more data packets can be sent without channel contention.

Fig. 10 shows the influence of the number of stations to the normalized throughput. Following the increasing number of stations, the collision probability becomes larger and the DCF gets low normalized throughput. However, in the proposed CR-DCF scheme, each station can send data without channel contention, the collision probability becomes lower, which makes relatively better normalized throughput. The smaller the reservation repetition interval is, the higher the normalized throughput becomes.

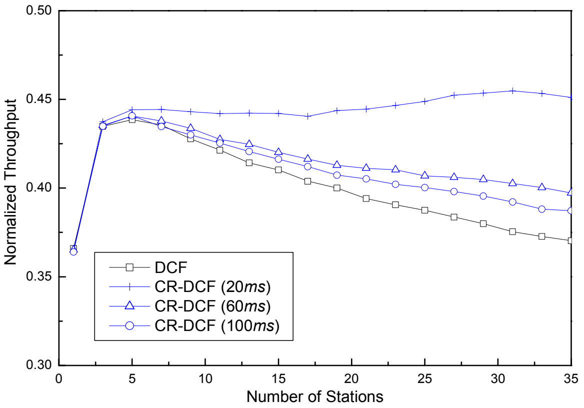


Fig. 10 Normalized Throughput According to the Number of Stations for Basic Method

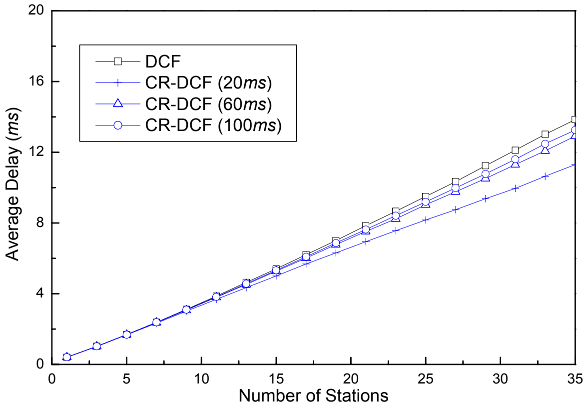


Fig. 11 Average Delay According to the Number of Stations for Basic Method

Fig. 11 shows average delay. The average delay is increasing when retransmission is increasing owing to collisions. Thus, as shown in Fig. 9, as the number of stations is increasing, the collision probability is also raised. The average delay is also proportional to the number. The proposed CR-DCF scheme shows the average delay always lower than that of the DCF regardless of the number of stations.

Figs. 12-14 are results of simulations with the RTS/CTS access method using four-way handshaking of RTS-CTS-DATA-ACK.

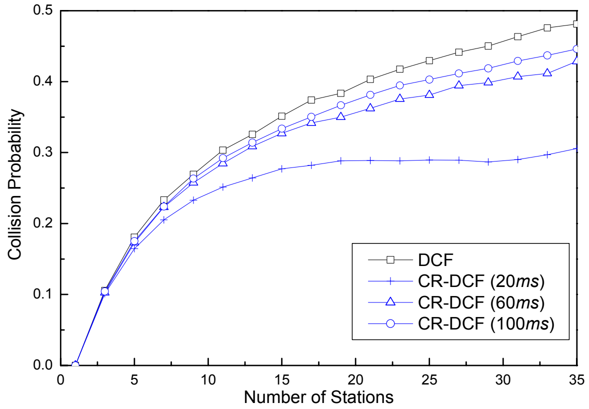


Fig. 12 Collision probability According to the Number of Stations for RTS/CTS Access Method

Fig. 12 shows a change of collision probability when using the RTS/CTS access method. It shows a similar result to that shown in Fig. 9. Whichever method is using such as the basic access method or the RTS/CTS method, since the situation of occurring a collision is the same, the result appears as identical.

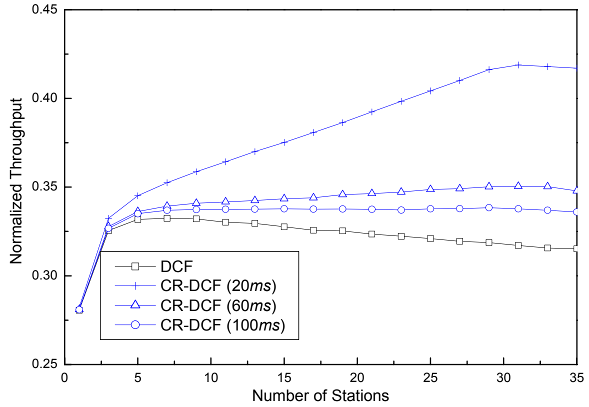


Fig. 13 Normalized Throughput According to the Number of Stations for RTS/CTS Access Method

Fig. 13 shows the influence of the number of stations to the normalized throughput. A station can transmit data packet without contention in the CR-DCF scheme, so it is always superior to the DCF. Compared with Fig. 10, the overall performance is low. This is because additional overheads are generated owing to the transmission of RTS/CTS packets.

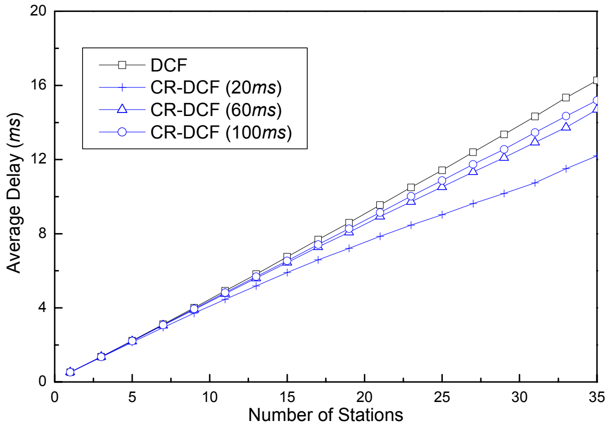


Fig. 14 Average Delay According to the Number of Stations for RTS/CTS Access Method

Fig. 14 shows average delay. The average delay tends to increase when the number of retransmissions is increasing owing to collisions. Compared with Fig. 11, overall delays are increased owing to overheads of RTS/CTS packets.

4. Conclusion

In IEEE 802.11 wireless LAN, the performance of the DCF is reduced as the collision probability is increased according to the number of stations. For this, we propose a transmission method based on the channel reservation. The proposed scheme divides the channel time into the reservation period and the contention period. A station can make a channel reservation in the contention period and the reservation period. A station which succeeds in reservation can send a data packet in the next reservation period without contentions. Thus, the proposed scheme reduces the collision probability and improve the network performance.

감사의 글

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저 자 소 개

Jong-Uk Hyun

He is now a B.S. student in Computer Software Engineering, Kumoh National Institute of Technology. His research interests include wireless networks.

E-mail: ko5192@naver.com

Sunmyeng Kim

He received the Ph.D. degree from Ajou University in 2006. He is now an associate professor in Department of Computer Software Engineering, Kumoh National Institute of Technology. His research interests include wireless networks and QoS.

E-mail: sunmyeng@kumoh.ac.kr