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IEEE 802.11b 무선 LAN의 MAC 프로토콜을 위한 개선된 충돌 해결 알고리즘

(A Developed Collision Resolution Algorithm in MAC Protocol for IEEE 802.11b Wireless LANs)

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요 약

무선 LAN은 이동중인 사람들이 무선으로 LAN에 연결을 가능하게 해주는 기술이다. 무선 LAN은 고속의 연결과 케이블이나 전화선, 그리고 데스크탑에 종속되지 않고 편리하게 인터넷에 접속할 수 있다. 802.11은 IEEE에서 규정한 무선 LAN의 표준안이다. 이 표준안은 무선에서 LAN에 접속할 수 있도록, 매체접근제어(MAC)와 물리(PHY) 계층을 정의하고 있다. MAC 프로토콜은 PHY 계층에 의존적이며, 공중망을 통해서 사용자 데이터의 전송을 제어한다. 그리고 규모가 큰 네트워크 백본에서 코어 프레이밍 동작과 상호작용을 제공한다. 무선 LAN에서 좋은 MAC 프로토콜은 제한된 스펙트럼 리소스를 효율적으로 공유할 수 있고, 동작의 간결성과, 높은 처리율 기능을 제공해야 한다. 높은 데이터 처리율을 갖는 효과적인 MAC 프로토콜을 설계하는 것이 본 논문의 주요 내용이다. 본 논문에서는 무선 LAN에서의 MAC 프로토콜에 적용시키기 위한 Developed Collision Resolution(DCR) 알고리즘을 제안한다. 이 알고리즘은 충돌 해결 속도를 증가시키기 위한 새로운 해법을 제공한다.

Abstract

Design of efficient Medium Access Control (MAC) protocols with both high throughput performances is a major focus in distributed contention based MAC protocol research. In this paper, we propose an efficient contention based MAC protocol for wireless Local Area Networks, namely, the Developed Collision Resolution (DCR) algorithm. This algorithm is developed based on the following innovative ideas: to speed up the collision resolution, we actively redistribute the backoff timers for all active nodes; to reduce the average number of idle slots, we use smaller contention window sizes for nodes with successful packet transmissions and reduce the backoff timers exponentially fast when a fixed number of consecutive idle slots are detected. We show that the proposed DCR algorithm provides high throughput performance and low latency in wireless LANs.

Keywords: MAC, Backoff, DCR algorithm

I. Introduction

Distributed contention based MAC protocol research in wireless networks start with ALOHA and slotted ALOHA in the 1970s. Later, MACA, MACAW, FAMA and DFWMAC were proposed by incorporating the Carrier Sense Multiple Access(CSMA) technique as well as the RTS and CTS handshaking mechanism for Collision Avoidance(CA). The most popular contention based wireless MAC protocol, CSMA/CA, has become the basis of the MAC proto col for the IEEE 802.11b standard[1 4]. However, it is observed that if the number of active users increase, the throughput performance of IEEE 802.11b MAC protocol degrades significantly because of the excessi

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-vely high collision rate. Many researchers have focused on analyzing and improving the performance of the IEEE 802.11b MAC[5].

To increase the throughput performance of a distributed contention based MAC protocol, an efficient collision resolution algorithm is needed to reduce the overheads in each contention cycle. In this paper, we propose a new efficient distributed contention based MAC algorithm, namely, the Developed Collision Resolution (DCR). We observed MAC algorithms come from packet collisions and the wasted idle slots due to backoffs in each contention cycle. The DCR algorithm attempts to resolve the collisions quickly by increasing the contention window sizes of both the colliding stations and the deferring stations in the contention resolution.

This paper is organized as follows. In chapter Ⅱ, we briefly describe the IEEE 802.11 standard with MAC protocol. In chapter Ⅲ, the proposed developed collision resolution (DCR) algorithm, and in chapter Ⅳ, performance evaluations are presented, and in the final chapter, we present the conclusions.

Ⅱ. IEEE 802.11b Medium Access Control

The most popular contention based medium access control (MAC) protocol is the carrier sense multiple access/collision avoidance (CSMA/CA), which is widely used in the IEEE 802.11 LANs.

A packet transmission cycle consists of a successful packet transmission by a source station followed by an acknowledgment (ACK) from the destination station. General operations of the IEEE 802.11 MAC protocol are as follow. If a station has a packet to transmit, it will check the medium status by using the carrier sensing mechanism. If the medium is idle, the transmission may proceed. If the medium is determined to be busy, the station will defer until the medium is determined to be idle for a DCF inter frame space (DIFS) and the backoff procedure will be invoked. The station will set its backoff timer to a random backoff time based on the current contention window size (CW):

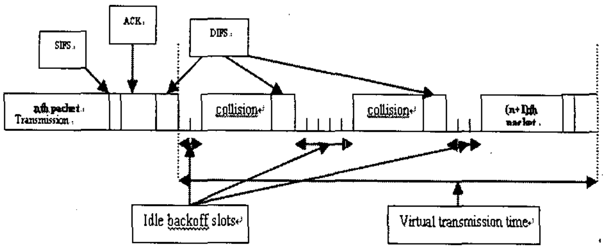

그림 1. CSMA/CA의 기본 기능
Fig. 1. Basic operation of CSMA/CA.

BackoffTime(BT)=Random() x aSlotTime

Where random() is an integer randomly chosen from a uniform distribution over the interval [0, CW 1].contention window (CW) size shall be increased. This process is called binary exponential backoff (BEB), which resolves collisions in the contention cycle.

Ⅲ. Proposed DCR algorithm for WLANs

3.1 The Basic Idea of DCR algorithm

There are two major factors affecting the throughput performance in the IEEE 802.11 MAC protocol: transmission failures and the idle slots due to backoff at each contention period, which show in Figure 1.

Under high traffic load (i.e., all M stations always have packets to transmit) and under some ergodicity assumption, we can obtain the following expression for the throughput (for example, based on Figure 1. we can examine one transmission cycle):

$$\rho = \frac{\overline{m}}{E[N_c](E[B_c]\cdot t_s + \overline{m} + DIFS) + (E[B_c]\cdot t_s + \overline{m} + SIFS + ACK + DIFS)} \tag{1}$$

where E[N_c] is the average number of collisions in a virtual transmission time (or a virtual transmission cycle), E[B_c] is the average number of idle slots resulting from backoff for each contention period, t_s is the length of a slot (i.e., aSlotTime), and $\overline{m}$ is the average packet length.

For this result, the best scenario in Figure 1. would be the following: a successful packet transmission must be followed by another packet transmission without any overheads, in which case, E[N_c] = 0,

$E[B_c]$ =0, the throughput would be

$$\rho_{best} = \frac{\overline{m}}{\overline{m} + SIFS + ACK + DIFS} \qquad (2)$$

This can be achieved only when a perfect scheduling is provided: in such a scenario, each station shall have the probability of packet transmission, $p_{trans}(i)$, at each contention period as follows:

$$p_{trans}(i) = \begin{cases} 1 & \text{if station i transmits its packet at current contention period} \\ 0 & \text{otherwise} \end{cases} \qquad (3)$$

This implies that if the current packet transmission is assigned to station *i*, then only station *i* will transmit and all other stations will defer their packet transmissions.

Suppose that under some random backoff schemes, we could assume that the backoff timer is chosen randomly, then the probability of packet transmission for station *i* during the current contention period would depend on the backoff timer:

$$p_{trans}(i) = \frac{1}{(B_i + 1)} \qquad (4)$$

where Bi is the backoff timer of station *i*. This means that if station *i* has the backoff timer 0 (i.e., B_i = 0), then its backoff time is 0 (i.e., BT = B_i × aSlotTime = 0) and station *i* will transmit a packet immediately. Therefore, this can be interpreted to imply that station *i* has the probability of packet transmission of 1 at current contention period. If station *i* has the backoff timer ∞, then its backoff time is also ∞, which can be interpreted that station *i* has the probability of packet transmission of 0 at current contention period. From this discussion, eq.(3) can be converted to eq.(5):

$$B_i = \begin{cases} 0 & \text{if station i transmits its packet at current contention period} \\ \infty & \text{otherwise} \end{cases} \qquad (5)$$

Thus, we conclude that if we could develop a contention based MAC algorithm, which assigns a backoff timer 0 to the station in transmission while assigning all other stations' backoff timers ∞ for each contention period, then we could achieve the perfect scheduling, leading to the maximum through put. Unfortunately, such a contention based MAC algorithm does not exist in practice. However, this does provide us the basic idea how to improve the throughput performance in the MAC protocol design. we can use the operational characteristics of the perfect scheduling to design more efficient contention based MAC algorithm to approximate the behavior of perfect scheduling.

From equation (3) and (5), we can summarize the operational characteristics which can be used to achieve high performance in contention based MAC algorithms as follows:

- Small random backoff timer for the station which has successfully transmitted a packet at current contention cycle: This will decrease the average number of idle slots for each contention period, E[Bc] in eq.(1).
- Large random backoff timer for stations that are deferring their packet transmissions at current contention period: A deferring station means a station which has nonzero backoff timers. Large random backoff timers for deferring stations will decrease the collision probability at subsequent contention periods and avoid future collisions more effectively.

Fast change of backoff timer for a station according to its current state: transmitting or deferring: When a station transmits a packet successfully, its next backoff timer should be set small. The net effect of this operation is that whenever a station seizes the channel, it will utilize the medium as long as it could, this way, the medium will be spent more on useful transmissions, thus the average number of idle slots can be reduced. When a station is deferring, then its random backoff timers should be large to avoid the obvious collisions with the station with successful packet transmissions, and the net effect is that all deferring stations will give the successful station more time to finish the back logged packets. More over, whenever a deferring node detects a start of busy period which is either for medium contention or for a successful packet transmission, it will expand its contention window size and resets its backoff timers for those deferring nodes to avoid “future” collisions. When a deferring station detects the medium is idle for a fixed number of slots, it would conclude that no other stations are transmitting. To reduce the average number of idle slots (E[Bc]), the deferring station will reduce the backoff timers exponentially fast after every idle slot detected. Intuitively, we can see that such fast change in backoff timers will increase the probability of successful packet transmissions, consequently, the average number of collisions in a virtual transmission time, E[Nc] in eq.(1), will be decreased.

3.2 Proposed DCR algorithm

As we mentioned above, the major deficiency of IEEE 802.11b MAC protocol comes from the slow collision resolution as the number of active stations increases. An active station can be in two modes at each contention period, namely, the transmitting mode when it wins a contention and the deferring mode when it loses a contention. When a station transmits a packet, the outcome is either one of the two cases: a successful packet transmission or a collision. Therefore, a station will be in one of the following three states at each contention period: a successful packet transmission state, a collision state, and a deferring state. In most distributed contention based MAC algorithms, there is no change in the contention window size for the deferring stations, and the backoff timer will decrease by one slot whenever an idle slot is detected. In the proposed DCR algorithm, we will change the contention window size for the deferring stations and regenerate the backoff timers for all potential transmitting stations to actively avoid “future” potential collisions, in this way, we can resolve possible packet collisions quickly. More importantly, the improved algorithm preserves the simplicity for implementation like the IEEE 802.11b MAC.

The DCR algorithm has the following characteristics:

1)Use much smaller initial (minimum) contention window size minCW than the IEEE 802.11b MAC;

2)Use much larger maximum contention window size maxCW than the IEEE 802.11b MAC;

3)Increase the contention window size of a station when it is in either collision state and deferring state;

4)Reduce the backoff timers exponentially fast when a prefixed number of consecutive idle slots are detected.

Item 1) and 4) attempt to reduce the average number of idle backoff slots for each contention period ($E[B_c]$) in eq.(1). Items 2) and 3) are used to quickly increase the backoff timers, hence quickly decrease the probability of collisions. In item 3), the DCR algorithm has the major difference from other contention based MAC protocol such as the IEEE 802.11b MAC. In the IEEE 802.11b MAC, the contention window size of a station is increased only when it experiences a transmission failure i.e., a collision. In the DCR algorithm, the contention window size of a station will increase not only when it experiences a collision but also when it is in the deferring mode and senses the start of a new busy period. Therefore, all stations which have packets to transmit including those which are deferring due to backoff will change their contention window sizes at each contention period in the DCR algorithm.

The detailed DCR algorithm is described as follows according to the state a station is in:

1)*Backoff Procedure*: All active stations will monitor the medium. If a station senses the medium for a slot, then it will decrement its backoff time (BT) by a slot time, i.e., $BT_{new} = BT_{old} - aSlotTime$. When its backoff timer reaches to zero, the station will transmit a packet. If there are $[(minCW + 1) \times 2 - 1]$ consecutive idle slots being detected, its backoff timer should be decreased much faster (say, exponentially fast), i.e., $BT_{new} = BT_{old} / 2$ (if $BT_{new} < aSlotTime$, then $BT_{new} = 0$). The net effect is that the unnecessary wasted idle backoff time will be reduced when a station runs out of packets for transmission.

2)*Transmission Failure (Packet Collision)*: If a station notices that its packet transmission has failed possibly due to packet collision i.e., if fails to receive an acknowledgement from the intended receiving station, the contention window size of the station will be increased and a random backoff time (BT) will be chosen, i.e., CW = min(maxCW, CW × 2), BT = uniform(0, CW - 1) × aSlotTime, where uniform(a, b) indicates a number randomly drawn from the uniform distribution between a and b and CW is the current contention window size.

3)*Successful Packet Transmission*: If a station has finished a successful packet transmission, then its contention window size will be reduced to the initial contention window size minCW and a random backoff time (BT) value will be chosen accordingly, i.e., CW = minCW, BT = uniform(0, CW - 1)× aSlotTime.

4)*Deferring State*: For a station which is in deferring state, whenever it detects the start of a new busy period, which indicates either a collision or a packet transmission in the medium, the station will increase its contention window size and pick a new random backoff time (BT) as follows: CW = min(maxCW, CW×2), BT = uniform(0, CW - 1)× aSlotTime.

In the DCR algorithm, the station that has successfully transmitted a packet will have the minimum contention window size and smaller backoff timer, hence it will have a higher probability to gain access of the medium, while other stations have relatively larger contention window size and larger backoff timers. After a number of successful packet transmissions for one station, another station may win a contention and this new station will then have higher probability to gain access of the medium for a period of time.

IV. Simulation and Performance Evaluation

In this section, we present the simulation studies for the proposed DCR algorithm and the IEEE 802.11 MAC protocol using DSSS specification. Thesimulation tool is the OPNET. The parameters used in the simulations are shown in Table 1, which are based on the IEEE 802.11b network configurations.

표 1. 시뮬레이션 초기 입력값
Table 1. Initial Simulation Parameters.

	WLAN_DCR	WLAN_MAC
SIFS (μs)	30	30
DIFS (μs)	950	950
Slot Time (μs)	460	460
Bit Rate (Mbps)	2	2
minCW	3	31
maxCW	2047	1023
Packet size (bytes)	1250	1250
Retry Counter	9	7
Work stations	10	10
Simulation Duration (min)	2	2

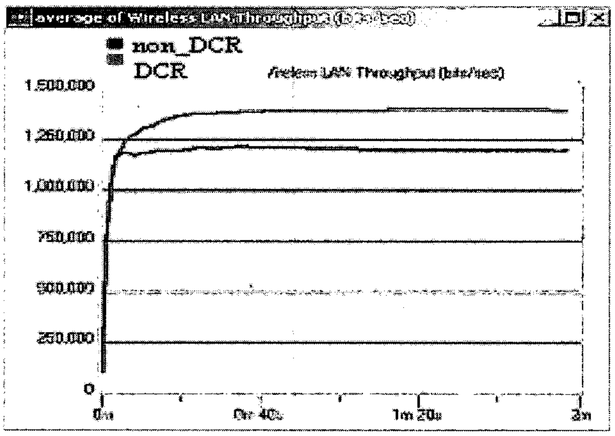

그림 2. 평균 출력값 비교 결과
Fig. 2. Average throughput comparison results.

In Figure 2. obviously, we can find from the third second the average network throughput which using DCR algorithm increases much more than the throughput which non using DCR algorithm. The average throughput which using DCR algorithm becomes stably at the twentieth seconds.

Figure 3. is the comparison results of the average network load of these two algorithms. From this figure we can see that at the beginning of simulation, i.e. in a very shot time (0s-2s), the network goes to the highest load, then it will become stably. Because of using smaller minimum CW than larger maximum CW in DCR algorithm, the probability of collisions becomes lower than non using DCR algorithm, the network load becomes lower than before.

Figure 4. illustrate the delay simulation results, after about 25 seconds, the delay which using DCR

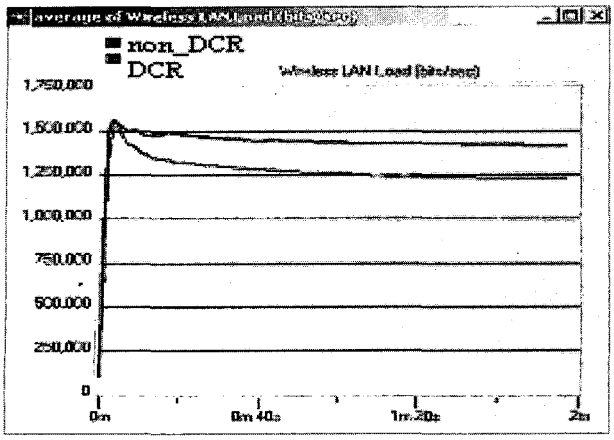

그림 3. 평균 부하율 비교 결과
Fig. 3. Average load comparison results.

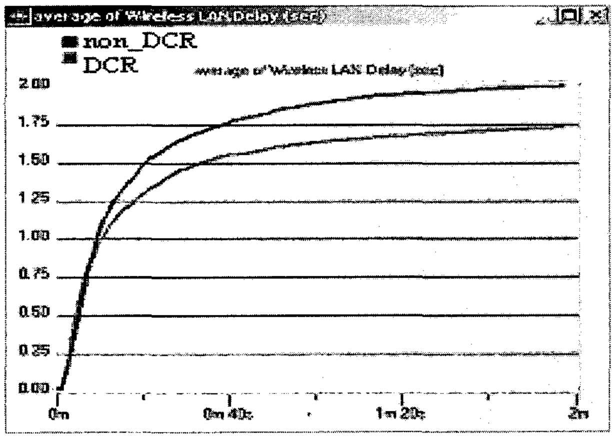

그림 4. 평균 지연 비교 결과
Fig. 4. Average delay comparison results.

algorithm always shorter than 2 seconds, but the delay which non using DCR algorithm almost longer than 2 seconds, and comparing the average delay results, we find actually, the average delay of using DCR algorithm is shorter than 1.75 seconds, much shorter than non using DCR algorithm after 7 seconds.

From all of the performance analyses above, we can say the IEEE 802.11b MAC algorithm without DCR shows very poor performance, and as the number of stations increases such as using 50 stations, the DCR algorithm will improve the WLAN perfor-mance more efficiently. Because in DCR algorithm, all stations except the one with successful packet transmission will increase their contention window size whenever the system has either a successful packet transmission or has a collision. This means all stations can quickly obtain the proper contention window size to prevent future collisions, consequently the probability of collisions will be decreased to quite small values. At the same time, a station with a successful packet transmission has the minimum window size 3, which is much smaller than the minimum contention window size in IEEE 802.11b MAC algorithm that is minCW = 31. This will reduce the wasted medium idle time to a much smaller value when compared to the IEEE 802.11b MAC without DCR algorithm.

V. Conclusions

In this paper, we improve on a contention based medium access control algorithm. The proposed DCR algorithm can achieve high performance while preserving the implementation simplicity in wireless local area networks. And each station changes the con-tention window size upon both successful packet transmissions and collisions for all active stations in order to redistribute the backoff timers to actively avoid potential future collisions. Due to this operation, each station can more quickly resolve collisions when there are a large number of active stations in the wireless LANs, other ideas in the DCR are to use much smaller minimum contention window size comparing to IEEE 802.11b MAC and fast decreasing backoff timers after detecting a fixed number of idle slots. These changes reduce the average number of idle slots in each contention period, which contributes to the performance improvement.

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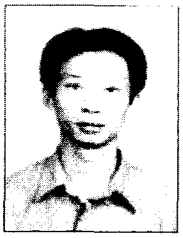

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