An Efficient MAC for Wireless LANs with Faster Resolution and Less Collisions

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◈ 목 차 ◈

Ⅰ. INTRODUCTION

The most popular contention-based wireless MAC protocol, the carrier sense CSMA/CA, becomes the basis for the MAC protocol for the IEEE 802.11 standard [17]. However, it is observed that when the number of active users increases, the throughput performance of the IEEE 802.11 MAC protocol degrades significantly because of the excessively high collision rate [1].

Many researchers have focused on analyzing and improving the performance of the IEEE 802.11 MAC (see, for example, [3-5], and references therein). To increase the throughput performance of a distributed contention-based MAC protocol, an efficient collision resolution algorithm is necessary to reduce the overheads (such as packet collisions and idle slots) in each contention window.

To this purpose, many novel collision resolution algorithms have been proposed. For example, improved backoff algorithms are proposed to adjust the increasing and decreasing factors of the contention window size and the randomly chosen backoff values; the out-band busy-tone signaling is used to actively inform others for the busy channel status; and the contention information appended on the transmitted packets can also serve the purpose to help the collision resolution [2-3,11-12].

Cali [5] derived the protocol capacity of IEEE 802.11 MAC protocol and presented an adaptive backoff mechanism instead of the exponential backoff mechanism. Bianchi [6] proposed a Markov chain model for the binary exponential backoff procedure to analyze and compute the IEEE 802.11 DCF saturated throughput. The performance evaluation in [6] assumes the saturated scenario where all stations always have data to transmit Based upon Bianchi's model. Foh and Zuckerman presented the delay performance of IEEE802.11 MAC in [7].

In this paper, we study the DCF MAC characteristics of the IEEE802.11 and proposed new LCFR protocols that assign radio medium resources more efficient, thus optimizing the channels utilize strategy. Our study focuses on QoS solution to IEEE 802.11 WLANs by enhancing the original MAC protocol. We actively redistribute the backoff timers for all active nodes and reduce the backoff timers exponentially fast. The MAC protocol with this new algorithm attempts to provide significantly higher throughput and low latency performance for the traffic in wireless LANs than the IEEE 802.11

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MAC algorithm. Its performance has been evaluated using OPNET.

The remainder of this paper is organized as follows. In Section II, presents a detailed strategyof the proposed LCFR algorithm. Section III, the analysis of the behavior of the proposed LCFR algorithm is presented. Section IV details the simulation used to compare the performance of LCFR to that of IEEE 802.11 and presents simulation results that reveal LCFR superiority in cases of medium and high loads in networks. Finally, concluding remarks are presented in Section V.

Ⅱ. LESS COLLISION FASTER RESOLUTION

The major deficiency of the IEEE802.11 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 less collision fast resolution (LCFR) 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 proposed algorithm preserves the simplicity for implementation like the IEEE 802.11 MAC.

The LCFR algorithm has the following characteristics:

1) Use much smaller initial (minimum) contention window size minCW than the IEEE 802.11 MAC;
2) Use much larger maximum contention window size maxCW than the IEEE 802.11 MAC;
3) Increase the contention window size (CW)of a station when it is in either collision state or deferring state (when $CW \geq maxCW$ then $CW = minCW$, namely CW returns to its initial value.
4) Reduce the backoff timers exponentially fast.

Items 1) and 4) attempt to reduce the average number of idle backoff slots for each contention period (E [Bc]) in (2). Items 2) and 3) are used to quickly increase the backoff timers, hence quickly decrease the probability of collisions. In item 3), the LCFR algorithm has the major difference from other contention based MAC protocols such as theIEEE 802.11 MAC. In the IEEE 802.11 MAC, the contention window size of a station is increased only when it experiences a transmission failure (i.e., a collision). In the LCFR 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 LCFR algorithm. And the CW repetition makes sure the fairness of the algorithm.

The detailed LCFR 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 idle for a slot, then it will decrement its backoff time (BT) exponentially, i.e., BTnew = BTold/2 (if BTnew < aSlotTime, then BTnew = 0).

When its backoff timer reaches to zero, the station will transmit a packet. For example, if a station has the backoff timer 2047, its backoff time is $BT= \lfloor \log_2 2047 \rfloor \times aSlotTime$. The backoff timer will be decreased by one half, i.e., BTnew = BTold/2 at each additional idle slot until either it reaches to zero or it senses a non-idle slot, whichever comes first. Therefore, the wasted idle backoff time is guaranteed to be less than or equal to 11× aSlotTime for above scenario. The net effect is that the unnecessary wasted idle backoff time will be greatly 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., it fails to receive an acknowledgment 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+1), (In the case of $CW\times 2+1 \geq \max CW$ then CW=minCW) BT = uniform(0, CW) × 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 (minimum)contention window size minCW and a random backoff time (BT) value will be chosen accordingly, i.e., CW=minCW, BT=uniform(0, CW)×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 changeits contention window size and pick a new random backoff time (BT) as follows: CW = min (maxCW, CW×2+1), (In the case of $CW\times 2+1 \geq \max CW$ then CW=minCW) BT = uniform (0, CW) × aSlotTim.

Ⅲ. PERFORMANCE ANALYSIS

In this section, we calculate the possibility of successful transmission P_S and the possibility of collision P_C during a contention period using LCFR algorithm.

As shown in Fig. 1, during thiscontention period, there are M stations, each station get a random number from its current contention window (CW) as its backoff timer:

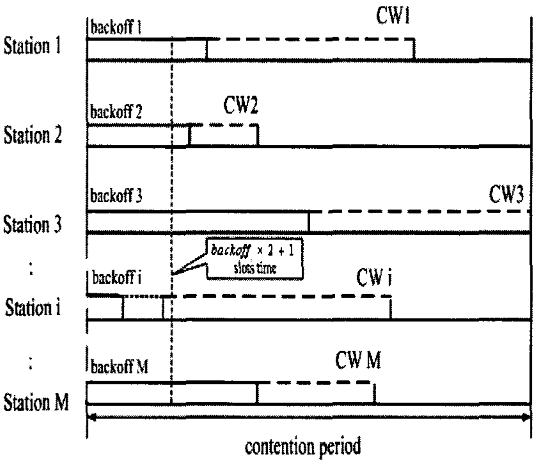

Fig.1 A contention period with a successful transmission in LCFR algorithm

$$\begin{aligned} &backoff1 = randow(0,\ CW_1) \\ &backoff2 = randow(0,\ CW_2) \\ &\quad\vdots \\ &backoff\,i = randow(0,\ CW_i) \\ &\quad\vdots \\ &backoff\,M = randow(0,\ CW_M) \end{aligned} \tag{1}$$

where $backoff_i$ is the backoff value and CW_i is the contention window length of station i. Function $random(0,\ CW_i)$ generates a random integer from the range 0 to CW_i for station i in this contention period (or transmission cycle)

It must be only one station has the minimum backoff value $backoff_{\min}$ and at least one stations have the minimum contention window length MIN_{CW} during this contention period.

$$Backoff_{\min} = Min\{backoff1,\ backoff2, \cdots, backoffM\} \tag{2}$$

$$CW_{\min} = MinCW_1,\ CW_2,\ \cdots,\ CW_M \tag{3}$$

Here, as shown in fig.1, we assume that station i has the minimum backoff value.

$$backoff_i = backoff_{\min} \tag{4}$$

To make sure successful transmission, the backoff value of other participant stations must larger than that of $2 \times backoff_i + 1$(namely, all backoff value except $backoff_i$ must exceed the red broken line as shown in Fig.1.

$$\begin{aligned} &2backoff_i + 1 \le backoff_j \le CW_j \\ &(j \in 1, 2, 3, \cdots, i-1, i+1, \cdots, M) \end{aligned} \tag{5}$$

$$\begin{aligned} P_S = {} & \frac{backoff_1 - 2backoff_i - 1}{CW_1} \times \frac{backoff_2 - 2backoff_i - 1}{CW_2} \times \\ & \cdots \frac{backoff_{i-1} - 2backoff_i - 1}{CW_{i-1}} \times \frac{backoff_i}{CW_i} \times \frac{backoff_{i+1} - 2backoff_i - 1}{CW_{i+1}} \\ & \cdots \times \frac{backoff_M - 2backoff_i - 1}{CW_M} \end{aligned} \tag{6}$$

From Fig.1, now we can obtain the following expression for the possibility of successful transmission P_s during one contention period using LCFR algorithm.

From this result, the possibility of successful transmission would be:

$$P_S = \frac{backoff_i}{CW_i} \bullet \prod_j \frac{backoff_i - 2backoff_i - 1}{CW_j} \tag{7}$$

The (11) can be converted to (14):

$$0 \le \frac{backoff_j - 2 \cdot\ backoff_i - 1}{CW_j} \le 1 - \frac{2backoff_i + 1}{CW_j} \tag{8}$$

According to FCLR algorithm, in the case of successful transmission without collisions, the backoff value of station i (the minimum backoff value in this contention period) should be:

$$0 \le backoff_i \le \frac{CW_{\min} - 1}{2} \tag{9}$$

The (9) can be converted to the following expression:

$$1 - \frac{\min CW}{CW_j} \le 1 - \frac{2backoff_i + 1}{CW_j} \le 1 + \frac{1}{CW_j} \tag{10}$$

In each contention period, we have:

$$\min CW \le CW_j \le \max CW \tag{11}$$

where $\min CW$ is the minimum value and $\max CW$ is the maximal value of contention window length. In the IEEE 802.11 Direct Sequence Spread Spectrum (DSSS) specification, the minimum value of contention window is 31, and the maximal one is 1023[17].

From (10) and (11), we can conclude:

$$0 \leq \frac{backoff_j - 2backoff_i - 1}{CW_j} \leq 1 - \frac{1}{\max CW} \tag{12}$$

From (7), (8) and (12), we can conclude the possibility of successful transmission P_S during one contention period could be:

$$P_S \leq \left(1 - \frac{1}{\max CW}\right)^{M-1} \cdot \frac{CW_{\min} - 1}{2CW_i} \tag{13}$$

After a successful transmission, the minimum contention window in the following contention period must be minCW. The possibility of successful transmission P_S for the this contention period would be

$$P_S \leq \left(1 - \frac{1}{\max CW}\right)^{M-1} \cdot \frac{\min CW - 1}{2\min CW} \tag{14}$$

While after a contention period with collisions, the possibility of successful transmission P_S for the following contention period will be:

$$P_S \leq \left(1 - \frac{1}{\max CW}\right)^{M-1} \cdot \frac{\max CW - 1}{2\max CW} \tag{15}$$

From above results, we can conclude the possibility of collisions P_C during each contention period:

$$P_C \geq \begin{cases} 1 - (1 - \dfrac{1}{maxCW})^{M-1} \cdot \dfrac{minCW - 1}{2minCW} \\ After a contention period without collisions \\ 1 - (1 - \dfrac{1}{maxCW})^{M-1} \cdot \dfrac{minCW - 1}{2minCW} \\ After a contention period with collisions \end{cases} \tag{16}$$

According to above analysis (7), (13), (14) and (15), we can see that the perfect schedulingmentioned above can not really be realized in factual system. In the ideal scenario, the possibility of collisions should be equalled to 0. It means the maximum contention window length maxCW should be infinite. $\max CW \to \infty$. It can hardly be realized in practice. However, LCFR algorithm can make great approach to these theoretic analyses and realize in practice simply by degrading the lower limit of the possibility of collisions P_C evidently.

Ⅳ. SIMULATION EVALUATION

In this section, we present the simulation studies for the proposed less collision fast resolution (LCFR) algorithms and the IEEE 802.11 MAC protocol using DSSS specification. The parameters used in the simulations are shown in Table I, which are based on the IEEE 802.11 network configurations ([17]).

Table 1. Network configurations

Parameter	SIFS	DIFS	A slot time	Bit rate
Value	10μs	50μs	20μs	2Mbps

We assume that the best-effort data packets are always available at all stations. In the simulations, the packet sizes for the best-effort data packets are geometrically distributed with parameter q ([5]).

Figures 2, 3 and 4 show the average throughput results of the IEEE 802.11 MAC and LCFR for 10, 20, and 50 contending stations, where the average packet length changes from 25 bytes to 1250 bytes. The IEEE 802.11 MAC algorithm shows very poor average throughput performance as the number of stations increases. The main reason is that theprobability of collisions becomes higher as the number of stations becomes larger. In the LCFR 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.

In Figures 5, 6 and 7, we can see that the LCFR algorithm significantly improve the average Delay performance over the IEEE 802.11 MAC algorithm. Moreover, the average Delay performance of the LCFR algorithm are not severely descended as the number of stations or the size of packet increases because of the highly effi-

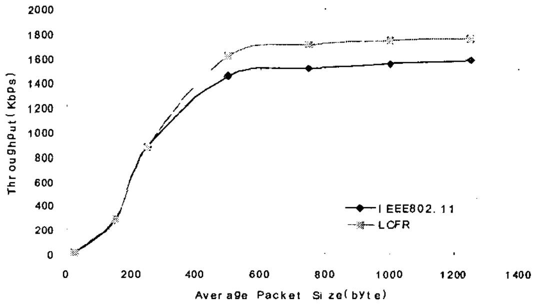

Fig.2 Average Throughput for 10 stations wireless LAN

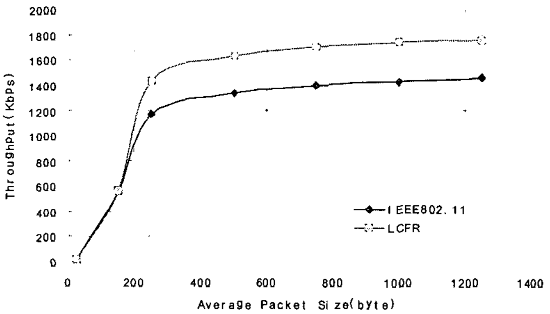

Fig.3 Average Throughput for 20 stations wireless LAN

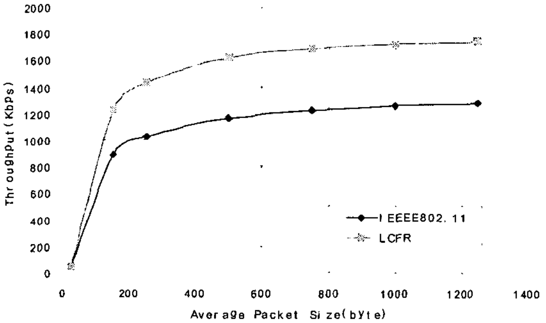

Fig.4 Average Throughput for 50 stations wireless LAN

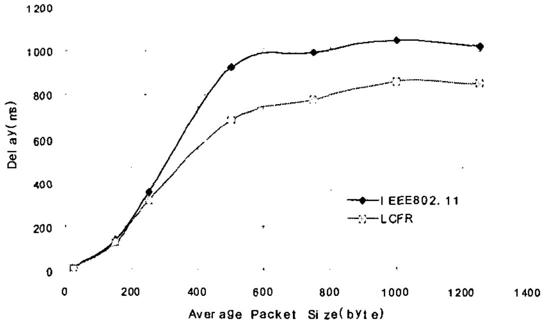

Fig.5 Average Delay for 10 stations wireless LAN

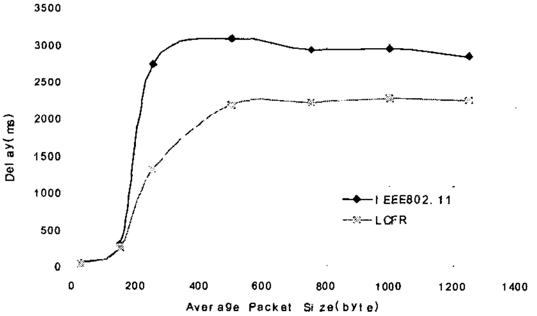

Fig.6 Average Delay for 20 stations wireless LAN

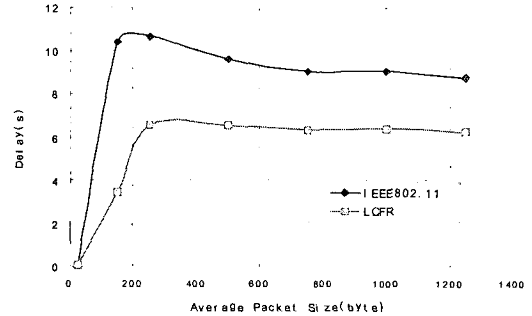

Fig.7 Average Delay for 50 stations wireless LAN

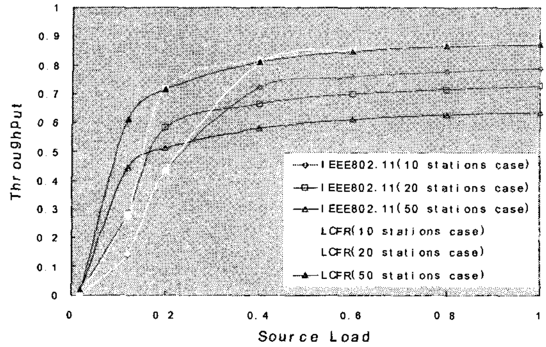

Fig.8 Source Load versus Throughput

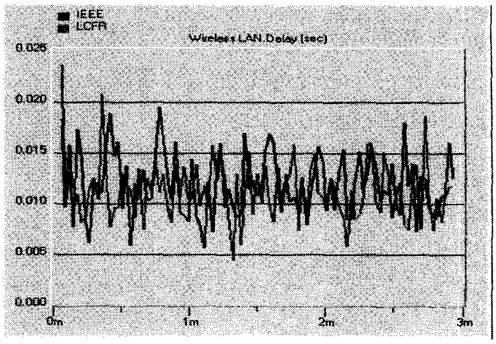

Fig.9 Delay for 10 stations Wireless

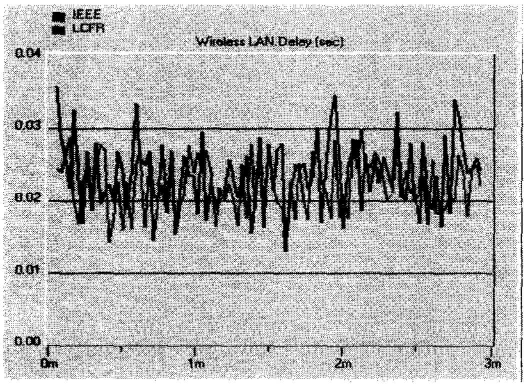

Fig.10 Delay for 20 stations Wireless

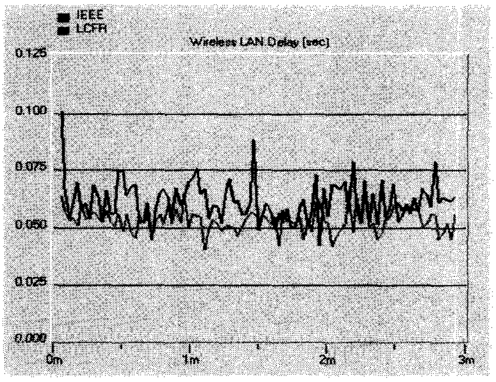

Fig.11 Delay for 50 stations Wireless

cient collision resolution strategy. It is clear that the LCFR algorithm transmits most packets successfully within pretty short time, while the IEEE 802.11 MAC transmits packets in much longer time due to collisions, which indeed shows that the LCFR algorithm does avoid collision more effective and resolve collision much faster than the IEEE 802.11 MAC algorithm does.

Fig.8 show the load vs. throughput of both IEEE 802.11 and LCFR algorithm for 10, 20 and 50 stations wireless LAN. From this figure, w can see that LCFR algorithm performs very efficiently under high load conditions while providing high throughput as network as network load increases.

Figure.9, 10 and 11 show thereal time packet delay for IEEE802.11 MAC algorithm and LCFR algorithm for 10, 20, and 50 stations wireless LANs. We can see the delay jitter of LCFR algorithm is much smaller than that of IEEE802.11 algorithm, especially the active stations increasing greatly in the wireless LANs.

V. CONCLUSIONS

In this paper, we propose a new contention-based medium access control algorithm the LCFR algorithm. It can achieve high throughput performance while preserving the implementation simplicity in wireless LANs.

In the LCFR algorithm,each station changes the contention window size upon both successful packet transmissions and collisions states 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 we incorporate in the LCFR are to use much larger maximum contention window size comparing to original IEEE 802.11 MAC and exponential fast decreasing backoff timers. These changes reduce the average number of idle slots in each contention period, which contributes to both throughput and delay improvement.

Extensive simulation studies for throughput and delay have demonstrated that the LCFR algorithm gives significant improvement compared to the IEEE802.11 MAC algorithm in achieving both high throughput and low delay simultaneously.

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