A Novel Mechanism of the Transmission Mechanism in IEEE 802.11

Kuo-Chih Chu[1], Shuo-Yu Chang[2], Kun-Chen Chung[3], and Wei-Tsong Lee [4]
[1]Dept. of Electronic Engineering, Lunghwa University of Science and Technology
[2] Chunghwa Telecom Co., Ltd. Data Communication Business Group
[3] Dept. of Information Engineering and Computer Science, Feng Chia University
[4] Dept. of Electrical Engineering, Tamkang University

Abstract

IEEE 802.11 Wireless Local Area Network (WLAN) Medium Access Control (MAC) layer provides a fair access protocol to the shared wireless medium based on Collision Sense Multiple Access with Collision Avoidance (CSMA/CA). IEEE 802.11 physical layers (PHYs) support multiple transmission rates. The transmission rate should be chosen in an adaptive manner since the wireless channel condition. If the stations refer to access point (AP) with a low data rate, data packets may be delivered slower than high data rate stations. This will reduce the usage of bandwidth and system performance in the wireless environment. In this paper, a mechanism was proposed to assign the backoff time slot dynamically. And, we verified our mechanism by using network simulator version 2 (NS-2). The performance of our mechanism was also compared with the conventional mechanisms. It was observed that the proposed mechanism performs better throughput than the conventional mechanism.

Keywords: IEEE 802.11, CSMA/CA, multiple transmission rates, backoff time slot

1. Introduction

In recent years, the rapid technological evolution of wireless devices, such as smart cards, laptop computers, mobile phones and personal digital assistants (PDA). These devices have contributed to a vast range of new services and applications. Study group 802.11 was formed under IEEE Project 802 to recommend an international standard for Wireless Local Area Networks (WLAN's). The final version of the standard has recently appeared, and provides detailed medium access control (MAC) and physical layer (PHY) specification for WLAN's.

In IEEE 802.11 protocol, the access mechanism of wireless media is called distributed coordination function (DCF). This is a random access mechanism based on carrier sense multiple access with collision avoidance (CSMA/CA) protocol.

Retransmission of collided packets is managed according to binary exponential backoff rules. The standard also defines an optional point coordination function (PCF), which is a centralized MAC protocol able to support collision free and time bounded services.

The IEEE 802.11 standard is a widely used protocol for wireless communications. It is a moderately complex algorithm involving collision detection, dynamic backoff algorithm, channel reservations, and acknowledgments. In this paper, we are interested in developing a rapidly executable model of 802.11's effect on network behavior. As we know, MAC layer governs the transmission of packets. We aim for an effective mechanism to decrease delays due to contention and retransmission. We propose a mechanism to assign the backoff time slot under different traffic load.

The rest of this paper is organized as follows. In Section 2 briefly summarizes the operation of IEEE 802.11 MAC layer and the IEEE 802.11 PHY layer. In Section 3, we present a detailed model description and analysis. In Section 4, we provide simulation scenario and the simulation parameters that we used. The simulation results are also presented in this section. Finally, we conclude this paper in Section 5.

2. IEEE 802.11 WLAN

The IEEE 802.11 MAC provides a fair access to the shared wireless medium through two different access mechanisms: a mandatory contention-based access protocol, called the Distributed Coordination Function (DCF), and an optional polling-based protocol, called the Point Coordination Function (PCF). The PCF is very rarely implemented in currently available devices. In this paper, we focus on the link adaptation for an IEEE 802.11g WLAN based on the DCF protocol. One should be able to extend the algorithm to other PHYs such as 802.11a PHY easily.

2.1 DCF of IEEE 802.11 MAC

The DCF access mechanism is a distributed medium access protocol based on Collision Sense Multiple Access with Collision Avoidance (CSMA/CA). Basically, the DCF works as follows: before a station starts a frame transmission, it shall sense the wireless medium to determine if it is busy. If the station detects that the wireless medium has been idle during more than a time interval called Distributed Inter Frame Space (DIFS), the station can transmit the frame immediately. If the medium is sensed as busy, the station waits until the channel becomes idle, then defers for an extra DIFS interval. If the medium remains idle, the MAC starts the backoff procedure by selecting a random backoff count. While the medium stays idle, the backoff counter is being decremented every slot time, and when the counter reaches zero, the frame is transmitted.

Priority access to the wireless medium is controlled by use of Inter Frame Space (IFS) intervals, i.e., time intervals between the transmissions of consecutive frames. The standard defines four different IFS intervals: Short IFS (SIFS), PCF IFS (PIFS), DCF IFS (DIFS), and Extended IFS (EIFS). A basic medium access method is illustrated in Figure 1.

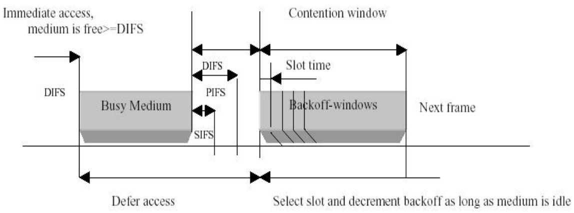

Figure 1. EEE 802.11 DCF channel access.

For each successful reception of a frame, the receiving station immediately acknowledges the frame reception by sending an acknowledgement (ACK) frame. The ACK frame is transmitted after a SIFS interval, which is shorter than the DIFS. If an ACK frame is not received within an "ACK timeout" period after the data transmission, the frame is retransmitted after another random backoff. When the frame is correctly transmitted and the corresponding ACK is received, the station performs a DIFS deference and another random backoff process, which is often referred to as "post-backoff".

To select the random backoff count, each station maintains a contention window (CW) value. The backoff count is determined as a random integer drawn from a uniform distribution over the interval [0, CW]. The CW size is initially assigned a CWmin, and it is increased exponentially when a transmission fails. After any unsuccessful transmission attempt, another backoff is performed with a new CW value determined as follows:

$$CW=2 \cdot (CW+1)-1$$

Once CW reaches the value of CWmax, it remains at the value of CWmax until it is reset. The CW is reset to Cwmin after a successful transmission or after reaching the maximum retry limit.

2.2 IEEE 802.11g PHY

IEEE 802.11g standard specifies a 2.4 GHz operating frequency with data rates of 1 and 2 Mbps using either direct sequence (DSSS) or frequency hopping spread spectrum (FHSS). The IEEE 802.11a standard specifies an OFDM physical layer (PHY) that splits an information signal across 52 separate subcarriers to provide transmission of data at a rate of 6, 9, 12, 18, 24, 36, 48, or 54 Mbps. IEEE 802.11b data is encoded using DSSS (Direct Sequence Spread Spectrum) technology. DSSS works by taking a data stream of zeros and ones and modulating it with a second pattern, the chipping sequence.

In the OFDM mode a pseudo binary sequence is sent through the pilot subchannels to prevent the generation of spectral lines. The remaining 48 subcarriers provide separate wireless pathways for sending the information in a parallel fashion. The resulting subcarrier frequency spacing is 0.3125 MHz (for a 20 MHz with 64 possible subcarrier frequency slots). The primary purpose of the OFDM PHY is to transmit Media Access Control (MAC) protocol data units (MPDUs) as directed by the 802.11g MAC layer. The OFDM PHY is divided into two elements: the physical layer convergence protocol (PLCP) and the physical medium dependent (PMD) sublayers.

The 802.11g version of OFDM uses a combination of binary phase shift keying (BPSK), quadrature PSK (QPSK), and quadrature amplitude modulation (QAM), depending on the chosen data rate. In the CCK (Complementary Code Keying) achieves 11 Mbps. Rather than using the Barker code, CCK uses a series of codes called Complementary Sequences. Because there are 64 unique code words that can be used to encode the signal, up to 6 bits can be represented by any one particular code word (instead of the 1 bit represented by a Barker symbol). The wireless radio generates a 2.4 GHz carrier wave (2.4 to 2.483 GHz) and modulates that wave using a variety of techniques [1].

3 Model Description And Analysis

3.1 Proposed Mechanism

Because the traffic flow plays a significant role of system performance, so we propose a method to optimize the proportion of traffic flow and then use these proportions to assign the length of back-off slot. The proposed method is based on the M/M/1 queueing model [2]. The M/M/1 queueing systems assume a Poisson arrival process. Figure 2 is the framework of the proposed model.

In figure 2, data traffic arrival according to a Poisson process with rate λ. P_i is defined as the ratio of the different data rate allocated to channel i, such that $\sum_{i=1}^{N} P_i = 1$. The third parameter, μ_i, represents the average service rate in different data rate channel i. The final parameter, ρ_i, denotes the utilization factor for different data rate channel i, and is given by $\rho_i = \frac{P_i \lambda}{\mu_i}$.

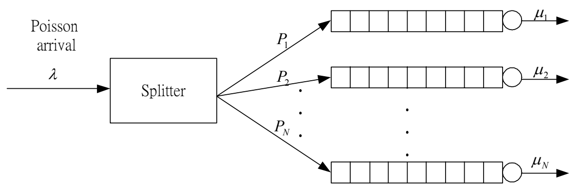

Figure 2. The framework of the proposed model

A data PDU from station may be pending in the queue because some earlier data have not be send out. Therefore, a parameter L_i is defined to represent the average number of data waiting in the queue of station with data rate i. We find this situation can be modeled simply as an M/M/1 queue, so we have

$$L_i(P_i) = \frac{\rho_i}{1-\rho_i} = \frac{\frac{P_i\lambda}{\mu_i}}{1-\frac{P_i\lambda}{\mu_i}}$$

According to the Little's formula [3], the average waiting time, $\delta_i(P_i)$, of a data in the queue of station with data rate i. is given by:

$$\delta_i(p_i) = \frac{1}{\mu_i - P_i\lambda}$$

$\delta(\vec{P})$ is defined as the average scheduling delay time of requests throughout the whole system. Vector $\vec{P}$ is an n-dimension vector and specified as $(P_1, P_2, ..., P_N)$. It can be shown that:

$$\delta(\vec{P})=\frac{\sum_{i=1}^{N} P_i\delta_i(P_i)}{\sum_{i=1}^{N} P_i} \qquad (1)$$

Since $\sum_{i=1}^{N} P_i = 1$, $P_i \geq 0, \forall i$, Equation (1) can be rewritten as:

$$\delta(\vec{P})=\frac{\sum_{i=1}^{N} P_i\delta_i(P_i)}{\sum_{i=1}^{N} P_i}=\sum_{i=1}^{N} P_i\delta_i(P_i)$$

Since the value of P_i is limited to $\sum_{i=1}^{N} P_i = 1$, we can use the Lagrange multiplier method to find the extreme value of $\delta(\vec{p})$ under this constraint. This limitation is taken as a constrained equation and is written as function $G(\vec{P})$. This yields the following simultaneous equations:

$$\begin{cases}\delta(\vec{P})=\sum_{i=1}^{N} P_i\delta_i(P_i) \\ G(\vec{P})=P_1+P_2+\ldots+P_N-1\end{cases} \qquad (2)$$

Setting $G(\vec{P})=0$, enables $\vec{P}=(P_1,P_2,\ldots,P_N)$ and the extreme value of $\delta(\vec{P})$ to be obtained from the Lagrange multiplier method. According to the definition of the Lagrange multiplier method:

$$\vec{\nabla}\delta(\vec{P})=\alpha\cdot\vec{\nabla}G(\vec{P}),$$

where α denotes the Lagrange multiplier. Hence:

$$P_i=\frac{\mu_i-\sqrt{\dfrac{\mu_i}{\alpha}}}{\lambda} \qquad (3)$$

$$\alpha=\frac{\dfrac{1}{\lambda}\left[\sum_{i=1}^{N}\sqrt{\mu_i}\right]^2}{\dfrac{1}{\lambda^2}\left[\sum_{i=1}^{N}\mu_i\right]^2-\dfrac{2}{\lambda}\left[\sum_{i=1}^{N}\mu_i\right]+1} \qquad (4)$$

It is noted that the results of Equations (3) and (4) both depend on the value of λ.

Equations (3) and (4) enable the extreme value of $\delta(\vec{P})$ to be derived. In order to restrict the extreme value of $\delta(\vec{P})$ to a reasonable range, two boundaries are imposed, i.e.

$0 \leq P_i \leq 1$

$0 \leq \rho_i \leq 1 \Rightarrow P_i \leq \dfrac{\mu_i}{\lambda}$

3.2 Backoff Slot Assignment Algorithm

After optimizing the proportion of traffic flow, we propose an algorithm to decide the backoff time slot size. Let T_i be the modified slot time and T_0 be original slot time.

If $P_i = 0$, $T_i = T_0$

Else $T_i=\dfrac{\dfrac{1}{p_i}}{\sum_{j=1}^{n} C_j}\cdot T_0 \quad C_j=\dfrac{1}{P_j} \quad P_j\neq 0,\forall j$

Here P_j means the probability of jth channels, if $P_j = 0$ let C_j=1.

4 SIMULATION AND DISCUSSION

4.1 Simulation Environment

This section of the paper discusses the simulation of the proposed mechanism and evaluates its performance. To be able to evaluate the implementation of the proposed mechanism in NS-2, a scenario must be run. The system discussed in the paper is a typical basic service set (BSS) where all stations are in the coverage area of the access point (AP). Each node, which refers to the AP, is equipped with a WLAN card that enables the node to communicate with each other based on 802.11g. As we know, IEEE 802.11g supports multi-rate. In our simulation, we model the data rates of 1 Mbps, 2 Mbps, 11Mbps and 54 Mbps for sending data packets. We divide the area into 4 subareas, each subarea nodes with the same data rate and 5 stations.

As shown in Figure 3, one AP and 20 stations exist in a 500 x 500 flat area. We assume the stations are evenly distributed in the area. For simplicity, all flows in the system are assumed to have the same type of traffic source. Each sender has Constant Bit Rate (CBR) traffic with the rate of 20 packet/second. At each station, a Poisson process simulates the arrival of frames for transmission.[4]

The packet size is set to be 1000 bytes and the simulation time is assumed to be 500 seconds. The RTS (Request to Send) /CTS (Clear to Send) threshold is sent to be 250 bytes and the fragmentation threshold 2200 bytes [5]. Table 1 is the Parameters in this simulation.

In our simulation, we add a NOAH (Non-Ad-Hoc) routing protocol [6] to decrease the overhead of the transmission packets in the NS-2 version 2.27. It is a wireless routing agent that (in contrast to Destination-Sequenced Distance Vector (DSDV), Dynamic Source Routing (DSR), ...) only supports direct communication between wireless nodes or between base stations. This allows to simulate scenarios where multi-hop wireless routing is undesired. NOAH does not send any routing related packets in the scenario.

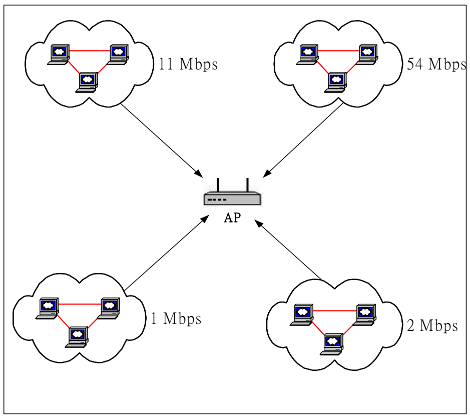

Figure 3. Simulation topology

TABLE 1. PARAMETERS USED IN THE SIMULATION

Parameter	*Value*
Channel Type	Wireless Channel
Propagation Model	Two Ray Ground
MAC	IEEE 802.11
Network Interface Queue Type	Drop Tail
Routing Protocol	NOAH
Antenna Model	Omni Directional
Topology size	500m x 500m
Number of stations	20
Number of access point	1
Traffic type	Constant Bit Rate
Packet rate	20 packet/s
Packet size	1000 bytes
aDIFSTime	50μs
aSIFSTime	10μs
aSlotTime	20μs

4.2 Performance Matrics

In this section, we calculate the average throughput considering the assumptions made above. Each successful frame transmission duration is equal to the data frame transmission time, plus the ACK transmission time, plus one SIFS. To be able to see the differentiation and congestion process of the proposed mechanism, we have looked at the average throughput for the stations.

$$Throughput = \frac{\mathrm{Re}\,ceived_{pkt}}{Total_{pkt}}$$

We use the equations (3) and (4) in last experiment , to set the ratio of the amount of backoff time slot for each different data rate under different loads, as shown in Table 2.

In this table, when load is light, we can see that the proposed mechanism uses shorter backoff time slot to transmit data only in data rate is 54 Mbps; and when load is heavy, it transmits data according to the ratio of data rate of each station. For example, when offered traffic load is 0.3, the 54Mbps stations backoff slot time will be changed to 0.1677 times of the conventionality.

4.3 Simulation Results

We analyzed the performance of proposed mechanism by simulating experiments using NS-2. The version we used is ns-2.27. Figure 4 shows the throughput obtained the conventional congestion mechanism with four different data rate, 1 Mbps, 2Mbps, 11Mbps and 54 Mbps. When the offered traffic load is getting heavily, the throughput will be reduced. It is caused by the serious congestion between stations in our scenario. In figure 4, we didn't change the backoff time slot size, each node uses the same time slot as the standard. It means that, in the conventional mechanism, each station has the same probability to transmit the data. Because of CSMA/CA is a fair access protocol, the result of each data rate approximately.

Table 2. The ratio of backoff time slot for each data rate under different loads

Data rate	**Traffic load**								
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
1 Mbps	1	1	1	1	1	1	1	1	0.6333
2 Mbps	1	1	1	1	1	1	1	0.4615	031668
11 Mbps	1	1	1	1	0.2404	0.2275	0.22	0.0329	0.0422
54 Mbps	0.1667	0.1667	0.1667	0.1667	0.01	0.0225	0.03	0.0054	0.0077

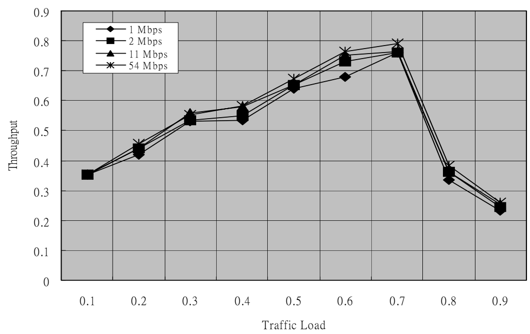

Figure 4. Throughput for conventional mechanism.

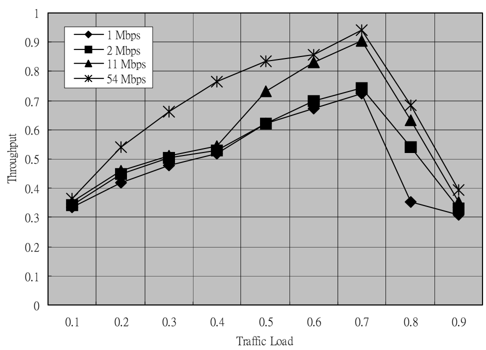

Figure 5. Throughput for proposed mechanism.

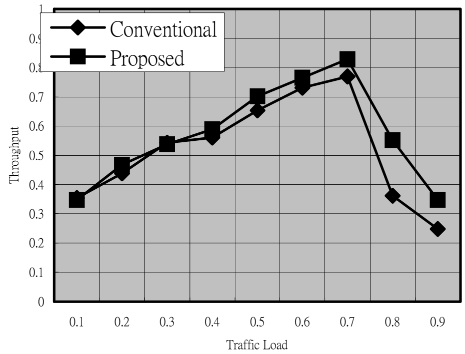

Figure 6. Throughput for the two different mechanisms

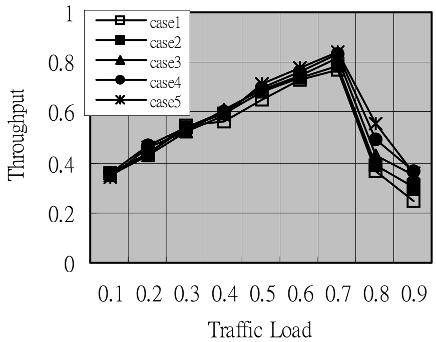

Figure 7. Throughput comparison of different case

TABLE 3. RATIO OF BACKOFF TIME SLOT IN DIFFERENT CASE

Case # / Data rate	Case 1	Case 2	Case 3	Case 4	Case 5
1 Mbps	1	1	1	1	Reference: Table 2
2 Mbps	1	1/2	1/2	1/2	
11 Mbps	1	1/3	1/4	1/11	
54 Mbps	1	1/4	1/8	1/54	

The second results are shown in figure 5. We have analyzed the average throughput obtained by the four data rate stations in different traffic load. In this simulation, we assign the backoff time slot size dynamically as in Table 2. In Figure 5, the throughput of 1Mbps and 2 Mbps stations are different from 11Mbps and 54Mbps stations. From our point of view, this makes sense due to the proposed mechanism which assigns the backoff slot time dynamically and decrease the probability of a collision on the medium. Because of shorter backoff slot time, the high data rate stations' data can be transmitted quickly. In the other word, the low data rate stations was assigned longer backoff slot time, it's more difficult to transmit the data in the BSS. As seen in Figure 5, we can realize that the proposed mechanism is not a fair algorithm to content the medium. But the channel utilization is better than conventional mechanism.

Figure 6 shows the whole system throughput of the conventional mechanism and the proposed mechanism. The system throughput increases as long as traffic load closer to 0.7. But the throughput significantly decreases as the traffic load over 0.7. It means that serious contention would be occurred when the traffic load over 0.7. In the simulation result, the proposed mechanism is better than the conventional mechanism clearly. This is due to the proposed mechanism that depends on the backoff slot time, as shown in Table 2. It is a consequence of the different backoff slot time size, which does affect the throughput in wireless environment. We have given an overview over the existing wireless LAN physical layer and MAC layer. As we know, the IEEE 802.11 WLAN supports multiple

PHY rates, and a transmitting station selects which rate to use for each frame transmission. We propose a novel mechanism for the IEEE 802.11 WLAN, which assigns the different backoff time slot for different traffic loads.

At last, the proposed mechanism is compared with different ratio of backoff time slot. In this experiment, we set 5 different cases. These cases are set by different ratio. Case 1 means each data rate has the same proportion of backoff slot. In case 2, we set backoff slot of 1 Mbps, 2 Mbps, 11 Mbps, 54 Mbps as 1, 1/2, 1/3, 1/4 respectively. In case 2, we set backoff slot of 1 Mbps, 2 Mbps, 11 Mbps, 54 Mbps as 1, 1/2, 1/4, 1/8 respectively. In case 4, we set the ratio of backoff slot is depend on its data rate. Case 5 is our mechanism, we can reference Table 2.

The proportion is shown in Table 3 and the result is shown in figure 7. Figure 7 shows the throughput of different cases. In the simulation result, we have a similar trend of these cases. But we found when the traffic load over 0.5, the proposed mechanism is better than others.

5. CONCLUSIONS

Current trends in wireless networks indicate a desire to provide a flexible wireless infrastructure that can support high performance along with traditional best effort. In this paper, we have given an overview over the existing wireless LAN physical layer and MAC layer. As we know, the IEEE 802.11 WLAN supports multiple PHY rates, and a transmitting station selects which rate to use for each frame transmission. We propose a novel mechanism for the IEEE 802.11 WLAN, which assigns the different backoff time slot for different traffic loads.

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在 IEEE 802.11 上傳送機制之研究

朱國志[1]，張碩佑[2]，鍾昆錚[3]，李維聰[4]

[1]龍華科技大學電子工程系

[2] 中華電信公司

[3]逢甲大學資訊工程系

[4]淡江大學電機工程系

摘要

IEEE 802.11 無線區域網路採用了 CSMA/CA 來做為傳輸的機制，在實體層也支援多種傳輸的速率。使用者端根據與無線網路存取點之間不同的信號品質，會選擇使用不同的傳輸速率。在這篇論文中我們將修改 CSMA/CA 的機制，使得傳輸速率較快的使用者在傳送時，只需要等待較短的等待時間；而傳輸速率較慢的使用者則等待較長的時間，如此將可以使得網路上可以傳遞更多的資料。最後藉由 NS-2 軟體的模擬，我們驗證我們的方法的確可以比原始方法在網路產出量上有更好的效能。

關鍵字: IEEE 802.11, CSMA/CA, 多傳輸速率,後退時間時槽