Proceedings of the 2004 International Conference on Information and Communication Technologies (ICT 2004), November 18-19, 2004
Edited by Dobri Atanassov Batovski and Sergey Alexandrovich Fedoseev, published by Assumption University, Thailand.

Maximization of System Throughput Subject to Access Time Fairness Constraints in Multi-Rate 802.11 WLANs

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Abstract

In the field of wireless communications, it is difficult to achieve good performance and fairness simultaneously, especially in advanced wireless local area networks (LANs), such as 802.11a/b/g, with multi-rate modulation. Although the long-term equal access probability results in throughput fairness, there is considerable performance degradation and unfair channel access time. We address the problem from the perspective of channel access time fairness. The objective of this paper is to design a contention-based Media Access Control (MAC) protocol for data communications in WLAN that can achieve near-fairness access times and maximize the aggregate throughput simultaneously. Our approaches utilize Contention Windows (CW), packet size, and multiple back-to-back packets as decision variables. Of these the multiple back-to-back packets approach offers the best solution. To evaluate our approaches, we introduce the Fairness Index (FI), which evaluates the throughput and the time fairness. In addition, we utilize the Network Simulation 2 (NS2) as a simulation tool to evaluate the theoretical maximum throughput. The simulation results show that our approach not only achieves near-fairness access times, but also improves the total throughput.

KEY WORDS: DCF, Fairness, Multi-Rate, Throughput and WLAN.

1. Introduction

The merit of the wireless network is that it provides free Internet retrieval, although the bandwidth is lower than a traditional wire network. We try, therefore, to improve the bandwidth to meet the demands of various applications. Current versions of WLAN, namely, 802.11b, 802.11g, and 802.11n with the highest rate of 11 Mbps, 54 Mbps, and 108 Mbps, respectively, have one important feature in that the multiple bit rates are subject to signal fading and interference. Furthermore, overhead and media sharing get a lower bit rate than a theoretical bandwidth for an individual host. However, many public places, such as airports and hotels provide wireless access services that are charged by transmission time. They charge the equivalent fees for the variable bit rate, which is unfair. We address the problem from the perspective of channel access time fairness, and propose a simple approach to provide near-fairness access times and improve the system total throughput.

The WLAN, which is similar to Ethernet, Token Ring, etc., shares the media LAN environment, using the following two main approaches as an MAC protocol: [2]

1) *Polling-based approach:* Point Coordination Function (PCF) uses a "poll-and-response" protocol to eliminate contentions among wireless stations. The coordinator is the control center that polls Mobile Hosts (MHs). When an MH wants to transmit, it must wait for the polling message and assignment of a channel by the coordinator.

2) *Contention-based approach:* Distributed Coordination Function (DCF), executes a "listen before talk" and p-persistence mechanism by all MHs. When the MH detects the channel is free, it still has to wait for a short period, i.e. the DCF Inter Frame Space (DIFS). Figure 1 shows that when the receiver receives a packet; it will send an Acknowledge (ACK) message back to the sender to notify successful transmission. If the MH still wants to transmit, it must wait for another DIFS and a random period (back-off). However, if there is a collision occurrence, it retransmits after another random period (backlog) [2].

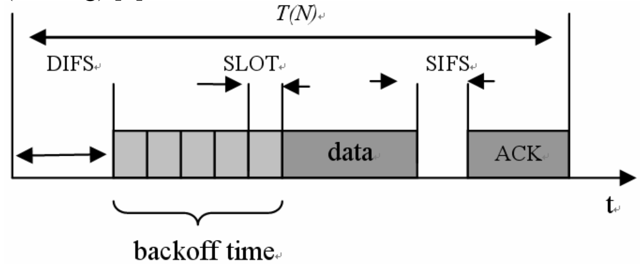

Figure 1. DCF basic mode mechanism

In this paper, we are interested in the widely available access method DCF, which uses the Carrier Sense Multi Access/Collision Avoidance (CSMA/CA) protocol to share a radio channel in a fair way. Two medium access techniques are used for packet transmission in DCF: the basic access mechanism and the optional Request-to-Sender/Clear-to-Send (RTS/CTS) mechanism [2]. In fact, the common access mechanism is a combination of these two mechanisms, i.e., packets are transmitted by means of the RTS/CTS mechanism if their payload size exceeds a given *rts_threshold* with packet size, otherwise, the basic access mode is used to transmit the packets. For the default in 802.11b WLAN, the *rts_threshold* is set to 2,304 bytes in order to ignore the RTS/CTS handshake [2]. The general WLAN environment coexists with Ethernet, whose maximum packet size limitation is equal to 1,500 bytes.

As described above, when a channel is free after the DIFS period, the MH sends out the data and waits for the receiver's ACK. If the medium is busy, it waits for a free DIFS and a random backoff period. If another station uses the medium during the backoff time of the station, the backoff timer stops. If the MH does not receive an ACK message after transmission, a collision has occurred and it enters the backlog procedure [2].

The back-off time (when busy for contention) and backlog time (when collision for channel resumes) are random intervals which follow the uniform [0, *cw*]**slot_time*. The initial *cw* (Contention Windows) value is equal to CW_{min}. Whenever the collision occurs the *cw* will double until it is large than CW_{max}. For example, the default numbers for the 802.11b standard are 20 µs, 31, and 1,023 respectively. We get:

$$\begin{cases} cw = 2^n * CW_{\min} & cw < CW_{\max} \\ cw = CW_{\max} & cw >= CW_{\max} \end{cases} \quad (1)$$

Because the *cw* value affects the channel access probability, various (CW_{min}, CW_{max}) intervals have been proposed to provide Quality of Services (QoSs) and differential services. For example, (0, $ranf()*2^{2+i/2} - 1$) as high priority, and ($ranf()*2^{2+i/2}$, $ranf()*2^{2+i}-1$) as low priority [5], adapt the initial *cw* value, *cw* increment value, and Inter Frame Space (IFS) to provide multiple class services [9], [18], and [24]. Meanwhile, IEEE 802.11e integrates different *cw* intervals and IFS lengths to provide 802.11 QoS standard [1]. Although they do not address the issue of access time fairness, we use the same concept to achieve near-fairness access times.

There has been very little research into the access time fairness issue in the 802.11 MAC protocol. The most common fairness problem is short-term back-off effort, which is caused by back-off recovery. The DFWMAC protocol still suffers from the fairness problem first investigated by Bharghavan *et al.* [19], [26]. This problem causes an MH that encounters a collision to wait a long time to return to CW_{min}. Once many MHs enter a long backlog state, if one of them makes a first transmission successfully, its own back-off period to transmit another packet will be short. Many researchers have used a series of handshake signals to partially resolve these problems, based on the work of Karn [16], Koksal *et al.* [4], and Bhargavan *et al.* [19].

In [17], the authors address the short term backoff effort problem within a general analytical framework that captures the unique characteristics of shared wireless channels, and allows the modeling of a large class of system-wide fairness models, via specification of the per-flow utility function. This shows that system-wide fairness can be achieved without explicit global coordination, so long as each node executes a contention resolution algorithm that is designed to optimize its local utility function.

Peng *et al.* [25] present a method for adjusting CW_{min} based on the current network load, to reduce collisions at the first transmission attempt. Kwon *et al.* [22] describe a "Fast Collision Resolution" algorithm that is intended to reduce the back-off times after a collision. Meanwhile, Cali *et al.* [6] propose a method for dynamically adjusting CW_{min} at each MH, based on an estimation of the number of currently active MHs. They also show that a reduction in the initial value of CW_{min} does not result in a performance improvement, but rather leads to a capacity reduction due to an increase in the collision probability.

In [12], the authors surveyed the relation between packet length and bandwidth. As expected, the bandwidth increases with increasing packet length. This, however, does not mean that the packet length can be increased because, at the MAC layer, we have to consider the limitation of the upper layer and Ethernet. In addition, increasing the packet length comes at the price of increasing the packet-error probability, due to a higher transmission-error probability or a higher collision probability. For this reason, we limit our packet size approach to 1,500 bytes for the basic mode.

In addition, the protocol provides a fragmentation mechanism, which allows an MH to transmit a number of MAC protocol data units (MPDUs) successively without performing the backoff delay. These fragments are set with the *more_frag* = 1 on the MAC control frame, then transmitted in sequence with only a SIFS between them, so that only the first fragment must contend for the channel access. Obviously, the SIFS should be shorter than DIFS. Sadeghi, Kanodia, Sabharwal, and Knighlty [3] introduced the Opportunistic Auto Rate (OAR), an enhanced protocol for multi-rate IEEE 802.11 in wireless ad hoc networks.

The key concept of OAR is to opportunistically exploit high quality channels when they occur via the transmission of multiple back-to-back packets. In particular, when the multi-rate MAC indicates that the channel quality allows transmission above the base rate, OAR grants channel access for multiple packet transmissions in proportion to the ratio of the achievable data rate over the base rate. Consequently, OAR nodes transmit more packets under high quality channels than under low quality channels. While the OAR focuses on ad hoc performance, the multiple back-to-back packets transmission approach is the primary motivation for our proposed approach.

Heusse, Rousseau, Berger-Sabbatel, and Duda pointed out that in some common situations in a wireless environment, the long term equal access probability results in considerable performance degradation. In other words, if there is at least one host with a low rate, the 802.11 cell presents a performance anomaly and the throughput of all hosts transmitting at the higher rate is degraded below the regular bandwidth [14]. Unfortunately, they only discuss the serious problem of channel access fairness with multi-rate MAC protocol without offering any solutions.

Our objective is to design a contention-based MAC protocol for data communication in a WLAN to achieve near-fairness access times and maximizes the aggregate throughput simultaneously. The fairness approach utilizes CW_{min}, packet size, and multiple back-to-back packets as variables to achieve channel near-fairness access times. To evaluate our approaches, we propose a simple probability distribution analytical model to get initial values with the MATLAB tool, and simulate them by NS2 tool.

Jun, Peddabachagari, and Sichitiu analyzed the Theoretical Maximum Throughput (TMT) of the different techniques with different bit rates [13]. They showed that the theoretical maximum throughput for 11Mbps with packet length 1,500 bytes is 6.06 Mbps in 802.11b standard. We compare these results with our simulation results.

The remainder of this paper is organized as follows. In Section 2, we briefly analyze the fairness problem of the DCF. In Section 3 we describe our approaches for improving the unfair access problem. In Section 4, the fairness metric is introduced. In Section 5, the performance evaluation of the DCF access scheme is simulated by the NS2 tools; this is followed by a discussion of the simulation results. Finally, in Section 6, we present our conclusions and the direction of our future work.

2. Problem description

Though the wired Ethernet protocol based on CSMA/CD is known to be fair, its wireless counterpart, 802.11b, based on CSMA/CA with varying bit rates has been proven to be unfair [14]. Because the contention window follows a uniform distribution and the MAC Service Data Unit (MSDU) size is equal, when one low bit rate MH captures the channel, it penalizes other high bit rate MHs. The long term throughput would be fair if the channel contention probability were equal. However, it causes a time fairness issue as different bit rates send the same size of packet (see Figure 2: "*F*" denotes "holding time of fast MH", and horizontal line "*t*" denotes time unit).

We choose the 802.11b specification [2] as our example. Let T_{DIFS} denote DIFS time (50μs); T_{SIFS} denote SIFS time (10μs); T_{ACK} denote ACK time, which includes PLCP time (192μs) transmitted on 1Mbps; T_{BT} denote average backoff time for only one MH within a cell; T_{Data} denote data time, which includes PLCP time and data transmission time; and T_{pro} denote propagation time. The default MSDU size L_p is 1,500 bytes; and the MAC header length L_h is 34 bytes, which defined in the 802.11b standard [2]. The total transmission time T_{total} and throughput for the basic mode, which are listed in Table 1, are calculated by (2) and (3) respectively. Table 1 shows that the slowest MHs transmit a maximum packet size about 6.65 (=13138/1981.6) times slower than fast MHs. Therefore, to charge the same fee for widely differing transmission times is quite unfair.

$$T_{Total} = T_{DIFS} + T_{BT} + T_{Data} + T_{pro} + T_{SIFS} + T_{ACK} + T_{pro} \tag{2}$$

$$Throughput = L_p * 8 / T_{Total} \tag{3}$$

3. Proposed approaches

We propose approaches that modify the parameters CW_{min}, packet sizes L_k, and multiple back-to-back packets B_k to achieve near-fairness access times and accounting near-fairness in WLAN under DCF. The total throughput is also improved. The approaches are as follows:

Table 1. Transmission time [unit: μs]

Bit Rate (Mbps)	T_{DIFS}	T_{SIFS}	T_{BT}	T_{ACK}	T_{Data}	T_{total}	Throughput (Mbps)
11	50	10	310	304	1308	1982	6.06
5.5	50	10	310	304	2423	3097	3.87
2	50	10	310	304	6328	7002	1.71
1	50	10	310	304	12464	13138	0.91

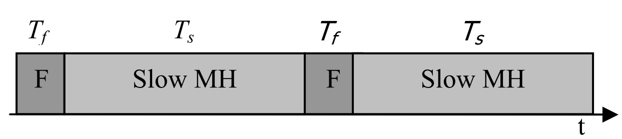

Figure 2. Throughput fairness causes time unfair

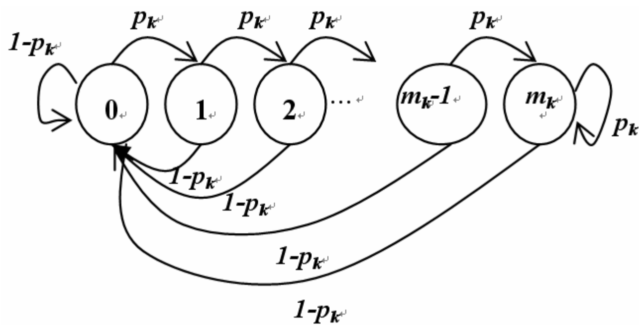

Figure 3. DCF transition diagram

$$\begin{array}{c} \\ 0 \\ 1 \\ 2 \\ . \\ . \\ . \\ m_k \end{array} \begin{array}{c} \begin{array}{cccccc} 0 & 1 & 2 & 3 & \ldots & m_k \end{array} \\ \left\| \begin{bmatrix} (1-p_k) & p_k & 0 & 0 & \ldots & 0 \\ (1-p_k) & 0 & p_k & 0 & \ldots & 0 \\ (1-p_k) & 0 & 0 & p_k & \ldots & 0 \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ (1-p_k) & 0 & 0 & 0 & \ldots & p_k \end{bmatrix} \right. \end{array}$$

Figure 4. DCF transition matrixes

A. Approach I: Setting CW interval by bit rate

We change CW_{min} by MH's bit rate to reset the backoff interval and let fast MHs have a high probability access to the channel. However, the *cw* intervals are not only dependent on the bit rate, but also relate to the non-linear collision probability function, which is subjected to the number of MHs within the cell. Therefore we refer to [8] to generate a simple DCF behaviour Markov chain transition diagram (Figure 3), and transition matrix (Figure 4).

We define the relative notations listed in Table 2 for our analytical model. Let $[t, t+1]$ denote a discrete and integral time scale representing a logical time unit. Each mobile host (MH) either decreases its back-off counter, or transmits a packet at the beginning of each logical time unit. Let $p_k(t)$ denote the collision probability of a class-k station transmitting a packet at time t. Assume that $p_k(t)$ is constant and independent of time, i.e., $p_k(t) = p_k$ for all integers $t \geq 0$, $k \in \{1,2,3,4\}$. Let $S_k(t)$ denote the back-off stage of the class-k station at time t, where $0 \leq S_k(t) \leq m_k$. Since $S_k(t+1)$ only depends on $S_k(t)$, and $\{S_k(t): t \geq 0\}$ is a discrete-time Markov chain, so we get:

$$\Pr\{S_k = s\} = \begin{cases} (1-p_k)p_k^s & \text{if } 0 \leq s \leq m_k - 1; \\ p_k^{m_k} & \text{if } s = m_k; \\ 0 & \text{if } s > m_k. \end{cases} \quad (4)$$

Table 2. Main notation list

Notation	Description
r	The number classes of bit rate, i.e., r=4 in 802.11b WLAN.
k	Denote the numerical symbol of distinct bit rates class in the system, $1 \leq k \leq r$. i.e. k=1 denote 1Mbps k=2 denote 2Mbps k=3 denote 5.5Mbps k=4 denote 11Mbps These four bit rate classes are included in the 802.11b WLAN system, $k \in \{1,2,3,4\}$.
n_k	The number of MHs that belong to class-k. e.g., n_3 denotes the number of MHs whose bit rate is equal to 5.5 Mbps.
N	The number of all MHs within a cell.
p_k	Collision probability of a class-k station.
q_k	Packet transmission probability of a class-k station.
s_i	The number of successful transmission packets of MH_i, where $1 \leq i \leq N$
t_i	The aggregate of successful transmission time of MH_i, where $1 \leq i \leq N$
m_k	Maximum backoff stage of class-k station.
R_k	The bit rate of class-k station.
Decision Variables	
W_k	Denotes the CW_{min} value of class-k station
L_k	The packet size (MSDU) of class-k packet.
B_k	The number of multiple back-to-back packets allowable for a class-k station in a block within a transmission cycle.

Let $B_{k,s}$ denote the back-off counter that a class-k station will choose in back-off stage s, where $0 \leq B_{k,s} \leq W_{k,min}-1$. Then the distribution of $B_{k,s}$ is:

$$\Pr\{B_{k,s} = i\} = \Pr\{B_k = i \mid S_k = s\} = \frac{1}{2^s W_k}, \quad \textit{for } i = 0, 1, 2, \ldots, (2^s W_k - 1) \quad (5)$$

Since the backoff counter follows a uniform distribution, the mean value of B_k of stage s for class-k is:

$$E[B_k \mid S_k = s] = \frac{2^s W_k - 1}{2} \quad (6)$$

Then, summating all the probabilities of (5) and multiplying them by (6), we get the average number of B of all back-off states by (7).

$$E[B_k] = \frac{(1-2p_k)(W_k - 1) + p_k W_k (1-(2p_k)^{m_k})}{2(1-2p_k)} \quad (7)$$

Note that Bianchi evaluated $p_k < 0.5$ to avoid (1-2p_k) being equal to the zero error [8].

At a steady state, the class-k station has to wait $E[B_k]$ logical time units before it can transmit a packet. In other words, the probability of the class-k station transmitting a packet at any logical time unit q_k is:

$$q_k = \frac{1}{E[B_k]+1} = \frac{2(1-2p_k)}{(1-2p_k)(W_k+1) + p_k W_k (1-(2p_k)^{m_k})} \quad (8)$$

The probability of one or more other stations transmitting packets at the same logical time unit as the class-k station follows a geometric distribution, so we get:

$$p_k = \left(1-(1-q_k)^{n_k - 1} \prod_{\substack{1 \le j \le r \\ j \ne k}} (1-q_j)^{n_j} \right) \quad (9)$$

Since the proportion of the channel access probability is approximately equal to the bit rate of each class, we add the following approximation constraint equation to iterate by W_k until we get an integer approximation solution:

$$\frac{R_i}{R_j} \approx \frac{q_i}{q_j} \quad \forall\ i \ne j; 1 \le i, j \le 4 \quad (10)$$

Finally, given the number of MH n_k, the number of class r, each class bit rate R_k, and maximum backoff stage m_k, we get CW_k by MATLAB tools to solve the above equations.

B. Approach II: Variant packet size by bit rate

Approaches II and *III* consider the bit rate, but the number of MHs is not matter modifying the maximum transmission packet size and multiple back-to-back packets. In order to fulfill the maximum packet size limitation in Ethernet, we set the maximum packet size of all the fastest MHs' to 1,500 bytes, and then change the MSDU size according to the bit rate to get the same transmission time. Figure 5 illustrates that the fractions of fast MHs and slow MHs channel access time are approximations when the slow MHs' packet size is shorter. Accordingly, the maximum packet size is reset to 1,534 (including the MAC header), 767, 279, and 140 bytes for 11Mbps, 5.5 Mbps, 2 Mbps, and 1Mbps bit rate MHs, respectively. Table 3 shows the time consumption approaches 1,981 µs per cycle time for each class of MHs.

C. Approach III: Set multiple back-to-back packets by bit rate

In this approach, we prefer to get the near-fairness time period from the slowest MHs, as shown in Figure 6. When the highest data rate continually improves, such as 802.11b and 802.11g have 11 and 54 times bandwidth than the original version of 802.11 standards, we utilize the multiple back-to-back packets to replace a single long packet to fulfill the packet size limitation. Thus, *Approach III* sets the slowest MHs' transmission time as cycle time to let fast MHs transmitting multiple back-to-back packets, but the slowest MHs only transmit one packet per cycle time.

We set the *more_frag* = 1 on the MAC control frame to transmit more than one packet per cycle time. The value of multiple packets field $B_k \in N$ is calculated according to (11). As shown the results in Table 4, a 2 Mbps MH can transmit 2 packets, a 5.5 Mbps MH can transmit 4 packets, and an 11 Mbps MH can transmit 8 packets per cycle time, respectively. The cycle time of each bit rate class gets the near-equal time period.

$$B_k = round\left(\frac{T_{total}(1Mbps) - T_{DIFS} - T_{BT}}{T_{Data} + T_{pro} + T_{SIFS} + T_{ACK} + T_{pro}}\right) \quad (11)$$

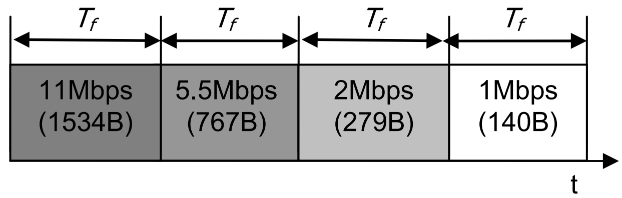

Figure 5. Variant maximum packet sizes to achieve time fairness

Table 3. Maximum packet size lists for each bit rate

Bit Rate (Mbps)	T_{DIFS}	T_{SIFS}	T_{BT}	T_{ACK}	L_p	T_{Data}	T_{total}
11	50	10	310	304	1534	8* L_p /11+192	1981.64
5.5	50	10	310	304	767	8* L_p /5.5+192	1981.64
2	50	10	310	304	279	8* L_p /2+192	1982.00
1	50	10	310	304	140	8* L_p /1+192	1986.00

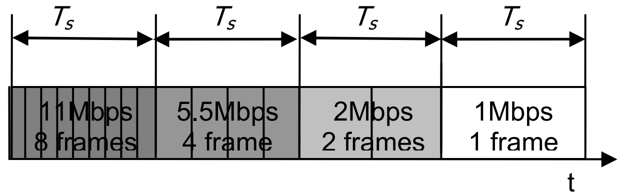

Figure 6. Multiple back-to-back packets of fast MHs

Table 4. Multiple back-to-back packets to achieve transmission cycle time near-fairness

Bit Rate (Mbps)	r	T_{DIFS}	T_{SIFS}	T_{BT}	T_{ACK}	T_{Data}	B_k	T_{total}
11	4	50	10	310	304	1308	8	13343
5.5	3	50	10	310	304	2423	4	11319
2	2	50	10	310	304	6328	2	13654
1	1	50	10	310	304	12464	1	13148

4. Fairness metric

To prove that our approaches achieve near-fairness access times and improve total throughput, in addition to evaluating the total throughput, we introduce the fairness index techniques which have the following four properties: (1) population size independence: the index applicable to any number of users, finite or infinite; (2) scale independence: the index can be independent of scale, i.e., the unit of measurement should not matter; (3) continuity: the index can be continuous so that any slight change in allocation should show up in the fairness index; and (4) bounded between 0 and 1: a totally fair system has a fairness of 1, while a totally unfair system approaches 0 [18]. The equation is as follows:

$$f(x_1, x_1, ..., x_n) = \frac{\left(\sum_{i=1}^{n} x_i\right)^2}{n \sum_{i=1}^{n} x_i^2}, \ where\ x_i > 0 \qquad (12)$$

where x_1, x_2, ... x_n denote the evaluated value and n is the total number of x_i.

We obtain an individual MH's number the amount of the successful transmission packets (s_i) and total channel access time (t_i). Each individual total access time is the aggregated the duration of two successful packet times of the sender. Then, the total channel access time (t_i) divided by the number of the successful transmission packets (s_i) is equal to the individual average packet access time as x_i and iterates into equation (12) to generate the Time Fairness Index (TFI) value, which gives (13).

$$TFI = \frac{\left(\sum_{i=1}^{N} (\frac{t_i}{s_i})\right)^2}{N\left(\sum_{i=1}^{N} (\frac{t_i}{s_i})^2\right)} \qquad (13)$$

Here, $N = \sum_{k=1}^{r} n_k$, namely the total number of MHs.

5. Simulation evaluation

In this section we compare the proposed approaches with our extended analytical model and simple equations using the NS2 simulation tool, which is a discrete event network simulator designed in 1989 as a variant of the REAL network. It was built by researchers at UC Berkeley using C++/OTCL [18]. All simulated MHs connect to one AP with saturation bandwidth, which also utilized by [7], [8], [10], and [21]. We show the total throughput and time fairness index versus the number of MHs for four bit rate classes in 802.11b WLAN under DCF. Table 5 lists the parameter values that are used for simulation in the 802.11b standard specification [2].

Figure 7 shows the simulated values of the aggregate throughput and average throughput for a varying number of hosts and compares them with the results of [14], as well as several measured values. Each point on the graph is taken from the NS2 simulation tool of 3,000 seconds. When all MHs own the same bit rate, they share the total throughput fairly. But, once one slow bit rate MH joins in the cell or one MH has low Signal Noise Ratio (SNR) to keep high transmission rate, the total throughput begins to decline.

The simulation result of 6.53Mbps is much better than the 6.06Mbps achieved by the Theoretical Maximum Throughput (TMT) in [13], because the latter only considers one MH within a cell. Consequently, there is no collision assumption. Figure 8 shows that with a few MHs within one cell, two or three for example, the collision probability is still low and we still get a total throughput higher than 6.06 Mbps (for 1,500 bytes MSDU). We also simulate the total throughput not only versus the number of MHs, but also by changing the packet size. Figure 9 shows

Table 5. Parameter values used for evaluation [2]

Parameters	Values	Parameters	Values
MSDU size	1500bytes	ACK length	14bytes
MAC header	34bytes	PHY header	16bytes
RTS length	20bytes	CTS length	14bytes
Slot time	20µs	DIFS	50µs
SIFS	10µs	Propagation time	1µs
CW_{min}	32	CW_{max}	1023

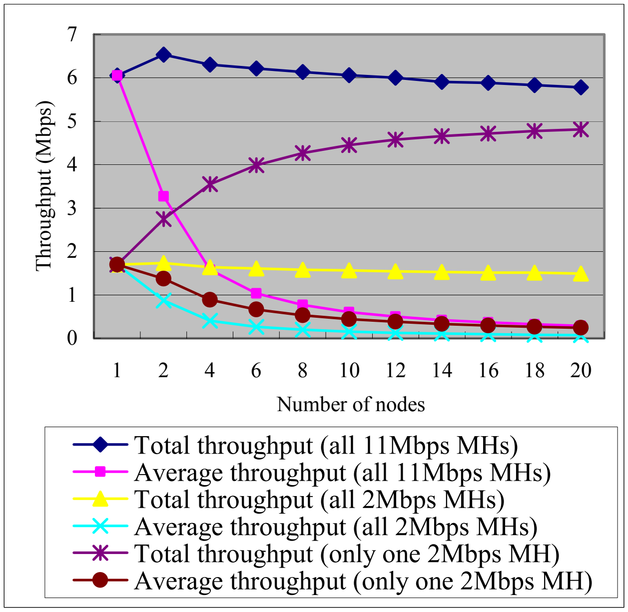

Figure 7. Throughput analysis of original DCF

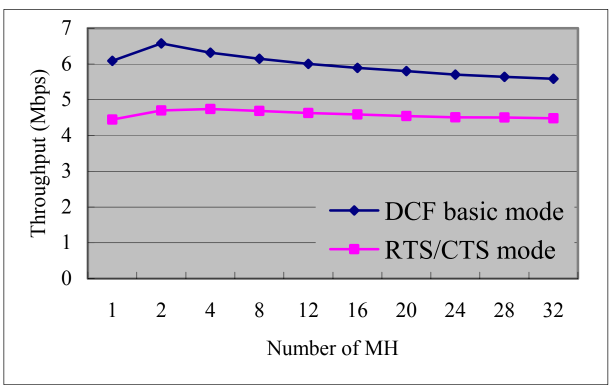

Figure 8. Maximum total throughputs versus the number of MHs

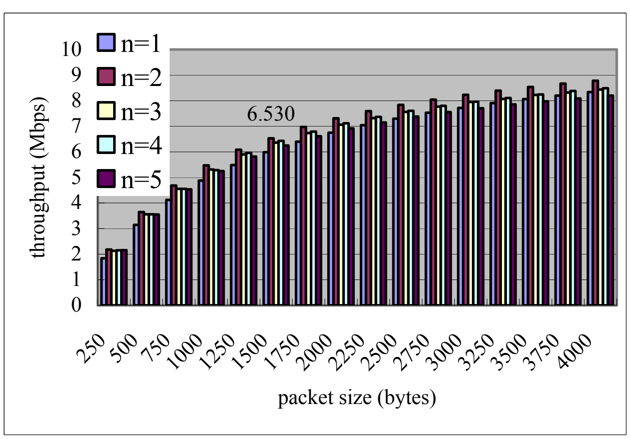

Figure 9. Maximum total throughputs versus packet size

the maximum total throughputs strike on the number of MHs equal 2 for differential packet size. The reason is that if more than two MHs share the same backoff period the transmission cycle is shorter from the system's point of view.

To evaluate our proposed approaches, we modify the minimum initial contention windows CW_{min}, packet size, and multiple packet parameters using the above scenario. The scenario, which is also used in [14], changes the number of MHs but only uses one slow MH (2 Mbps) in a cell. For example, in *Approach I*, CW_{min} = 81, which is derived from Equations (4) to (10) by MATLAB tools when the number of MHs n_k is equal to 20. In the second approach, we modify the maximum packet size to 279 bytes for the slow MH (see Table 3). Finally, *Approach III* transmits 4 packets within one cycle for fast MHs compared to a slow MH, which only transmits one packet to degrade the cycle time (see Table 4). We then collect the total throughput, average throughput, and cycle time for each successful packet. The total throughput is calculated by the number of packets successfully transmitted by each individual MH, rather than as an aggregate of the throughput of all MHs. Each successfully transmitted packet time is obtained from a packet that is generated to transmit until it successfully receives an ACK.

We also evaluate the proposed throughput and time fairness approaches by the Fairness Index (FI), which is introduced in Section 4. Figure 10 shows the access time proportion of the original mode. As expected, we found that the lowest MHs require about 5 times more transmission time than the other high bit rate, as the number of MHs is equal to 20. However, once we choose any of the proposed approaches, all MHs consume the near fair proportion time (about 5% per each MH) with standard deviations of 0.19%, 0.49%, and 0.18%, respectively. Figure 11 shows that the time FI versus the number of MHs of our proposed approaches all approximates to 1, which means the channel access time is fair. However, the time FI under original mode is less than 1, which means that the time is unfair for different bit rate classes.

Under near-fairness access times, Figure 12 shows the proposed approaches also improve about 8.3% by adapting packet size constraints the channel access time, about 30.1% by multiple packets with 20 nodes by saturation bandwidth simultaneously. Approach III does not cut the packet size, increase the *cw* value, or degrade the collision probability for each class to get the best throughput. Overall, we can improve total throughput via the fair transmission time regulative approach.

6. Conclusions

The contribution of this paper is that throughput and time FI are evaluated. The proposed approaches modify three parameters, namely: contention windows (CW_{min}), packet size (L_k) and multiple back-to-back packet (B_k), to achieve near-fairness access times and improve total throughput. In the first approach, we propose an extended analytical model, which, when solved by MATLAB tools, results in the suggested CW_{min} value. In the second approach, the packet size is set to a different length by the bit rate according the fast MHs. Finally, in the third approach, i.e., the multiple back-to-back packets approach, the cycle time is set according the slowest MH and lets the fast MH transmit more than one packet per cycle time. This is the best solution with the highest throughput. From our simulation results, we evaluate that the theoretical maximum throughput is as high as 6.53Mbps when the number of MHs is equal to 2 in 802.11b WLAN. We also evaluate our proposed approaches by FI. As expected the time FI values not only approximate to 1, which shows that our proposed approaches achieve fairness access times, but also improve the total throughput by at least 30.1% under the time-base mechanism when there is at least one slower MH in the same cell. Combining these parameters into a complete analytical model to achieve optimal time fairness will be the focus of our future work.

7. References

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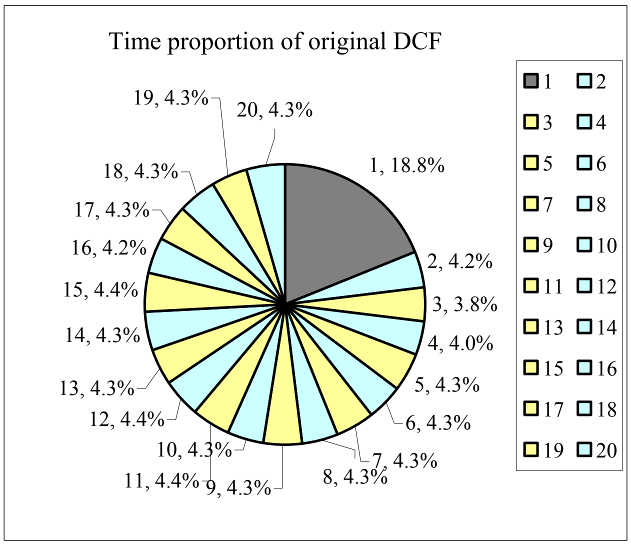

Figure 10. Time analysis in original DCF

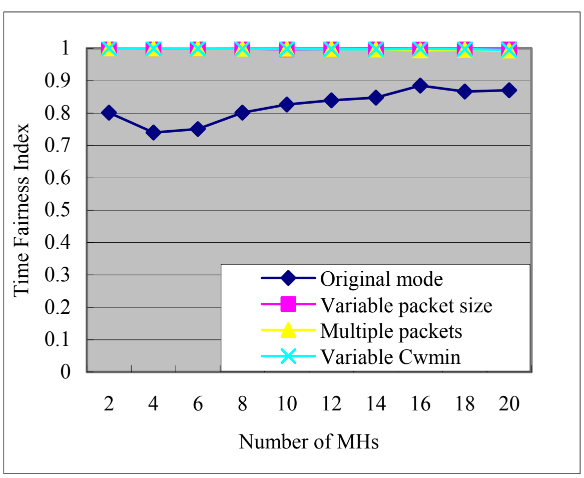

Figure. 11 Time fairness index versus the number of MHs

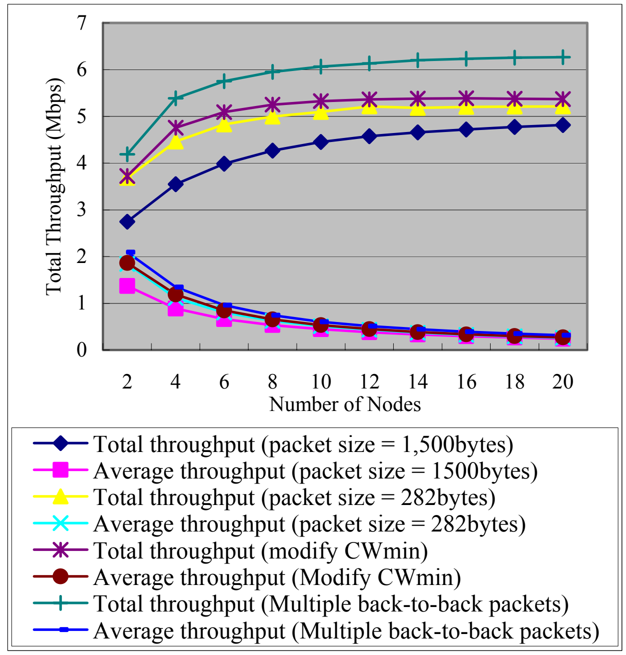

Figure 12. Improve total throughputs by proposed approaches