A Multichain Backoff Mechanism for IEEE 802.11 WLANs

Shiang-Rung Ye and Yu-Chee Tseng

***Abstract*—The distributed coordination function (DCF) of IEEE 802.11 standard adopts the binary exponential backoff (BEB) for collision avoidance. In DCF, the contention window is reset to an initial value, i.e., CWmin, after each successful transmission. Much research has shown that this dramatic change of window size may degrade the network performance. Therefore, backoff algorithms, such as gentle DCF (GDCF), multiplicative increase–linear decrease (MILD), exponential increase–exponential decrease (EIED), etc., have been proposed that try to keep the memory of congestion level by not resetting the contention window after each successful transmission. This paper proposes a multichain backoff (MCB) algorithm, which allows stations to adapt to different congestion levels by using more than one backoff chain together with collision events caused by stations themselves as well as other stations as indications for choosing the next backoff chain. The performance of MCB is analyzed and compared with those of 802.11 DCF, GDCF, MILD, and EIED backoff algorithms. Simulation results show that, with multiple backoff chains and collision events as reference for chain transition, MCB can offer a higher throughput while still maintaining fair channel access than the existing backoff algorithms.**

***Index Terms*—Backoff algorithms, medium access control (MAC), multichain backoff (MCB), wireless local area networks (WLANs).**

I. Introduction

THE wireless local area network (WLAN) is emerging as a promising technology providing high-speed and low-cost wireless communications. In WLANs, the medium access control (MAC) plays an important role on efficient and fair use of the wireless medium. In 1970s, Abramson and his colleagues first proposed an elegant MAC protocol, called ALOHA [1]. In ALOHA, stations are allowed to transmit immediately upon receiving data from upper layers. A variant of ALOHA divides time into contiguous time slots and allows transmission to start only at the beginning of the time slot. This reduces the vulnerable time of the pure ALOHA. It has been shown that with Poisson arrival process, the maximum throughputs of pure ALOHA and slotted ALOHA are only 0.184 and 0.368, respectively [2].

The inefficacy of ALOHA protocols results from its high collision probability in heavy traffic load. To decrease the collision probability, carrier sense multiple access (CSMA) scheme [2] requires stations to sense carriers on the wireless channel before transmitting data. In this scheme, if the medium is busy, stations have to defer their transmission until the medium becomes idle. This prevents stations' frames from colliding with ongoing transmitted frames of other stations. When a station detects the medium is busy, it can persistently wait for the medium to become idle and then transmit with a probability of 1 or p $(0 < p < 1)$. The former is called 1-persistent CSMA and the latter is p-persistent CSMA. Alternatively, a station can stop monitoring the wireless medium. After a random time period, it listens to the medium again to check whether the medium has become idle. This is called nonpersistent CSMA.

The distributed coordination function (DCF) of IEEE 802.11 is a variant of persistent CSMA with a collision avoidance (CA) scheme. Two types of carrier sense mechanisms are defined in DCF, namely 1) "physical carrier sense" and 2) "virtual carrier sense." The former is supported by physical (PHY) layer via actual channel assessment, whereas the latter is supported by the MAC layer. The virtual carrier sense is carried out by the network allocation vector (NAV), which is declared by the duration/ID field in control frames or data frames. In DCF, only when both carrier sense mechanisms indicate that the medium is idle can a station proceed with the remainder of contention procedure.

The CA scheme of DCF further reduces frame collision probability by requiring each backlogged station to perform binary exponential backoff (BEB) after the medium becomes idle. In BEB, if a station successfully transmits a frame, its contention window will be reset to an initial value, i.e., CWmin. However, if the transmission fails, the window size is doubled. The maximum window size is restricted to CWmax. The CWmin and CWmax are defined in the PHY layer of IEEE 802.11. For frequency hopping (FH), CWmin $= 15$ and CWmax $= 1023$, and for direct sequence spread spectrum (DSSS), CWmin $= 31$ and CWmax $= 1023$.

In the literature, it has been shown that the size of the contention window has a great impact on the performance of DCF [3]–[10]. In this paper, we propose a multichain backoff (MCB) algorithm that enables stations to adapt to different congestion levels by exploiting multiple backoff chains with the collision events that occur on the wireless channel as reference for switching among the chains. The advantage of the MCB is that it does not have to estimate the number of contending stations, traffic load, etc., but provides high throughput and fair channel access for WLANs with a small or large population.

The remainder of this paper is organized as follows: In Section II, we review related work on backoff algorithms. In Sections III and IV, we present the MCB algorithm and the analysis of its saturation throughput, respectively. Section V shows simulation results and analytic results, and Section VI concludes this paper.

Manuscript received September 17, 2004; revised June 27, 2005 and September 26, 2005. The review of this paper was coordinated by Prof. Y.-B. Lin.

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Digital Object Identifier 10.1109/TVT.2006.877467

II. RELATED WORK

In the literature, there have been many studies of backoff algorithms [3]–[7], [11]–[16]. In [11], to prevent the contention window of BEB from oscillation, the multiplicative increase–linear decrease (MILD) algorithm increases the contention window by 1.5 times when collision occurs and decreases the contention window by 1 when transmission succeeds. To ensure fair access to the wireless medium, a station is required to attach its contention window in each transmitted frame. Whenever other station overhears this frame, it has to adopt this window size. However, since a station with a smaller contention window has a better chance to win the channel, this may force other stations with a large window size to adopt this small window size. When the network is in high traffic load, this may increase collision probability and decrease the network throughput. In [3] and [4], it is suggested to choose a contention window according to the estimated number of competing stations. While this may significantly improve performance, it relies on the accurate estimation of the number of competing stations.

The exponential increase–exponential decrease (EIED) algorithm [15], [17], [18] increases the contention window by a multiple when collision occurs and exponentially decreases the window size when transmission succeeds. With a relatively small decrement of the window size compared with the increment, EIED can outperform 802.11 DCF. However, our simulation results show that with such a relatively small decrement, EIED may suffer from unfair channel access when the number of contending stations is small. The linear increase–linear decrease (LILD) algorithm always adjusts the contention window by a constant [8], [18]. This is not suitable for the network with a large population. The GDCF backoff algorithm [9] doubles the contention window after each unsuccessful transmission and halves the window size after c consecutive successful transmissions, where c is a system parameter. Although GDCF greatly improves the performance of 802.11 DCF, it may cause unfair medium access for some values of c. The works [5] and [12] show that the performance of DCF is highly related to the number of contending stations and CWmin; the CWmin has to change with the number of contending stations to obtain a better throughput. Motivated by this observation, we propose a backoff algorithm that employs multiple backoff chains, each of which is used in a different congestion level. Thereby, stations can adapt to different congestion levels by switching among the chains.

III. MCB ALGORITHM

In MCB, each station maintains a transition diagram, as demonstrated in Fig. 1, to determine its current contention window. The diagram consists of c backoff chains, numbered from 0 to $c-1$, each of which represents a sequence of backoff stages and is defined by the following parameters:

- w_i: the minimum contention window of chain i:
- m_i: the maximum backoff stage of chain i:
- u_i: the transition probability from chain i to chain $i+1$. In the case of $i = c-1$, $u_{c-1} = 0$:
- v_i: the transition probability from chain i to chain $i-1$. In the case of $i = 0$, $v_0 = 0$.

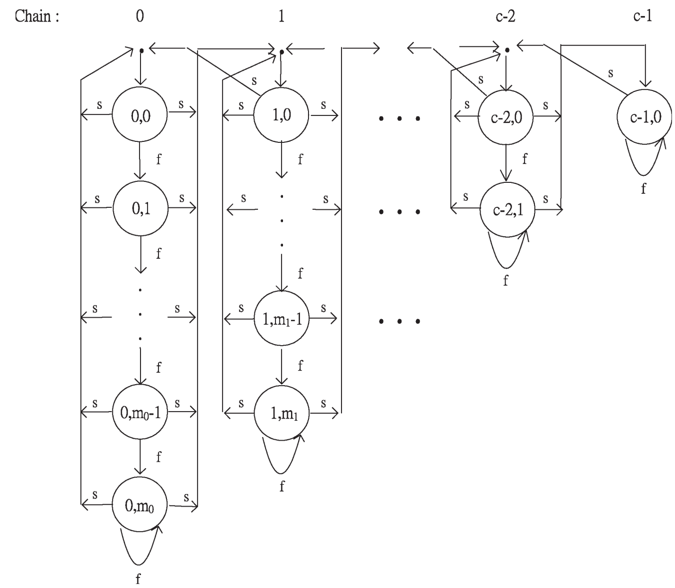

Fig. 1. Transition diagram of MCB. The pair (i, j) denotes jth backoff stage of chain i. The symbols s and f denote possible transitions after a successful transmission and a failure transmission, respectively.

For each backoff chain i, we define $w_0 = \text{CWmin}$ and $w_{c-1} = \text{CWmax}$. For $i = 1, \ldots, c-2$, w_i could be

$$w_i = \text{CWmin} + i \cdot \left\lfloor \frac{\text{CWmax} - \text{CWmin}}{c-1} \right\rfloor .$$

Alternatively, we may increase w_i in an exponential manner as follows:

$$w_i = (\text{CWmin} + 1) \cdot \left\lfloor \frac{\text{CWmax} + 1}{\text{CWmin} + 1} \right\rfloor^{\frac{i}{c-1}} - 1.$$

Within a backoff chain, the contention window is doubled for the next backoff stage but is limited to CWmax. Parameters u_i and v_i are probabilities for a station to switch from its current chain to the next chain and the previous chain, respectively, after each successful transmission. The simplest assignment is to let all u_i be the same and all v_i be the same. For this case, the optimal values are derived in Section IV-B.

The MCB algorithm works as follows: Initially, a station is in stage 0 of chain 0. Before transmitting data, it randomly chooses a backoff value from the current contention window. When the medium is sensed to be idle for a DIFS period, the backoff procedure is started. During backoff, the backoff counter is decreased by 1 for each idle slot being detected. However, if the medium is busy during a backoff slot, the backoff counter is frozen, and the station has to wait until the medium becomes idle. During the backoff period, the station shall also detect any collision event caused by other stations. A collision flag f_{col} is used to record whether frame collision occurs on the wireless channel. f_{col} is set to 1 if a station itself experiences a collision or it detects that the medium has been busy for a duration longer than the transmission time of the smallest frame but does not correctly receive a frame. f_{col} is reset to 0 after each successful transmission. Once the backoff counter reaches 0, the station will start to transmit data. Assume that a station is transmitting in stage j of chain i. In the case that the transmission fails, it will move to stage $j+1$ of chain i if $j < m_i$ or stay in the same stage if $j = m_i$. In the case that the transmission succeeds, the station will move to stage 0 of chain $i+1$ with probability $(f_{\mathrm{col}} \cdot u_i)$, stage 0 of chain $i-1$ with probability $((1-f_{\mathrm{col}}) \cdot v_i)$, and stage 0 of chain i with probability $(1 - f_{\mathrm{col}} \cdot u_i - (1-f_{\mathrm{col}}) \cdot v_i)$. Intuitively, if a station encounters collision or detects a collision event, this may imply that the network traffic load has increased or just a coincidence. Therefore, it will move to the next chain with a larger minimum contention window or stay at the same chain. Similarly, if no collision is encountered and detected, it moves to a chain with a smaller minimum contention window or stay at the same chain.

IV. Performance Analysis

In this section, we analyze the saturation throughput of MCB, which is defined to be the maximum achievable throughput, obtained by continuously increasing the traffic load to a limit. To operate the network in a saturation condition, all transmit queues of stations are assumed to be nonempty all the time. It is also assumed that, under such a condition, the collision probability for each transmission attempt is a constant and independent value p.

A. Saturation Throughput

Fig. 2 shows the Markov chain of MCB. Each state is represented by a triple (i,j,k), which means that the station is in stage j of chain i and has a backoff value k. Let τ be the probability that a station will transmit in a randomly chosen backoff slot, and let χ_i be the probability that a station will detect at least one collision event on the wireless channel during its backoff period in stage 0 of chain i. For a given backoff slot, the probability that a contending station will not detect any collision event is $((1-\tau)^{n-1} + \tau(n-1)(1-\tau)^{n-2})$, where n is the total number of stations. Since a station will choose a backoff value from the current contention window w_i with an equal probability of $(1/(w_i+1))$, we have

$$\chi_i = \sum_{k=0}^{w_i} \frac{1-\left((1-\tau)^{n-1}+(n-1)\tau(1-\tau)^{n-2}\right)^k}{w_i+1}$$
$$= 1-\frac{1-\left((1-\tau)^{n-1}+(n-1)\tau(1-\tau)^{n-2}\right)^{w_i+1}}{(w_i+1)\left(1-(1-\tau)^{n-1}-(n-1)\tau(1-\tau)^{n-2}\right)}. \quad (1)$$

The transition probability from stage j of chain i to stage 0 of chain $i+1$ is $(1-p)\cdot\chi_i\cdot u_i$ if $j=0$ and is $(1-p)\cdot u_i$ if $j>0$. Similarly, transition probability from stage j of chain i transits to stage 0 of chain $i-1$ is $(1-p)\cdot(1-\chi_i)\cdot v_i$ if $j=0$ and is 0 if $j>0$. Let $P_{i,j,k|i',j',k'}$ denote the probability that a station changes from state (i',j',k') to (i,j,k).

The nonnull one-step transition probabilities are summarized as follows:

$$\begin{cases} P_{i,j,k-1|i,j,k} = 1 \\ P_{i,0,k|i,j,0} = \frac{(1-p)(1-u_i)}{W_{i,0}}, \ 0 < j \le m_i, \ i < c-1 \\ P_{c-1,0,k|c-1,0,0} = \frac{1-(1-p)(1-\chi_{c-1})v_{c-1}}{W_{c-1,0}} \\ P_{i,0,k|i,0,0} = \frac{(1-p)(\chi_i(1-u_i)+(1-\chi_i)(1-v_i))}{W_{i,0}}, \ 0 < i < c-1 \\ P_{0,0,k|0,0,0} = \frac{(1-p)(1-\chi_0\cdot u_0)}{W_{0,0}} \\ P_{i,j+1,k|i,j,0} = \frac{p}{W_{i,j+1}}, \ j < m_i \\ P_{i,m_i,k|i,m_i,0} = \frac{p}{W_{i,m_i}}, \ i < c-1 \\ P_{i+1,0,k|i,j,0} = \frac{(1-p)u_i}{W_{i+1,0}}, \ j > 0, \ i < c-1 \\ P_{i+1,0,k|i,0,0} = \frac{(1-p)\chi_i u_i}{W_{i+1,0}}, \ i < c-1 \\ P_{i-1,0,k|i,0,0} = \frac{(1-p)(1-\chi_i)v_i}{W_{i-1,0}}, \ i > 0 \end{cases} \quad (2)$$

where $W_{i,j} = (w_i+1)\cdot 2^j$. Let $b_{i,j,k}$ be the stationary probability that a station will be in state (i,j,k). Since $b_{i,j,0} = b_{i,j-1,0}\cdot p$

$$b_{i,j,0} = b_{i,0,0}\cdot p^j, \quad 0 < j < m_i$$
$$b_{i,m_i,0} = b_{i,0,0}\cdot\frac{p^{m_i}}{(1-p)}. \quad (3)$$

With (3), we can express each $b_{i,j,k}$ in terms of $b_{i-1,0,0}$, $b_{i,0,0}$, and $b_{i+1,0,0}$. For $0 < j < m_i$ and $0 \le k < W_{i,j}$

$$b_{i,j,k} = \frac{W_{i,j}-k}{W_{i,j}}\cdot b_{i,j-1,0}\cdot p$$
$$= \frac{W_{i,j}-k}{W_{i,j}}\cdot b_{i,0,0}\cdot p^j \quad (4)$$

and for $j = m_i$ and $0 \le k < W_{i,m_i}$

$$b_{i,m_i,k} = \frac{W_{i,m_i}-k}{W_{i,m_i}}(b_{i,m_i,0}\cdot p + b_{i,m_i-1,0}\cdot p)$$
$$= \frac{W_{i,m_i}-k}{W_{i,m_i}}\cdot b_{i,0,0}\cdot\frac{p^{m_i}}{1-p}. \quad (5)$$

In the case that $j=0$, for $0 < i < c-1$ and $0 \le k < W_{i,0}$

$$\begin{aligned} b_{i,0,k} = \frac{W_{i,0}-k}{W_{i,0}} & \\ \times \big(b_{i,0,0}\big(&(1-u_i)(p-p^{m_i+1}) \\ &+(1-p)(1-\chi_i\cdot u_i - v_i + \chi_i\cdot v_i)\big) \\ &+ b_{i-1,0,0}\cdot u_{i-1}(\chi_{i-1} - p\chi_{i-1} + p - p^{m_{i-1}+1}) \\ &+ b_{i+1,0,0}\cdot(1-p)\cdot(1-\chi_{i+1})\cdot v_{i+1}\big). \end{aligned} \quad (6)$$

For $j=0$, $i=0$, $b_{0,0,k}$, and $0 \le k < W_{0,0}$

$$\begin{aligned} b_{0,0,k} = \frac{W_{0,0}-k}{W_{0,0}} & \\ \times \big(b_{0,0,0}&\left((1-u_0)(p-p^{m_0+1}) + (1-p)(1-\chi_0\cdot u_0)\right) \\ &+ b_{1,0,0}\cdot(1-p)\cdot(1-\chi_1)\cdot v_1 \end{aligned} \quad (7)$$

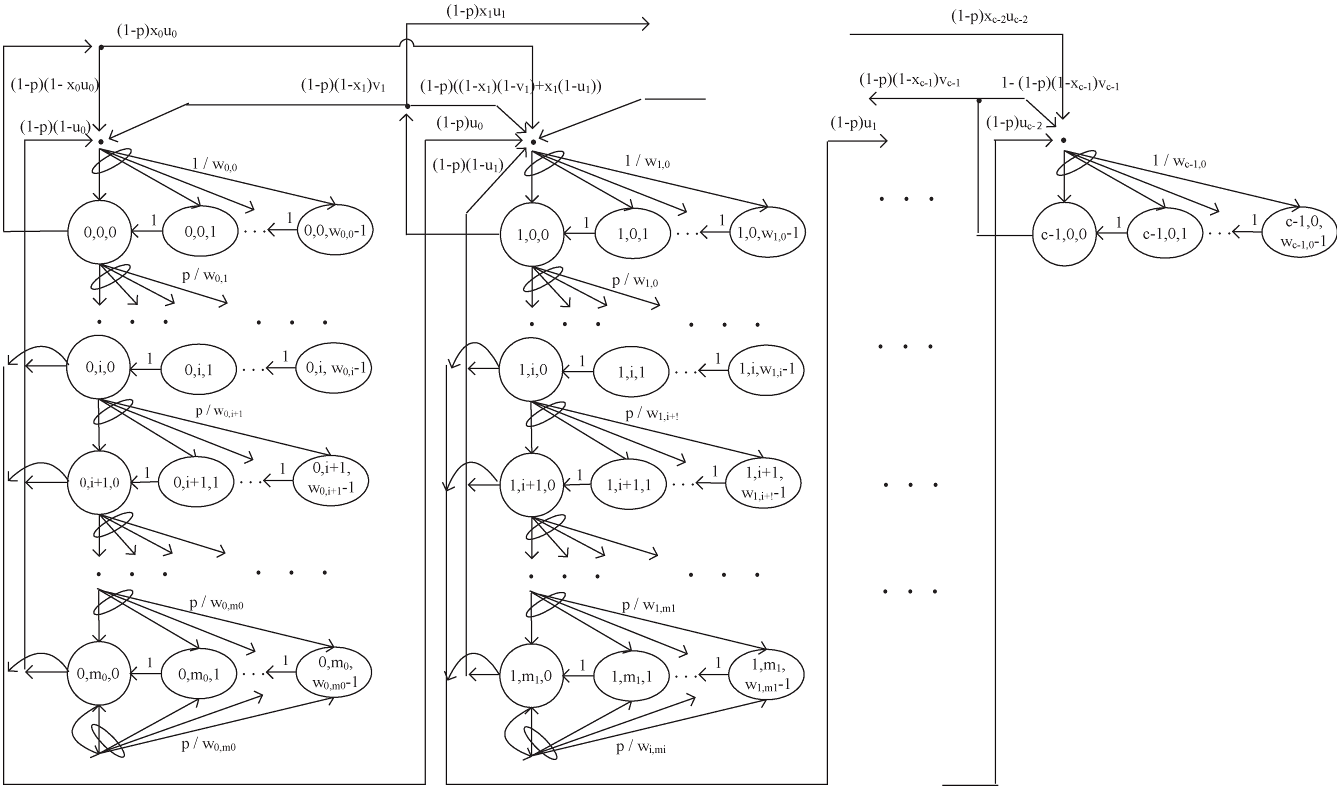

Fig. 2. Markov chain model of MCB.

and for $j = 0$, $i = c-1$, and $0 \le k < w_{c-1,0}$

$$
\begin{aligned}
b_{c-1,0,k} = {} & \frac{W_{c-1,0} - k}{W_{c-1,0}} \\
& \times \left(b_{c-2,0,0} \cdot u_{c-2}\left(p - p^{m_{c-2}+1} + (1-p)\chi_{c-2}\right)\right. \\
& \quad \left. + b_{c-1,0,0} \cdot (1 - (1-p)(1-\chi_{c-1})v_{c-1})\right). \quad (8)
\end{aligned}
$$

From (7), $b_{1,0,0}$ can be written as

$$
\begin{aligned}
b_{1,0,0} = {} & \frac{b_{0,0,0}}{(1-p)(1-\chi_1)v_1} \\
& \cdot \left(1 - (1-u_0)(p - p^{m_0+1}) - (1-p)(1-\chi_0 \cdot u_0)\right). \quad (9)
\end{aligned}
$$

From (6), for $1 < i < c-1$, $b_{i,0,0}$ can be in a recurrence form

$$
\begin{aligned}
b_{i,0,0} = {} & \frac{b_{i-1,0,0}}{(1-p)(1-\chi_i)v_i} \\
& \times \left(1 - \left((1-u_{i-1})(p - p^{m_{i-1}+1}) + (1-p)\right.\right. \\
& \qquad \left.\left.(1 - v_{i-1} - \chi_{i-1} \cdot u_{i-1} + \chi_{i-1} \cdot v_{i-1})\right)\right) \\
& - \frac{u_{i-2}(\chi_{i-2} - p\chi_{i-2} + p - p^{m_{i-2}+1})}{(1-p)(1-\chi_i)v_i} \cdot b_{i-2,0,0} \quad (10)
\end{aligned}
$$

and for $i = c-1$

$$
b_{c-1,0,0} = \frac{u_{c-2}\left(p - p^{m_{c-2}+1} + (1-p)\chi_{c-2}\right)}{(1-p)(1-\chi_{c-1})v_{c-1}} b_{c-2,0,0}. \quad (11)
$$

By (3)–(11), all stationary probabilities are expressed in terms of $b_{0,0,0}$, p, and τ. Since the sum of all probabilities must be 1

$$
\sum_{i=0}^{c-1} \sum_{j=0}^{m_i} \sum_{k=0}^{W_{i,j}-1} b_{i,j,k} = 1. \quad (12)
$$

Moreover, since a station only transmits when its backoff counter is 0, it follows that

$$
\tau = \sum_{i=0}^{c-1} \sum_{j=0}^{m_i} b_{i,j,0}. \quad (13)
$$

From (12) and (13), we have an equation with two unknown variables, i.e., p and τ. The collision probability can be expressed in terms of τ, i.e.,

$$
p = 1 - (1-\tau)^{n-1}. \quad (14)
$$

By solving (13) and (14), we can obtain p and τ.

The saturation throughput S is given by

$$
\begin{aligned}
S &= \frac{E[\text{amount of data transmitted in a time slot}]}{E[\text{length of a time slot}]} \\
&= \frac{P_s P_{\mathrm{tr}} T_{\mathrm{data}}}{(1-P_{\mathrm{tr}})\rho + P_s P_{\mathrm{tr}} T_s + (1-P_s) P_{\mathrm{tr}} T_c} \quad (15)
\end{aligned}
$$

where $P_{\mathrm{tr}} = 1 - (1-\tau)^n$ is the probability that a transmission occurs in a randomly chosen backoff slot, $P_s = (n\tau(1-\tau))^{n-1}/P_{\mathrm{tr}}$ is the probability that a transmission succeeds in a backoff slot, ρ is the length of a backoff slot, T_s is the time required to complete a frame exchange sequence, and T_c is the

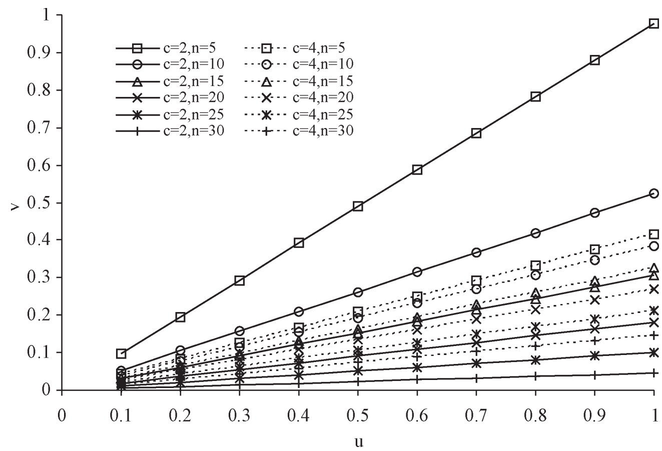

Fig. 3. u to v that give the optimal throughput under different n and c for frame size of 1024 bytes.

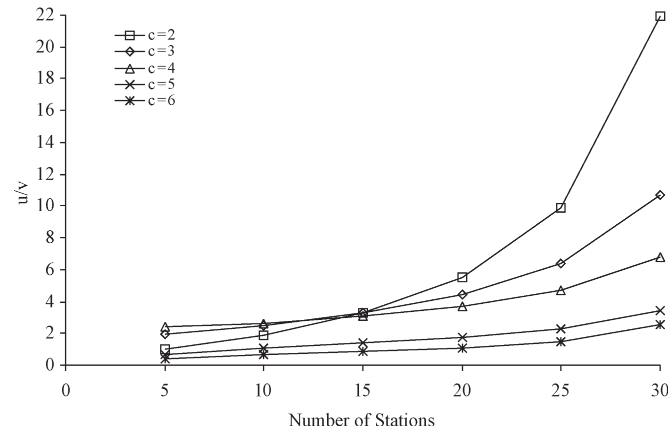

Fig. 4. Ratios of u to v that give the optimal throughput under different n and c for frame size of 1024 bytes.

length of a colliding duration. T_s and T_c are $(\text{DIFS} + \text{DATA} + \text{ACK} + \text{SIFS})$ and $(\text{DIFS} + \text{DATA})$, respectively, if direct transmission is used and are $(\text{DIFS} + \text{RTS} + \text{CTS} + \text{DATA} + \text{ACK} + 3\text{SIFS})$ and $(\text{DIFS} + \text{RTS})$, respectively, when RTS–CTS exchange is used.

B. Optimal Values of u and v

In the case that all $u_i's$ are the same and all $v_i's$ are the same, the optimal u and v can be obtained from the optimal transmission probability τ, which maximizes the saturation throughput. Let us define $v = v_i$ and $u = u_i$ for all backoff chains. Equation (15) can be rewritten as

$$S = \frac{T_{\text{data}}}{T_s - T_c + 1/f(\tau)}$$

where

$$f(\tau) = \frac{n\tau(1-\tau)^{n-1}}{T_c/\rho - (1-\tau)^n(T_c/\rho - 1)}.$$

The saturation throughput S is maximized when $f(\tau)$ is maximized. Taking the derivative of $f(\tau)$ and setting it to 0

$$f'(\tau) = (1-\tau)^n - T_c/\rho\,(n\tau - (1-(1-\tau)^n)) = 0$$

under the condition $\tau \ll 1$, we have $\tau \approx 1/(n \cdot \sqrt{T_c/(2\rho)})$. With the optimal τ, we have an equation that relates the optimal u and v from (13).

Fig. 3 plots u and v that give the maximum throughput for the frame size of 1024 bytes. The figure shows that parameters u and v are almost linearly related. The mean value of the ratios of u to v is shown in Fig. 4. When n increases, the ratio of u to v also increases, which implies that stations have to move to backoff chains with a larger minimum contention. However, the increment is smaller when more backoff chains are used.

V. Performance Evaluation

This section presents simulation results of the performance of MCB as opposed to MILD, DCF, GDCF, and EIED algorithms. The custom simulation programs are written in C++ that simulate networks with an ideal wireless channel (i.e., no hidden terminals). In addition to saturation throughput, a fairness index (FI) [10] is used to examine the fairness property of a backoff algorithm, i.e.,

$$\text{FI} = \frac{\left(\sum_i S_i\right)^2}{n \cdot \sum_i (S_i)^2} \tag{16}$$

where S_i is the saturation throughput received by station i. The FI is bounded in the interval [1, 0]. An algorithm is fair as its FI is close to 1. Table I lists the MAC-layer and PHY-layer parameters used in our simulations. For ease of discussion, we assume the same u and the same v for all chains throughout the simulations.

TABLE I
SIMULATION PARAMETERS

Channel Rate	1 Mbps
aSlotTime	20 us
aSIFS	10 us
aDIFS	50 us
CWmin	31
CWmax	1023
DATA	1024 bytes
ACK	120 bits

Fig. 5 presents the saturation throughput under different u and v. The frame size is 1024 bytes. First, we vary u from 0 to 1 with fixed $v = 0.5$. The figure shows that saturation throughput decreases as the number of competing stations n increases. Given a fixed n, the throughput increases as u increases. Next, we fix $u = 1$ and change v from 0 to 1. When v is small, the saturation throughput drops and then increases as n increases. This drop is due to bad ratios of u to v, which cause large backoff overheads. However, as n increases, the overheads will decrease, and the throughput will increase.

Fig. 6 shows the saturation throughput under the frame size of 128 bytes. In Fig. 6, we first fix $v = 0.5$ but vary u. The throughput increases when u increases from 0 to 0.1. Further increase of u will degrade the performance. Fig. 7 shows the relations between throughput and frame sizes. When the frame size increases, the throughput also increases since less backoff overhead is incurred.

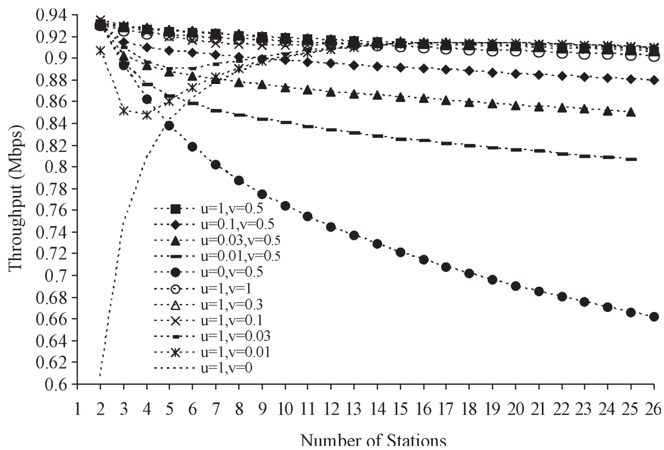

Fig. 5. Saturation throughput under different u and v with the frame size of 1024 bytes.

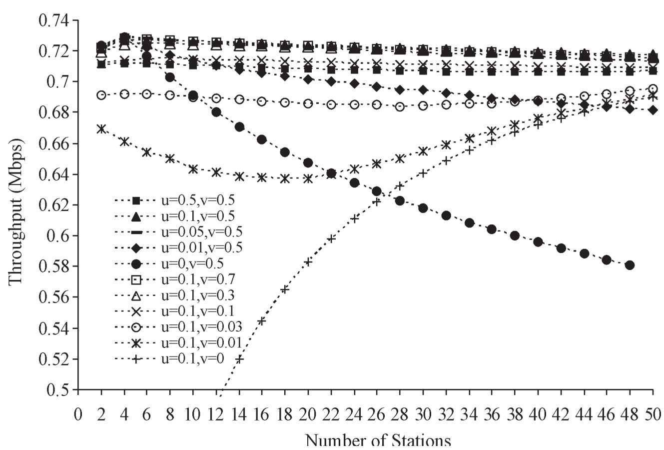

Fig. 6. Saturation throughput under different u and v with the frame size of 128 bytes.

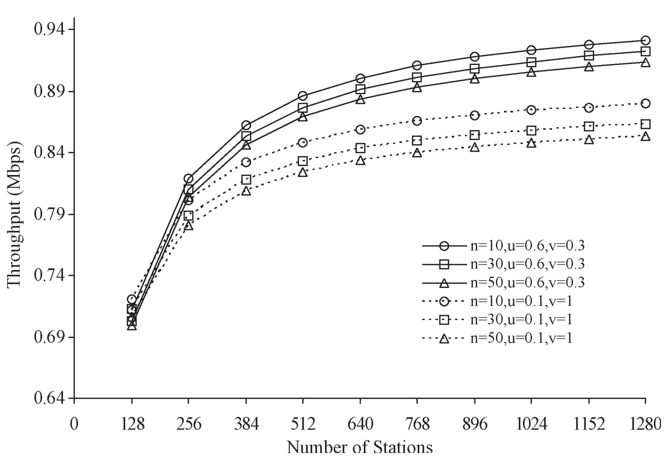

Fig. 7. Saturation throughput versus frame sizes.

A. Number of Backoff Chains

Fig. 4 has shown that when the number of contending stations n increases, the increment on the ratio of u to v will be smaller if more backoff chains are used. In Fig. 8, u and v are chosen to maximize the throughput for $n = 6$ and $n = 46$, respectively. In the case that u and v are chosen for $n = 6$, the throughput of a two-chain MCB drops more when the number of stations n increases. In the case that u and v are chosen for $n = 46$, the throughput of a two-chain MCB decreases more when n is small. Fig. 9 compares the analysis results with the simulation results of saturation throughput of a four-chain MCB. The figures show that the analyzed throughput has the same trend as the simulation throughput and that for some values of u and v, the analysis results match the simulation results.

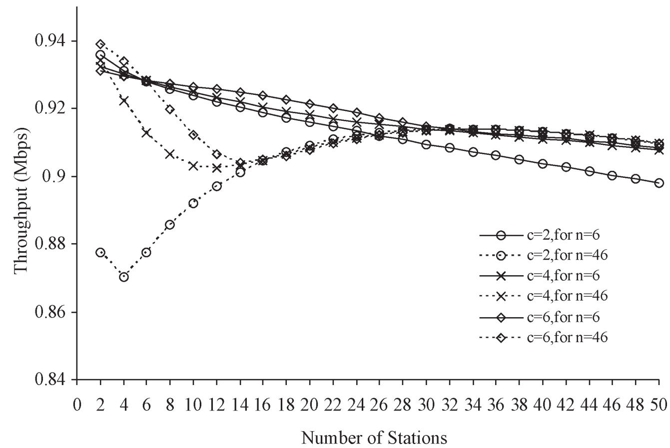

Fig. 8. Throughput of MCB with u and v, which are chosen for $n = 6$ and $n = 46$, respectively.

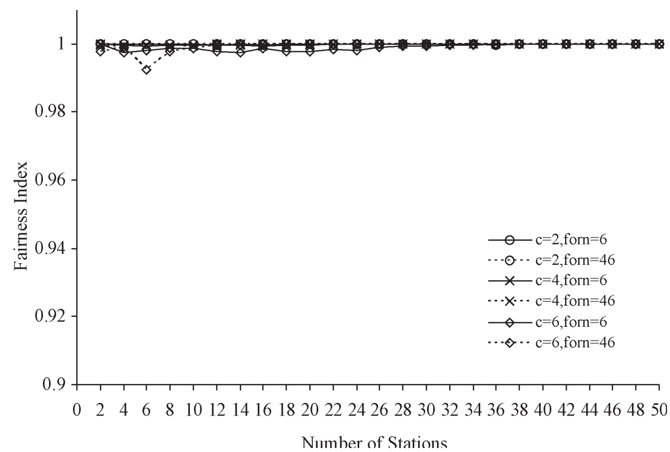

Fig. 9. Saturation throughput of a four-chain MCB: analysis versus simulation.

B. Comparisons With Existing Algorithms

In the following, we compare the performance of a four-chain MCB with those of the existing algorithms. The minimum contention windows of the four chains are 31, 127, 511, and 1023, respectively. u and v are chosen from the simulation results in Figs. 5 and 6. They are 0.1 and 0.3, respectively, for the frame size of 128 bytes and are 1 and 0.3, respectively, for the frame size of 1024 bytes.

1) Comparing With GDCF: In Fig. 10, we compare the throughput of MCB with that of GDCF, assuming the frame size of 128 bytes. For GDCF, we increase its parameter c from 1 to 5. It is clear that MCB outperforms GDCF. Figs. 11 and 12 compare MCB and GDCF under the frame size of 1024 bytes. With a large c, GDCF suffers from unfair channel access when n is small. In the case of $n = 2$, when window sizes of the two stations are different, a collision event will double the difference

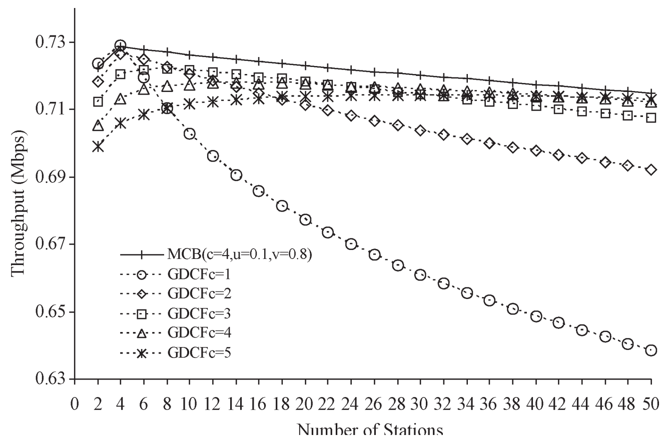

Fig. 10. Saturation throughput of MCB and GDCF (128 bytes).

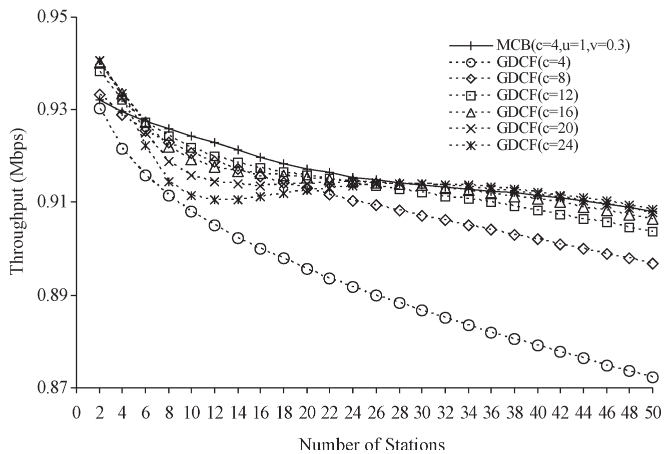

Fig. 11. Saturation throughput of MCB and GDCF (1024 bytes).

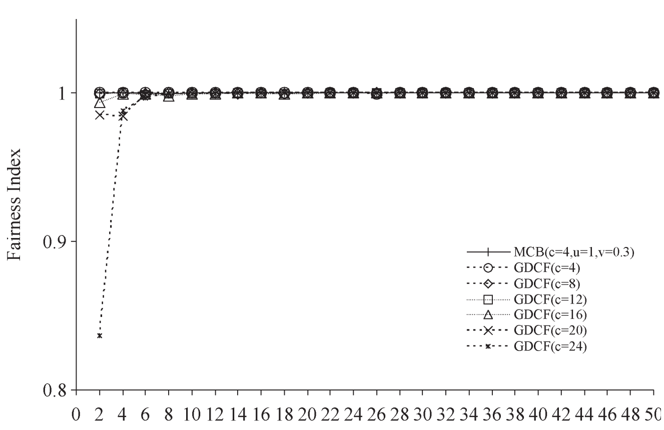

Fig. 12. FI of MCB and GDCF (1024 bytes).

of their window sizes. Since the station with a small contention window has shorter backoff time, it may reach c successful transmissions and then halve its contention window faster than the other station, which further enlarges the difference of the two contention windows and causes unfair channel access.

2) Comparing With IEEE 802.11 and MILD: Fig. 13 shows the throughputs of MCB, IEEE 802.11, and MILD. The throughput of MILD is lower than those of MCB and IEEE 802.11. In MILD, a station can advertise its contention window only if no other station successfully transmits during its

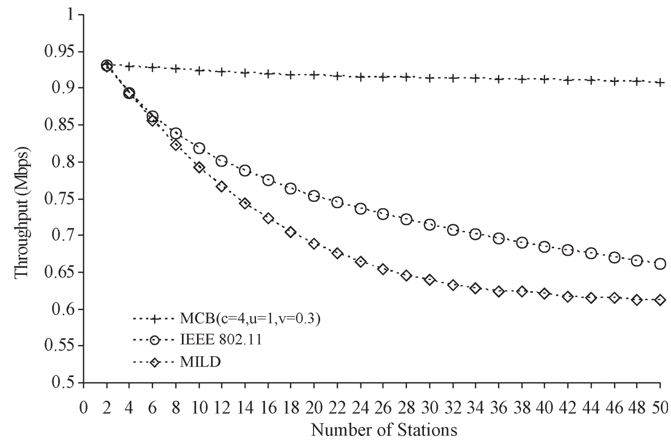

Fig. 13. Saturation throughput of MCB, IEEE 802.11, and MILD.

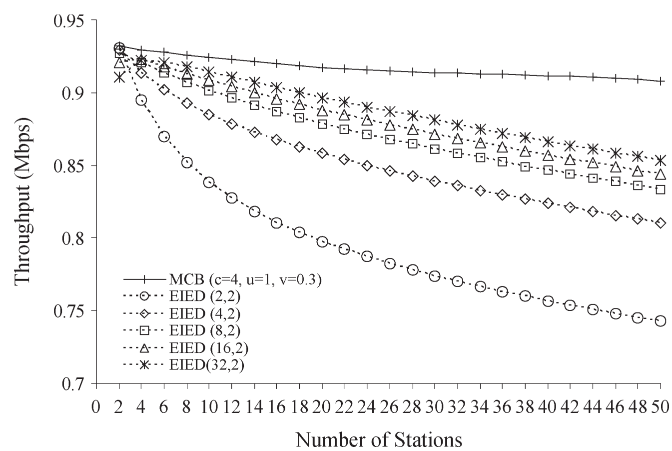

Fig. 14. Saturation throughput of MCB and EIED(x, y) with fixed $y = 2$.

backoff period. However, there is a high probability that a station with a smaller contention window successfully transmits during this period. This will force other stations to adopt this small contention window. In high traffic load, this will increase collision probability. IEEE 802.11 is outperformed by MCB since MCB offers more than one chain, allowing stations to adapt to different congestion levels.

3) Comparing With EIED: Figs. 14 and 15 compare the throughput of MCB to that of EIED. We use EIED(x, y) to denote that if a collision occurs, $\mathrm{CW}_{\mathrm{new}} = \min(x \cdot (\mathrm{CW}_{\mathrm{old}} + 1) - 1, \mathrm{CWmax})$, and if a transmission succeeds, $\mathrm{CW}_{\mathrm{new}} = \max(\lfloor(\mathrm{CW}_{\mathrm{old}} + 1)/y\rfloor - 1, \mathrm{CWmin})$. In Fig. 14, we fix $y = 2$ and increase x from 2 to 32. In Fig. 15, we fix $x = 2$ and vary y from 1.01 to 2. For EIED(2, 1.01), Fig. 16 shows that the wireless medium is unfairly utilized when $n < 8$. For EIED(2, 1.01) at $n = 2$, when a collision occurs, the difference between the two window sizes is doubled. Since the decrement of contention windows is small (the decrement is 1 when $\mathrm{CW} < 100$), the window sizes are hardly reduced to CWmin after a number of successful transmissions. Once a collision occurs, the difference between the two window sizes is doubled.

VI. Conclusion

In this paper, we have proposed a new MCB algorithm. MCB explores the possibility of using multiple backoff chains and considering collision events on the wireless channel as hints

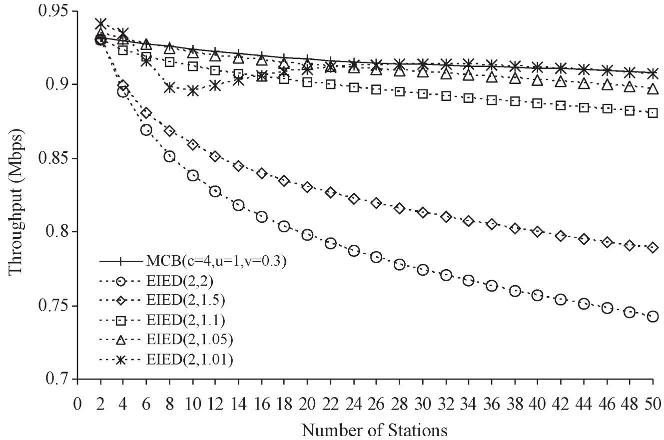

Fig. 15. Throughput of MCB and EIED(x, y) with fixed $x = 2$.

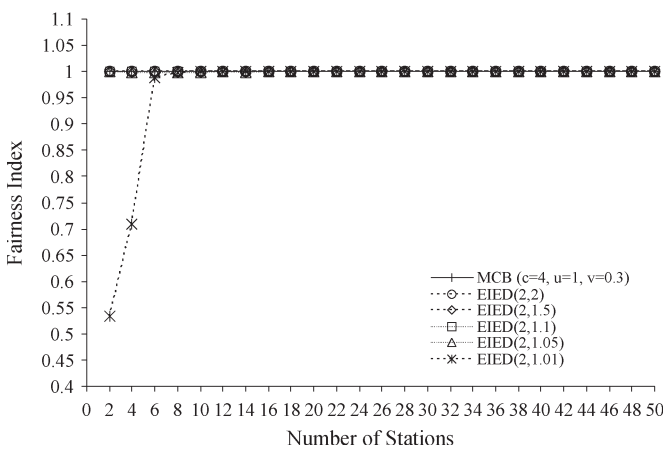

Fig. 16. FI of MBC and EIED(x, y) with fixed $x = 2$.

to choose a proper chain. With the capability of switching to different backoff chains, MCB offers higher throughput than the existing algorithms, such as GDCF, IEEE 802.11, MILD, and EIED, yet still provides fair access to the wireless channel. In [18], backoff procedures are employed to avoid consecutive burst errors on an error-prone wireless channel to obtain better network performance. How to apply our multichain concept to resolve this issue could be directed to future work.

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