An Exponential-Linear Backoff Algorithm for Contention-based Wireless Networks

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ABSTRACT
In this paper, a backoff mechanism, Exponential Linear Backoff Algorithm (ELBA), is proposed to improve system performance over contention-based wireless networks. In the ELBA, the variation of contention window size is combined both exponentially and linearly, dependent on the network load, as indicated by the number of consecutive collisions. In the ELBA, a threshold is set to determine the network load. If the contention window size is smaller than the threshold, a light network load, the contention window is tuned exponentially. Conversely, if the contention window size is larger than the threshold, a heavy network load, the contention window size is tuned linearly. The numerical results show that the ELBA provides a better system throughput and collision rate in both light and heavy network loads than the related backoff schemes, including binary exponential backoff (BEB), exponential increase exponential decrease (EIED) and linear increase linear decrease (LILD).

Categories and Subject Descriptors
C.2.1 [**Computer-Communication Networks**]: Network Architecture and Design – *wireless communication.*

General Terms
Algorithms

Keywords
802.11, DCF, EIED, BEB.

1. INTRODUCTION
In recent years, Wireless Local Networks (WLANs) are becoming more and more popular. The IEEE 802.11 protocol [1] is the one of the most deployed wireless access technologies all over the world. The IEEE 802.11 standard includes detailed specifications for both the Medium Access Control (MAC) and the Physical Layer (PHY). MAC has defined two medium access coordination functions; the contention-based Distributed Coordination Function (DCF) and the contention-free based Point Coordination Function (PCF). Every 802.11 station should implement DCF mode, while the implementation of PCF is optional in the standard. IEEE 802.11 DCF is based on a Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) protocol. In the DCF scheme, all stations compete for the wireless channel with the same priorities. In order to minimize the collision probability due to multiple simultaneous transmissions, all stations compete for the wireless channel with a contention resolution method, namely Binary Exponential Backoff (BEB). This is accomplished by doubling the channel arbitration time (backoff period) every time a station experiences transmission collision. The channel arbitration time decreases rapidly to its minimum value after a successful transmission. The channel arbitration time is also called Contention Window size (CW size) and ranges from its minimum value (CW_{min}) to maximum value (CW_{max}). However, if there are a large number of stations competing for the wireless channel, this aggressive reduction in the CW size can lead to performance degradation [2], since it encourages more collisions after any successful transmission.

Accordingly, there is related proposal, Exponential Increase Exponential Decrease (EIED) [3], that suggests a slower reduction in a backoff period after a successful transmission. In an EIED mechanism, the backoff period is doubled after a collision and halved after a successful transmission. The EIED mechanism improves the performance of the DCF mechanism in a larger number of competitive stations. Actually, when there are more wireless nodes, the CW size should be kept large to avoid frequent collision. However, the rapid variation of CW size in the EIED mechanism may be too sensitive to adapt to the network condition. The other algorithm, Linear Increase Linear Decrease (LILD), which is based on MILD originally proposed in [4], can provide better performance than DCF and EIED mechanisms when the number of stations is large. In an LILD mechanism, the backoff period is plus one or CW_{min} after a collision and minus one or CW_{min} after a successful transmission. The variation of CW size in LILD is more retarded than in EIED and DCF mechanisms so LILD can adapt to the large number of stations. By contrast, for the same reason, an EIED mechanism is more suitable than an LILD mechanism in rapid variation of network load.

Intelligent adjustment of CW size has been an important issue in previous studies [5-7]. Increasing backoff time needed by a

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contending station to access the channel decreases collision probability, but throughput degradation and high delays are caused. For example, a smaller CW size has less channel waiting time to transmit packets, but the small size may lead to a higher collision rate because stations select the same backoff time. On the other hand, a larger CW size may reduce collision rate, but the channel utilization is decreased because there is more idle channel time for backoff procedure. Improving network performance by dynamically tuning the CW size to the current network load is the objective of this paper. An intelligent backoff mechanism, Exponential Linear Backoff Algorithm (ELBA), is proposed to provide an improved system throughput over wireless networks. The variation of CW size is combined both exponentially and linearly, based on the network load. ELBA usage would tune CW size in such a way that stations will increase system throughput and decrease collision rate in light and heavy network loads.

The remainder of this paper is organized as follows. The related works are introduced in section 2, including DCF, EIED and LILD. The proposed ELBA algorithm is introduced in section 3. Section 4 discusses experimental settings and analyzes numerical results. Finally, the paper is summarized and possible future work presented.

2. RELATED WORKS

2.1 802.11 Distributed Coordination Function

In the DCF mechanism, each station with a new packet ready for transmission monitors the channel activity. If the channel is sensed idle for a period of time equal to a Distribute Inter-Frame Space (DIFS), the station transmits the packet. Otherwise, if the channel is sensed busy, the station persists to monitor the channel until it is measured idle for a DIFS. At this moment, the station initializes a backoff timer and defers transmission for a randomly selected backoff interval in order to minimize the probability of transmission collision with other stations. The backoff timer is decremented when the channel is sensed idle, frozen when the channel is sensed busy and reactivates when the channel is sensed idle again for a DIFS. The station transmits when the backoff timer reaches zero.

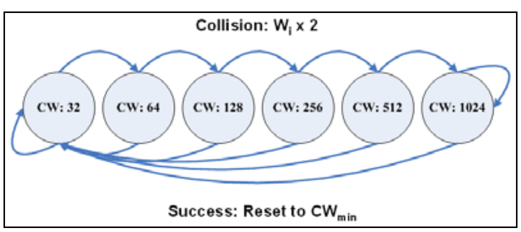

Figure 1. Markov chain model for the DCF scheme.

DCF adopts an exponential backoff scheme. The backoff counter for every station depends on the collisions and successful packet transmissions experienced by the station in the past. Before transmitting each packet, a station uniformly selects a random value for its backoff time in the range $[0, W_i - 1]$. The value W is called a contention window (CW) and W_i is the current CW. The number of failed transmissions of this packet is specified by i. At the first transmission attempt, W is set equal to a minimum value of the contention window, $W_0 = CW_{min}$. After each unsuccessful transmission, W is doubled ($W_i = 2 * W_{i-1} = 2^i * W_{min}$), up to a maximum value $CW_{max} = 2^m * CW_{min}$. The m is the maximum number of backoff stages. Once W_i reaches CW_{max}, it will remain at this value until it is reset to CW_{min} after a successful packet transmission. Figure 1 illustrates a transition diagram of a backoff stage in the BEB scheme. The values CW_{min} and CW_{max} are assumed as 32 and 1024.

2.2 Exponential Increase Exponential Decrease (EIED)

Several modifications have been proposed for the baseline BEB scheme [3, 6-7]. Recognizing that returning immediately from the final state (CW_{max}) to the initial state (CW_{min}) is too aggressive and can lead to increased collision probability the EIED aims to reduce CW size more slowly after successful transmissions. The EIED is to both increase and decrease the window size exponentially. The transition diagram of a backoff stage for EIED is shown in figure 2 with equal increase and decrease rates ($r_i = 2$, $r_d = 2$). When a successful transmission occurs, the contention window becomes half of the current CW, $W_i = W_{i-1} / 2$; Conversely, the contention window is doubled, $W_i = W_{i-1} * 2$, for each failed transmission in the same as the DCF mechanism.

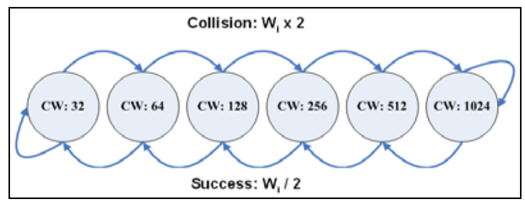

Figure 2. Markov chain model for the EIED scheme.

2.3 Linear Increase Linear Decrease (LILD)

The LILD mechanism is an enhancement of the MILD mechanism [4]. In order to slow down the variation of contention windows, the LILD increases and decreases the contention window size linearly, different from the exponential variation in the EIED mechanism. Figure 3 illustrates a transition diagram of a backoff stage in the LILD scheme. After each unsuccessful transmission, W is increased by W_{min} ($W_i = W_{i-1} + CW_{min}$), up to a maximum value CW_{max}. When a successful transmission occurs, the contention window is decreased by ($W_i = W_{i-1} - CW_{min}$), up to a minimum value CW_{min}.

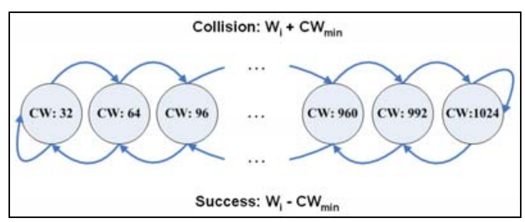

Figure 3. Markov chain model for the LILD scheme.

2.4 Comparison of the related works

For channel competition in wireless networks, the adjustment of a contention window is an important part. A proper contention window size will improve system throughput and reduce transmission collisions. According to the work mentioned above, the EIED mechanism provides a rapid variation of a contention window, so EIED is suitable for a variable load or low number of stations. In contrast, an LILD mechanism is applicable for invariable loads or a large number of stations because the contention window size is tuned linearly and varied slowly. There is a tradeoff between wasting some backoff time and risking a collision followed by the retransmission.

3. EXPONENTIAL-LINEAR BACKOFF ALGORITHM (ELBA)

3.1 Basic Concept of ELBA Mechanism

In the ELBA mechanism, the contention window size of the backoff counter is adjusted based on the current network conditions, as indicated by the number of consecutive collisions. A low transmission collision rate implies that the number of wireless nodes is low, and hence the contention window should be set small. Conversely, a more consecutive transmission collision rate indicates that there are more wireless nodes to compete in the wireless channel, and hence the size of contention window should be set large to avoid collisions. According to the comparison in section 2, the EIED mechanism performs better than the LILD mechanism in a light load. Conversely, when network is in heavy load, the LILD mechanism gives better performance than the EIED mechanism. The ELBA mechanism combines the advantages of both EIED and LILD to adapt to the different loads of a wireless network. In the ELBA mechanism, a threshold, Contention Window Threshold ($CW_{Threshold}$), is set to determine whether the competitive wireless nodes are low or high. If the contention window size is smaller than the threshold, a light network load, the contention window is tuned exponentially. If the contention window size is larger than the threshold, a heavy network load, the contention window size is tuned linearly.

Table 1. The Algorithm of the ELBA Mechanism

1. ELBA CW decrease procedure
   (after each successful transmission)
   If ($W_{i-1} = CW_{min}$)
   $W_i = CW_{min}$
   Else if ($W_{i-1} <= CW_{Threshold}$)
   $W_i = W_{i-1} / 2$
   Else if ($W_{i-1} <= CW_{max}$)
   $W_i = W_{i-1} – CW_{min}$
2. ELBA CW increase procedure
   (after each transmission collision)
   If ($W_{i-1} <= CW_{Threshold}$)
   $W_i = W_{i-1} * 2$
   Else if ($W_{i-1} < CW_{max}$)
   $W_i = W_{i-1} + CW_{min}$
   Else if ($W_{i-1} = CW_{max}$)
   $W_i = CW_{max}$

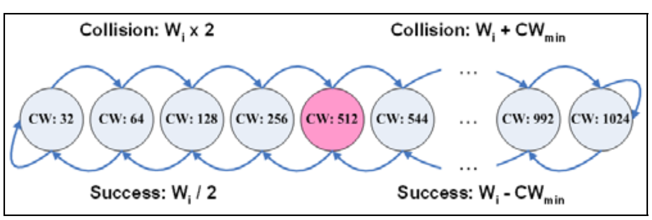

Figure 4. Markov chain model for the ELBA scheme.

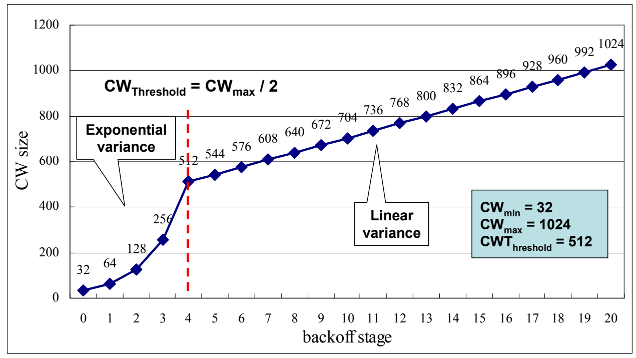

Figure 5. Variation of contention window with backoff stage in ELBA scheme.

3.2 The algorithm of the ELBA mechanism

Table 1 presents the algorithm of the proposed ELBA mechanism. As shown, when a station counts down to zero and successfully transmits a packet, the contention window size will be decreased to a small size. First, if the W_{i-1}, the contention window size of the current countdown procedure, is equal to CW_{min}, the size of W_i, the contention window size for the next countdown procedure, will not be changed. If the W_{i-1} falls between CW_{min} and $CW_{Threshold}$, the W_i will be set to half of W_{i-1} (exponentially). Finally, if the size of W_{i-1} is between $CW_{Threshold}$ and CW_{max}, the size of W_i will be set to W_{i-1} minus CW_{min} (linearly). On the other hand, when a collision happens for the packet transmission, the contention window size will be increased to a large size. First, if the W_{i-1} is smaller than $CW_{Threshold}$, the W_i will be set to double of W_{i-1} (exponentially). If the W_{i-1} falls between $CW_{Threshold}$ and CW_{max}, the W_i will be set to W_{i-1} plus CW_{min} (linearly). Finally, if the W_{i-1} is equal to CW_{max}, the contention window size will not be changed.

Figure 4 shows the state diagram of contention window variation in the ELBA algorithm. In the figure, the CW_{min} is 32, the CW_{max} is 1024 and the contention window threshold is half of CW_{max} (=512). Figure 5 illustrates the variation of contention window size with backoff stage. When the contention window is smaller than the $CW_{Threshold}$, the ELBA performs as the EIED mechanism to adapt a light network load. The ELBA performs as the LILD mechanism to adapt a heavy network load when the contention window is larger than the $CW_{Threshold}$. The hybrid backoff of the ELBA can provide a better performance than the EIED and LILD mechanisms in all network loads.

4. NUMERICAL RESUTLS

4.1 Simulation Settings

In this section, we study the performance improvement of the proposed ELBA as compared to the related backoff schemes, including DCF, EIED and LILD. The simulation results presented in this section were obtained using a simulator NS-2. In simulation tests, we consider a LAN of n stations operating at saturation conditions and under an error free medium and no hidden terminal problems. The 802.11 WLAN system parameters (PHY: DSSS) used in the simulation are in the same as [2].

4.2 Performance Comparison of Backoff Schemes

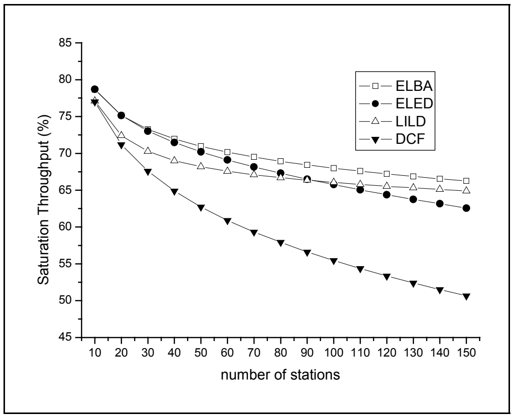

Figure 6. Saturation throughput of different backoff schemes.

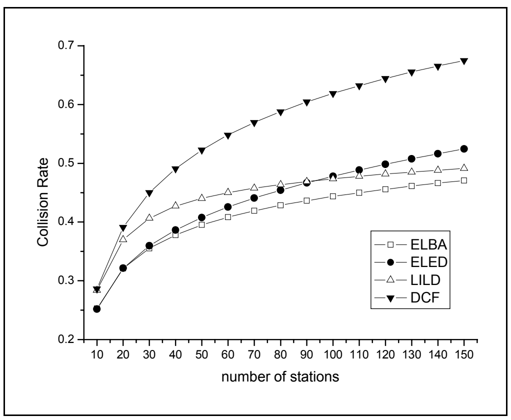

Figure 7. Collision rate of different backoff schemes.

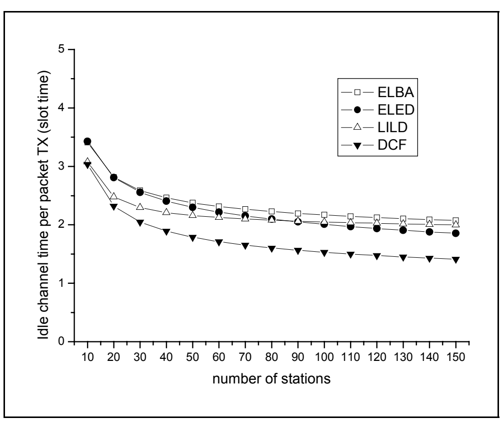

Figure 8. Idle slot times per packet transmission of different backoff schemes.

In this experiment, we evaluate the performance improvement of ELBA within different network loads. The number of wireless nodes is set as 10 to 150 with 10 intervals. Figure 6 shows the saturation throughput for all backoff schemes. The figure reports the throughput decrease when the number of wireless nodes increases. As mentioned in section 2, EIED performs better than LILD in a lower number of nodes. Conversely, in more wireless nodes LILD provides higher throughput than an EIED scheme. No matter in light or heavy load, the throughput of the ELBA scheme is always higher than that of DCF, EIED and LILD. Figure 7 illustrates the collision probability as a function of the number of stations. As expected, ELBA provides the lowest collision probability than the other three schemes in all network load scenarios. Figure 8 depicts the average number of idle slot times per successful transmission. We observe that the ELBA scheme slightly increases the idle time but significantly decreases the collision probability to improve system throughput.

5. CONCLUSION AND FUTURE WORK

In this paper, a backoff algorithm, ELBA, is proposed to improve system performance for contention-based wireless networks. The ELBA mechanism combines the advantages of EIED and LILD to tune a contention window based on the network load. When the number of nodes is low, the contention window varies exponentially; on the other hand, the contention window is tuned linearly when there are more competitive wireless nodes. The numerical results show that the ELBA improves system throughput and collision rates in both a light and heavy network load than BEB, EIED and LILD. In our future work, we will consider the analysis model of ELBA for evaluating system performance based on the model proposed by Bianchi in [2]. Besides, the optimum threshold of the ELBA is also an important research issue.

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