A Traffic Adaptive Backoff Approach for Wireless Networks

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***Abstract*—An efficient backoff algorithm is required to achieve a high network capacity in wireless networks. The IEEE 802.11 Distributed Coordination Function (DCF) has generally been used in wireless LAN. The DCF algorithm uses a Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) with a Binary Exponential Backoff (BEB). The increasing solution of Contention Window (CW) in BEB is very effective to decrease the probability of collision. But, BEB cannot be adaptive to the dynamic change of traffic load, so it sometimes acts as the cause of the delay and the collision. This paper proposes a Traffic Adaptive Backoff Algorithm (TABA) which tunes the value of CW parameter depending on the slot utilization and the collision count during a monitoring period. TABA determines a more appropriate CW, so it reduces the delay to access the channel and the collision rate without the decrease of throughput. In this paper, we evaluate the performance of the proposed TABA, and compare the TABAs performance with existing backoff algorithms by using simulation. Our proposed mechanism shows that it outperforms the existing methods because it has better adaptability to the load variation of the network.**

Keywords-wireless networks; backoff; contention window.

I. INTRODUCTION

The Distributed Coordination Function (DCF) of the IEEE 802.11 [6] that used Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) [8] is a representative Medium Access Control (MAC) protocol [1] for wireless networks. It is based on a random slot selection basis from the Contention Window (CW) in which all stations participating in transmission are involved. In the CSMA/CA, every contending station senses the carrier before the transmission. The carrier sense avoids collisions by testing the signal energy in the occupied band. When the station does sense the carrier, it starts to transmit its frames. When the channel, however, is detected as busy, it schedules its transmission at random moments to decrease the probability of a collision. At each collision, the station increases its CW exponentially. This exponential increase of CW is very effective in reducing the probability of a collision. It sometimes, acts however, as the cause of a transmission delay of data. The proper selection of backoff parameters is an essential factor in enhancing the network performance. In this paper, we propose a Traffic Adaptive Backoff Algorithm (TABA), which tunes the length of the CW period depending on the slot utilization and the collision count during the monitoring period. Our mechanism reduces the delay and the collision rate without the decrease of throughput. Section 2 describes the existing backoff algorithms. Section 3 and Section 4 present the TABA and simulation results. Section 5 contains the conclusion.

II. RELATED WORKS

A. Binary Exponential Backoff Algorithm (BEB)

The basic access method in the IEEE 802.11 MAC protocol is the DCF which is a CSMA/CA protocol [1]. The backoff count is determined as a pseudo-random integer drawn from a uniform distribution over the interval [0,CW]. The set of CW values shall be sequentially ascending, with integer powers of 2 minus 1, beginning with CW_{min} and continuing up to CW_{max} value. The value of CW shall take the next value every time there is unsuccessful attempt of transmission until reaching the value of CW_{max}. The CW shall be reset to CW_{min} after every successful attempt transmission, and shall remain at the value of CW_{max} until it is reset.

B. Estimation-Based Backoff Algorithm (EBA)

In [2], they proposed Estimation-Based Backoff Algorithm (EBA) to tune the backoff window size depending on the number of idle slots during the backoff period. The EBA algorithm estimates the system status by using the idle slot counts during the backoff period, and it determines a proper contention window size that accurately matches the current network conditions. But, the CW range which EBA set is shorter than the CW range which BEB set. It reduces transmission delay in low offered low. It is caused many collisions.

III. PROPOSED SCHEME

In this paper, we propose Traffic Adaptive Backoff Algorithm (TABA) which adaptively updates the length of CW

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depending on the estimate of channel utilization at each node to enhance the system performance. The detailed algorithm is as follows.

Given $\boldsymbol{N}$ nodes in wireless network, a random variable $\boldsymbol{X}$ is defined as the number of nodes to transmit their data during a slot. Then, the probability that $\boldsymbol{k}$ nodes out of $\boldsymbol{N}$ nodes try to send their data is given by

$$P(\boldsymbol{X} = \boldsymbol{k}) = \binom{\boldsymbol{N}}{\boldsymbol{k}} \boldsymbol{p}^{k} (1 - \boldsymbol{p})^{N-k} \tag{1}$$

where $\boldsymbol{p}$ denotes the probability that a node has data to transmit during a slot. We can get the probability that the channel is IDLE during a slot, denoted by ***P(IDLE)*** by setting $\boldsymbol{X} = 0$ in Eq.(1). Similarly, we can also get the probability of the successful packet transmission during a slot in the wireless network, denoted by ***P(SUCC)*** by setting $\boldsymbol{X} = 1$. In addition, we can get the probability that there happens a collision during a slot, denoted by ***P(COLL)***, as follows.

$$\begin{aligned} \boldsymbol{P(COLL)} &= 1 - \boldsymbol{P(SUCC)} - \boldsymbol{P(IDLE)} \\ &= 1 - Np(1 - \boldsymbol{p})^{N-1} - (1 - \boldsymbol{p})^{N} \end{aligned} \tag{2}$$

And we can get the throughput $\boldsymbol{S}$ of the wireless network by

$$\boldsymbol{S} = \frac{\boldsymbol{P(SUCC)}}{\boldsymbol{P(COLL)} + \boldsymbol{P(SUCC)} + \boldsymbol{P(IDLE)}} = \boldsymbol{P(SUCC)} \tag{3}$$

We differentiate $\boldsymbol{S}$ with regard to $\boldsymbol{p}$ to find the value of CW maximizing $\boldsymbol{S}$, denoted by $\boldsymbol{CW_{TABA}}$, by

$$\frac{d\boldsymbol{S}}{d\boldsymbol{p}} = \boldsymbol{N}(1 - \boldsymbol{p})^{N-1} - \boldsymbol{N}(\boldsymbol{N} - 1)\boldsymbol{p}(1 - \boldsymbol{p})^{N-2} = 0 \tag{4}$$

So, we have

$$\boldsymbol{CW_{TABA}} = \boldsymbol{N} \tag{5}$$

In our algorithm, all nodes should examine the status of slots during a monitoring period (denoted by $\boldsymbol{T}$) with a length of several time slots. Another random variable $\boldsymbol{Z}$ is defined as the number of collided slots when $\boldsymbol{k}$ nodes out of $\boldsymbol{N}$ nodes transmit their data during the monitoring period $\boldsymbol{T}$. From (1) and (2), we can easily get the average value of $\boldsymbol{Z}$ by

$$E(\boldsymbol{Z}) = \boldsymbol{T} \times \boldsymbol{P(COLL)} \tag{6}$$

The number of slots used to carry data plus the collided slots, denoted by $\boldsymbol{U}$, can be obtained by

$$\boldsymbol{U} = \boldsymbol{T}\left(1 - 2(1 - \boldsymbol{p})^{N}\right) \tag{7}$$

Arranging (7) with respect to N, we have

$$\boldsymbol{CW_{TABA}} = \frac{log(\boldsymbol{T} - \boldsymbol{U}) - log(2\boldsymbol{T})}{log(\boldsymbol{T} - 1) - log(\boldsymbol{T})} \tag{8}$$

Figure 1 shows the algorithm and notation of parameters used in the TABA. The duration of the monitoring period $\boldsymbol{T}$ is determined based on measurement of the collision count and slot utilization. $\boldsymbol{T}$ is initially given 8 slots, and stays unchanged if there is no collision. It is also reset to 8 slots every successful transmission. If the node experiences a collision, the value of $\boldsymbol{T}$ will be determined depending on the value of $\boldsymbol{CW_{TABA}}$. If $\boldsymbol{T} < \boldsymbol{CW_{TABA}}$, $\boldsymbol{T}$ will be doubled for each collision in the same way as the BEB. However, if $\boldsymbol{T} \geq \boldsymbol{CW_{TABA}}$, $\boldsymbol{T}$ will not be changed even though there is a collision. This way, we can adaptively adjust the length of backoff period depending on the collision count and slot utilization.

N = Number of contention nodes
BT = Backoff time
BE = Backoff Exponential
CW = Contention Window
CW_{TABA} = Optimal CW
T = Monitoring period
U = Number of successful slots plus collision slots during T

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Count $U$
$CW_{TABA} = \frac{log(T - U) - log(2T)}{log(T - 1) - log(T)}$
$BT$ = Random(0, $CW_{TABA}$ - 1)
If collision occur and ($T < CW_{TABA}$)
    $BE \leftarrow BE + 1$
    $T \leftarrow 2^{BE} - 1$
else collision occur and ($T \geq CW_{TABA}$)
    $T \leftarrow T$
End if
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Figure 1. Traffic Adaptive Backoff Algorithm

Figure 2 shows an example for determining the length of CW and $\boldsymbol{T}$. Initially, assuming that $\boldsymbol{T} = 8$ and $\boldsymbol{U} = 6$, then we have $\boldsymbol{CW_{TABA}} = 14$ from (10). This means that there will be a good possibility that the nodes can transmit their data without collision using a contention window with a length of 13 slots. In this case, the backoff time is randomly selected from [0, 13]. If there happens a collision in this case, the monitoring period $\boldsymbol{T}$ changes to 15 because $\boldsymbol{T} < CW_{TABA}$. On the other hand, when $\boldsymbol{T} = 15$ and $\boldsymbol{U} = 4$, we will have $\boldsymbol{CW_{TABA}} = 11$, the backoff time is randomly selected from [0, 10]. If there happens a collision at this time, the monitoring period $\boldsymbol{T}$ does not change because $\boldsymbol{T} \geq \boldsymbol{CW_{TABA}}$.

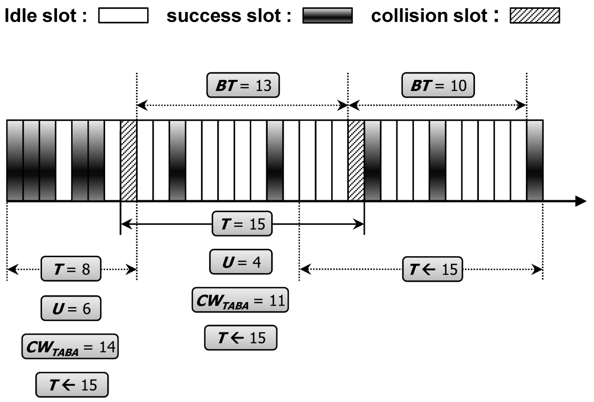

Figure 2. Example of TABA operation.

IV. Simulation

In order to evaluate the performance of our mechanism, a simulation study has been performed. We evaluate the performance in terms of the delay, the collision count, and the throughput. The system model for analysis consists of an Access Point (AP) and nodes. The number of nodes is assumed infinite. It is also assumed that all stations only transmit their packets to AP and AP does not generate its own packets. In addition, several assumptions have been made to reduce the complexity of the simulation model. The first, the effects of propagation delay are neglected assuming that the transmission distance is very close in order to transmit a packet. The second, the channel is error-free, that means that each transmitted packet was successfully and correctly received at its destination. The third, the packet transmission where is all stations transfer to AP is assumed to be a Poisson traffic source and there is no interference from the nearby Basic Service Sets (BSSs). The parameters used for the performance evaluation are listed in Table 1.

Table I
Parameter in The Simulation.

Parameter	Value
`Monitoring period (T)`	8 ~ 1023 slots
`Min of` CW_{TABA}	7 slots
`Max of` CW_{TABA}	7796 slots
`Paket size`	100 bytes
`Slot time`	50us
`Transmission Rate`	16Mbps

Figure 3 shows the average length of CW in our algorithm and the existing algorithms. When the offered loads are below 0.5, the TABA selects a shorter CW than the BEB. On the other hand, when the offered loads are over 0.6, the TABA selects a longer CW than the BEB. We can also see that the TABA gives a longer CW than the EBA over all the range of offered loads. This indicates that the TABA selects the CW more adaptively to the network traffic than other existing algorithms. And, this can contribute to reducing collision ratio while enhancing throughput.

In Figure 3, we see that the TABA provides a longer CW than the BEB when the offered load is heavy. This contributes to reducing collisions as shown in Figure 4. We can see that the EBA gives much more collision count than the TABA because it uses a shorter CW.

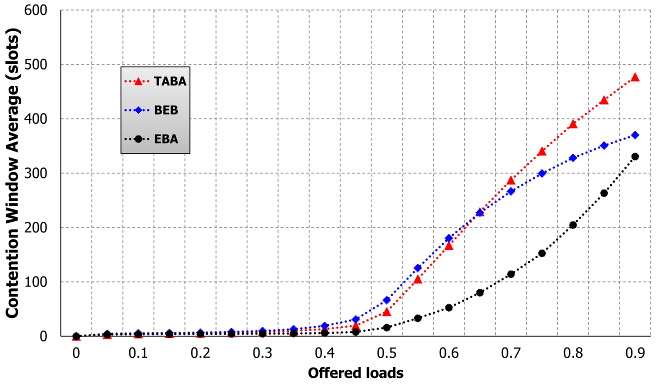

Figure 3. The average length of contention window.

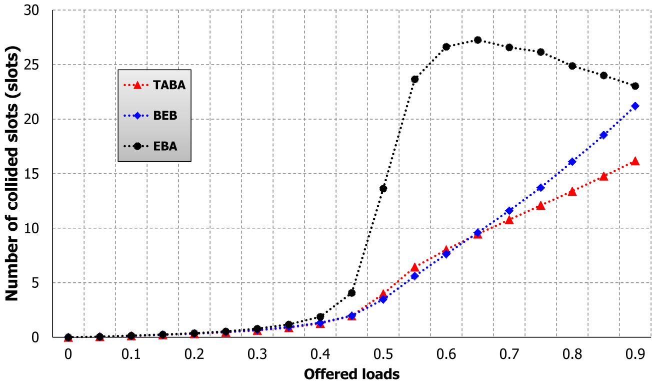

Figure 4. Collision Count.

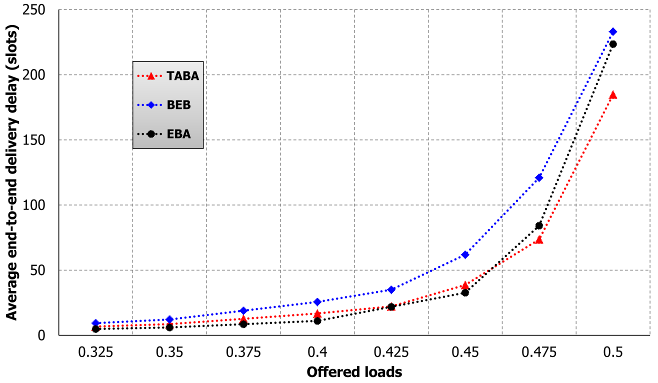

Figure 5. Average end-to-end delivery delay.

Figure 5 shows the average end-to-end delay that includes the waiting time at the interface queue and transfer time. We can see that our algorithm provides a shorter end-to-end delay at low traffic intensities than the existing algorithms. On the other hand, we can see no significant difference among all algorithms under heavy offered loads even though the TABA uses a relatively longer CW than the existing algorithms. This indicates that the TABA adaptively adjusts CW depending on traffic loads in the network.

Figure 6 shows the throughput in the TABA and the existing schemes. As shown in Figures 3 and 4, the EBA selects a shorter CW than the BEB and the TABA. For example, if the TABA selects 13 for CW, the node experiences a single collision on the average until a successful transmission when the offered load is 0.4. On the other hand, if the EBA selects 6 for CW. In this case, the node experiences two collisions on the average until a successful transmission. This example indicates that a shorter CW of the EBA can contribute to reducing delay time, but it causes more collisions. The EBA uses a relatively shorter CW. This can contribute to reducing delay time, but it causes more collisions and thus lower throughput when the offered load approaches to high value. Since the TABA adaptively determines the length of CW, it can produce a higher throughput when the offered load is heavy due to less collision. In addition, the TABA also offers a higher throughput at low traffic intensities because it reduces the delay in comparison with BEB and EBA.

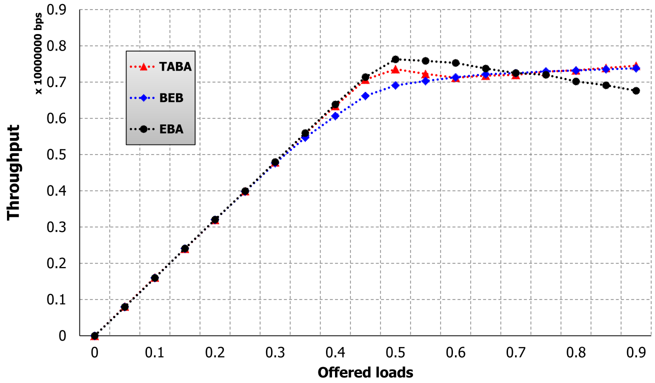

Figure 6. Throughput..

Simulation results assure that our TABA scheme can offer a higher throughput by choosing the appropriate value of CW depending on the slot utilization and the collision count. It can also reduce the delays without a noticeable increase of collisions.

V. CONCLUSION AND FUTURE WORKS

The proper choice of the CW parameters has a positively large influence on the network performance in the wireless network. In this paper, we proposed Traffic Adaptive Backoff Algorithm (TABA) to dynamically select the size of CW depending on the slot utilization and the collision count during the monitoring period. We compared the performance of our algorithm with the existing backoff algorithms. Simulation results indicate that the TABA dynamically adapts to the variation of the wireless protocols, and may reduce the MAC protocol delay and collision rate without a decrease in throughput. For future work, we plan to eliminate assumption for simulation and use a test bed with realistic environment.

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