Adaptive Logarithmic Backoff Algorithm for MAC Protocol in High Density WLAN

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Abstract: In high density scenarios Wireless Local Area Network (WLAN) faces serious interference, which results in the contradiction between low throughput and people's requirement. With the development and application of network communication technology, the fairness communication of high throughput in high density WLAN has become one of the important problems to be solved urgently. When each network node has the same transmission power and the Ad Hoc model of WLAN is adopted, the backoff algorithm in Media Access Control (MAC) protocol has an important influence on the performance of WLAN. Aiming at the shortages of the existing backoff algorithm, combined with the advantages of logarithmic backoff (LB) algorithm and adaptive adjustment factor for contention window (CW), an adaptive logarithmic backoff (ALB) algorithm is proposed, which can dynamically change the contention window with the contention of the channel, so as to reduce the probability of the collision between the network nodes. Compared with the existing binary exponential backoff (BEB) algorithm, exponential increase exponential decrease (EIED) algorithm and logarithmic backoff (LB) algorithm, the proposed algorithm can effectively improve the network performance in aspects of fairness, throughput, packet-loss rate and network delay.

Key words: communication network; high density WLAN; backoff algorithm; adaptive adjustment

0 Introduction

In recent years, Device-to-Device (D2D) communication has been appeared and as a key candidate technology for 5G. Combined with D2D communication, the WLAN is further developed [1]. In the airport, meeting rooms and other occasions, a small range of users are very much. If the interference of high density scenes is not effectively controlled, the performance of WLAN will be severely affected [2].If there are no effective measures to be taken to avoid the interference of the same frequency, the increase in the number of users will lead to the decline of the network performance. The existing research usually adopts the method of optimizing channel assignment [3], reducing the transmission power [4], carrier sensing [5], and other methods to reduce the interference of the same frequency in high density scenarios. Optimal channel allocation algorithm can improve the throughput to a certain extent. However, in any case, the channel allocation algorithm cannot avoid the interference of the same frequency in high density scenarios. Reducing the radiation power can reduce the interference, but also reduces the intensity of the useful signal at the same time. Carrier sensing is helpful to the reasonable allocation of time slots between each user node, which can avoid collision to a certain extent. However, only one pair of nodes can transmit data at the same time and the same channel, network resources are wasted on the listening and contention channel, so the total throughput is limited. Because these methods cannot well solve the interference problem in high density WLAN, there is an urgent need to research a new method, which is used to control interference effectively, and to meet the people's growing requirements of the high-speed network service.

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In the communication mode of the shared wireless channel, MAC layer protocol determines that how multi-users are fair and efficient to share the limited wireless channel resources. The Ad Hoc model of WLAN adopts the distributed control method, when multiusers in network send packets at the same time, conflict may occur, so the backoff algorithm, which is adopted to reduce the collision probability, improve network throughput and ensue the fairness of channel access, has become the design difficulty of MAC protocol. BEB algorithm is easy to implement, but the adjustment factor of CW is fixed, so with the competition increasing, the throughput decreases seriously [6]. EIED algorithm can enable the network node have relatively fair chance to access channel. But for a specific network, its adjustment parameters cannot be adaptive to the dynamic change of Ad Hoc networks [7]. In [8], the adaptive backoff algorithm with historical traffic, which is designed based on the estimation of channel error and network state, makes the failed transmission nodes can get the opportunity to compete for accessing channel. In a certain extent, the algorithm improves the fairness, but it requires extra storage space and the multiple operations, so the network delay is increased. Combined with the characteristics of the logarithm function and the number of network competitive nodes, LB algorithm can improve the fairness of node competition and network throughput [9]. But for some large network, the CW becomes small after the packet is sent successfully, which is not long enough for backoff, so it is easy to cause the conflict among network nodes, and result in a decline in the network performance.

Aiming at the shortages of the existing backoff algorithm in the channel access fairness, network throughput and so on, in the environment of IEEE 802.11 distributed coordination function (DCF), an adaptive dynamic backoff algorithm is studied, which can improve the overall performance of the high density WLAN.

1 Number estimation of competitive nodes

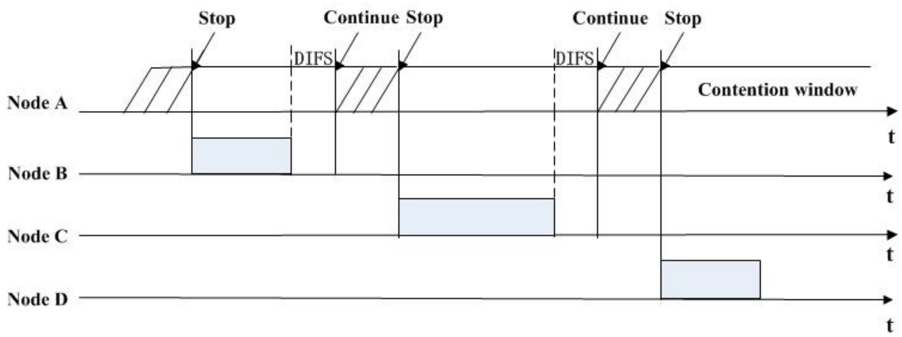

Fig. 1 The Number Estimation of Competitive Nodes

The joining and leaving the network of network node is random, that is the number of network node n is dynamic. For IEEE 802.11 DCF, the current channel state needs to be known by the carrier sensing technique before network node sends packets. If channel is busy, transmission will delay until it detects the channel is idle for a DIFS. In order to avoid collision, node uses the backoff algorithm to generate a random backoff time. The backoff time (a time slot is as a unit) is deposited in a backoff counter. When channel is idle for a time slot, the backoff counter value is decreased by 1 until the backoff counter value is reduced to 0. The node will determine whether the channel is idle, if channel is also idle, then transmission goes on. Or if channel is detected busy at the backoff process, it means that the other nodes are transmitting data or collision occurs between multiple nodes. At this time, the backoff counter will be stopped until nodes detect channel idle for a DIFS again. So the number of competitive nodes is estimated by calculating the average stopped time of backoff counter. As shown in Fig. 1, in the backoff process of node A, the stopped time of backoff counter is three. This phenomenon indicates that there are at least three nodes in the channel competition.

Let avg_node_count be the average stopped time in the backoff process. In order to make the estimation result be more accurate, the Exponentially Weighted Moving Average (EWMA) method is used to calculate avg_node_count in the observation period.

$$\begin{aligned} n = avg\_node\_count(new) &= \lambda * current\_node\_count \\ &\quad + (1-\lambda) * avg\_node\_count(old) \end{aligned} \tag{1}$$

Where $current\_node\_count$ is the latest stopped time of backoff counter. λ $(0<\lambda<1)$ denotes the weight coefficient of EWMA. When λ is more close to 1, the real time performance of the estimated value of the competitive nodes is stronger.

2 Adaptive adjustment factor

With the increase in the number of competitive nodes, the channel contention becomes more and more intense and the collision probability p of packet transmission becomes bigger, so the network performance will become worse. The optimal packet transmission probability τ_{opt}, which can make the network achieve the maximum throughput, is determined by two parameters that are the number of competitive nodes n and the collision length T_c^*. The value of packet transmission probability τ is related to the initial CW value W and the maximum backoff order m [10]. For example, two important parameters (W and m) in BEB algorithm are fixed, so that the packet transmission probability is not adaptive changes. The adjustment factor for CW is fixed (CW is doubled when transmit successfully, and reduced to the minimum value when failed to send data). This leads to a drop in network throughput. Especially, when the network competition is aggravate, the successful transmission nodes have more chance than failed ones to access channel. So the unfair competition between competitive nodes is caused. For the LB algorithm, by the initial value of CW is adjusted to $CW_{min} * \log_a n$ for improving the packet transmission probability, the packet transmission probability τ is dynamically approximated to optimal packet transmission probability τ_{opt}. Besides, the adjustment factor $\log_a n$ of LB algorithm changes with the variation of competitive nodes number, which makes the CW change be more smooth and improve the fairness of accessing channel. But when the node sends data successfully, the CW will be adjusted to $CW_{min} * \log_a n$ that is too small for the network with a large number of competitive nodes. So the successful sending node has greater chance to access channel, and then the fairness and other network performance are decreased.

In ALB algorithm, the adjustment factor can adjust CW adaptively, which is shown as (2).

$$\begin{cases} CW = CW_{min} * (1+\log_a n) \ \ \text{The Initial value of CW} \\ CW = Max(CW_{min} * (1+\log_a n), CW * (1 - \dfrac{1}{2*(1+\log_a n)})) \ \ \text{Packet is sent successfully} \\ CW = Min(CW * (1+\log_a n)\ , CW_{max}) \ \ \text{Packet is sent failed} \end{cases} \tag{2}$$

Where the initial CW value is set as $CW_{min} * (1+\log_a n)$. When the node is failed to transmit packet, the CW is expand to $1+\log_a n$ times of the current value and the maximum CW is CW_{max}. Here, $1 - \dfrac{1}{2*(1+\log_a n)}$ is the adaptive adjustment factor when the nodes transmit packet successfully, $1+\log_a n$ is the adaptive adjustment factor when the nodes fail to transmit packet. These adjustment factors are increasing function with the number of competitive nodes n. The CW of large n is bigger than that of small n. That is, the value of

n is larger, the backoff time, no matter with nodes transmitting packet successfully or not, is longer, so the collision probability can be reduced effectively.

3 ALB algorithm

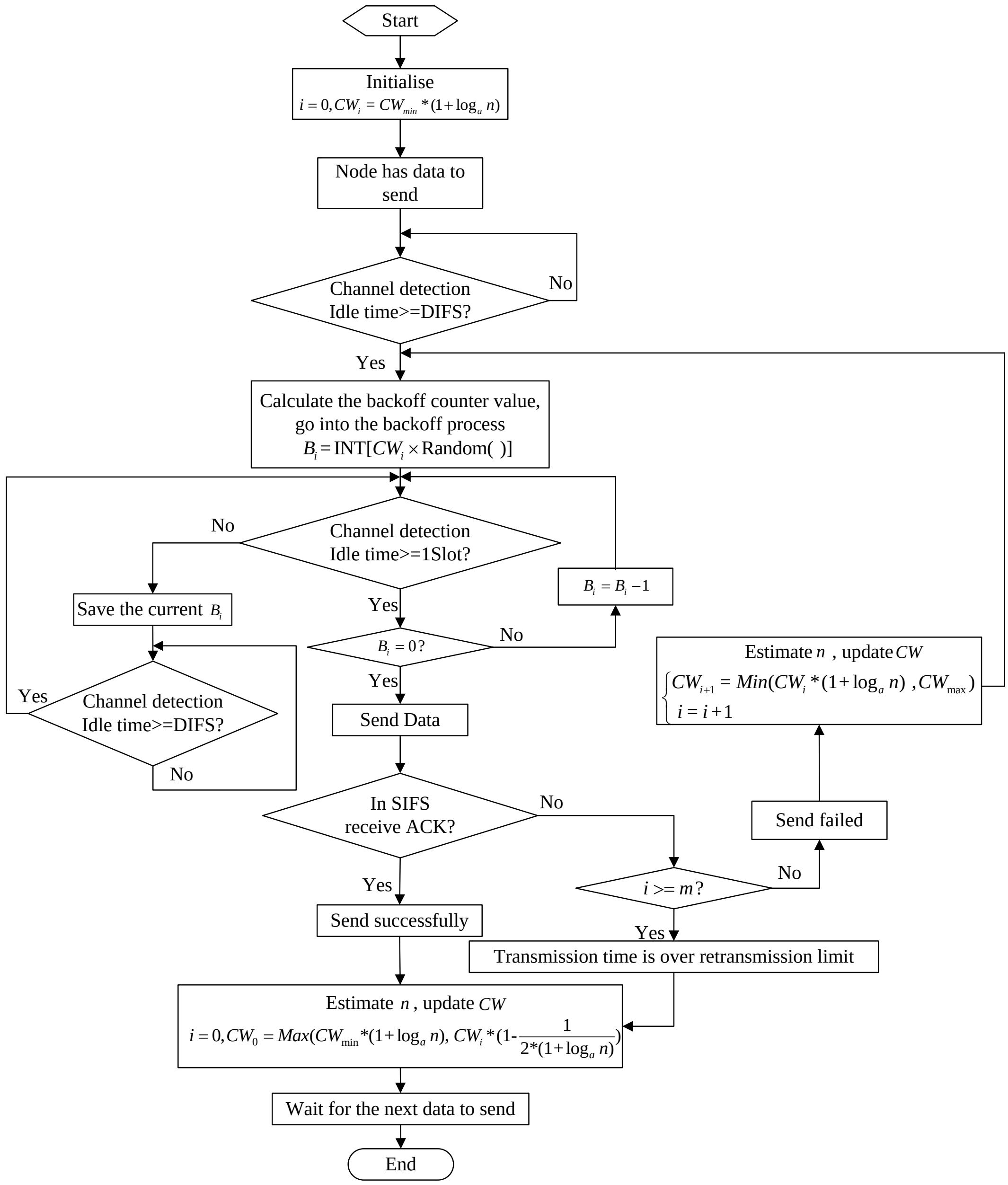

Fig. 2 The Flowchart of ALB Algorithm

ALB flowchart is shown in Fig. 2. Assuming CW_i (i is the backoff time, $0 \le i \le m$, m is the maximum number of retransmission) is the current CW. $CW_{\min}$ is the minimum CW. $CW_{\max}$ is the maximum CW. B_i is the current value of backoff counter. ALB algorithm is described as follows.

Step 0: Before the packet is transmitted, each node monitors channel firstly. When the channel is idle for a DIFS, the backoff stage is entered. The initial CW value is set as follow.

$$CW_0 = CW_{min} * (1 + \log_a n) \tag{3}$$

Sept1: When node enters into the backoff stage, the backoff time is calculated and stored in the backoff counter. The value of the backoff counter can be expressed as follow.

$$B_i = INT[CW_i \times Random(\ )] \tag{4}$$

Step 2: Node keeps monitoring the channel. When the channel is idle for a DIFS and the current value of the backoff counter is not 0, the value of backoff counter B_i is minus 1. When the current value of the backoff counter is 0, the node sends packet and jumps to step 3. In the backoff process, if node detects the channel is busy, the value of B_i should be maintained until the detected channel continuous is idle and the idle time is DIFS, then node jumps back to Step 2.

Step 3: If the packet sending is failed and m is not reach the maximum value, the number of competitive nodes should be estimated, and CW can be adjust as follow.

$$CW_{i+1} = Min(CW_i * (1+\log_a n), CW_{max}), 0 \le i < m \tag{5}$$

After CW updates according to (5), node jumps to Step 1 for the backoff retransmission. If packet transmitting is successful or the maximum time of retransmission m is reached, the node will reset the CW as (6) and jump to step 1. Also, it is necessary to estimate the number of competitive nodes.

$$\begin{cases} CW_0 = Max(CW_{\min} * (1+\log_a n),\ CW_i * (1 - \dfrac{1}{2*(1+\log_a n)})\ ) \\ i = 0 \end{cases} \tag{6}$$

4 Simulation results and analysis

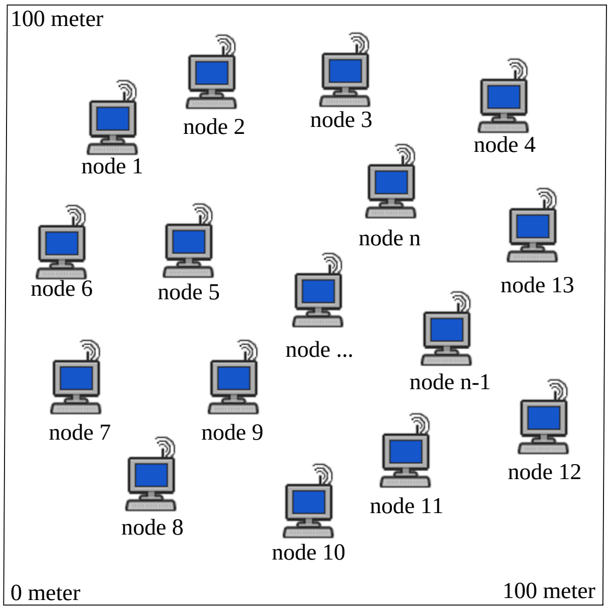

Fig. 3 The Simulation Network Model

The OPNET network simulator is used to analyze the performance of ALB algorithm. The Simulation Network Model is shown in Fig. 3. In an area of 100*100 square meter, the network consists of n mobile nodes, followed by node 0, node 1, node 2, ..., node n-1, node n. Each node transmits packet with the same power and the traffic generation uses the ON-OFF mode. The target address of each network node is selected randomly. When the number of competing nodes is estimated, the value of λ is 0.9. The running time of the simulation system is 40 minutes, which can ensure the stable data of time average is gotten. The performance comparison between the proposed ALB algorithm and the exiting backoff algorithms, such as BEB, EIED

($R_D = 2, R_I = 2$), LB algorithm, is made. The simulation parameters are shown in Tab. 1.

Tab. 1 Simulation Parameters

Parameter	Value	Parameter	Value
Physical characteristics	DSSS	Date rate (Mbps)	1
Slot time (μs)	20	CW_{max}	1023
SIFS (μs)	10	$CW_{\min}$	11
DIFS(μs)	50	Packet size (bytes)	1024
MAC_{hdr} (bit)	224	PHY_{hdr} (bit)	192
The base a	2	Maximum retransmission number	4

4.1 Throughput performance

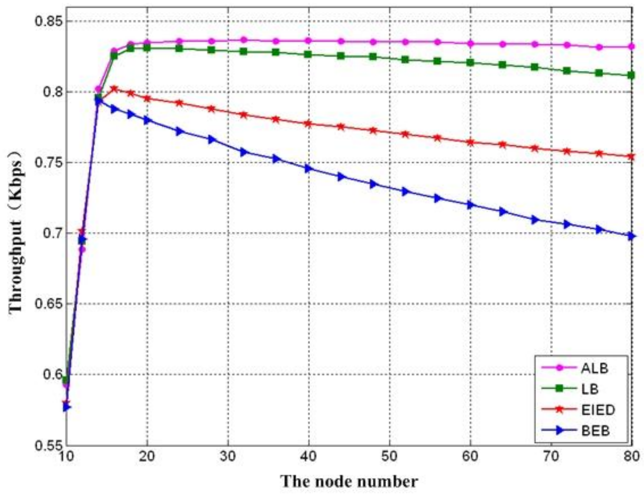

Fig. 4 The Throughput Performance Comparison

By changing the number of competitive nodes, the normalized throughput comparison can be gotten and shown in Fig. 4. The following conclusions can be obtained: (1) With the increase in the number of competitive nodes, the network throughput of each algorithm shows a downward trend. Compared with the downward trend of BEB algorithm, EIED algorithm and LB algorithm, that of ALB algorithm is slower. However, the network throughput of ALB algorithm is the best. This is mainly due to the initial CW and window adjustment factor of BEB algorithm and EIED algorithm is fixed, with the increase in the number of competitive nodes, the CW of these two algorithms cannot adjust adaptively with the change of network condition, so the network conflicts are increased and the network throughput is decreased obviously. On the other hand, the initial CW of LB algorithm and ALB algorithm can adjust with the node number dynamically, so the conflict probability is reduced and the performance of network throughput is improved. Specifically, ALB algorithm adopts the adaptive CW adjustment factor that can further reduce the conflict probability between nodes and improve the network throughput. Compared with LB algorithm, ALB can improve the shortcomings of LB that is the backoff time of LB is too short after node sends packet successfully in the fierce competition scenario. (2) With the increase in the number of competitive nodes, ALB algorithm outperforms the other three algorithms in throughput performance. The throughput performance of ALB algorithm is improved 20.9% compared with BEB, 11.94% compared with EIED, and 3.93% compared with LB, respectively.

4.2 Fairness performance

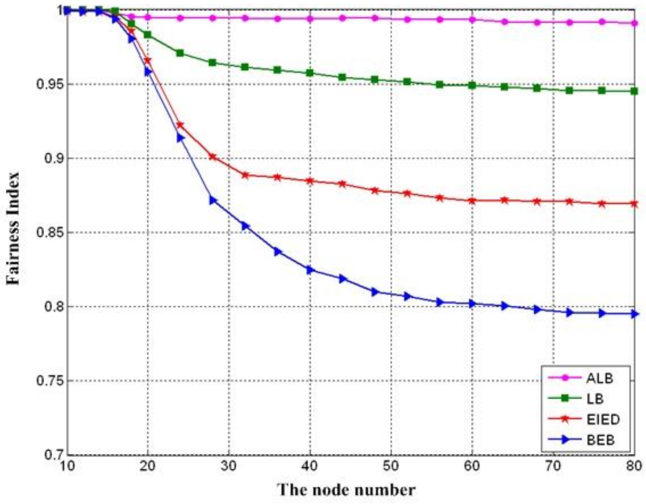

Fig. 5 The Fairness Performance Comparison

The fairness index (FI) in paper [11] is used to evaluate the fairness performance. By changing the number of competitive nodes, the fairness performance comparison is shown in Fig. 5. The following conclusions can be obtained: (1) With the increase in the number of competitive nodes, the fairness index of each algorithm shows a downward trend. Compared with the downward trend of BEB algorithm, EIED algorithm and LB algorithm, that of ALB algorithm is slower and close to 1. In BEB algorithm, the CW is reduced to the minimum value after the packet is sent successfully, and enlarged to two times of the current window after the packet is failed to send, so the successful transmission node is conducive to access channel again, so the decline in fairness index is caused. In EIED algorithm, the CW is reduced to half of the current window after the packet is sent successfully, and enlarged to two times of the current window after the packet is failed to send. Compared with BEB algorithm, the fairness index of EIED algorithm is improved, but the change of CW is also not smooth enough, so the fairness index is also caused to decline. In LB algorithm, the CW adjustment factor $\log_a n$, which can change with the number of competitive nodes, makes the change of CW be smoother, so the fairness index is improved. But the CW is adjust to $\log_a n$ times of the minimum value after the packet is sent successfully, that is too small for the more competitive network, so the backoff time of the successful transmission node is short, the chance of accessing channel is greater and the fairness index is decreased. ALB algorithm improves the shortcomings of LB algorithm. The CW is adjust to $1\text{-}\frac{1}{2*(1+\log_a n)}$ times of the current window after the packet is sent successfully, the change of CW is more smooth, the CW of large competitive node number is larger than that of small competitive node number, so the shortcoming, that is the successful transmission node has more chance to access channel than failed transmission node, is improved. (2) With the increase in the number of competitive nodes, ALB outperforms the other three algorithms in fairness performance. The fairness performance of ALB algorithm is improved 25.30% compared with BEB, 14.67% compared with EIED, and 5.04% compared with LB, respectively.

4.3 Delay performance

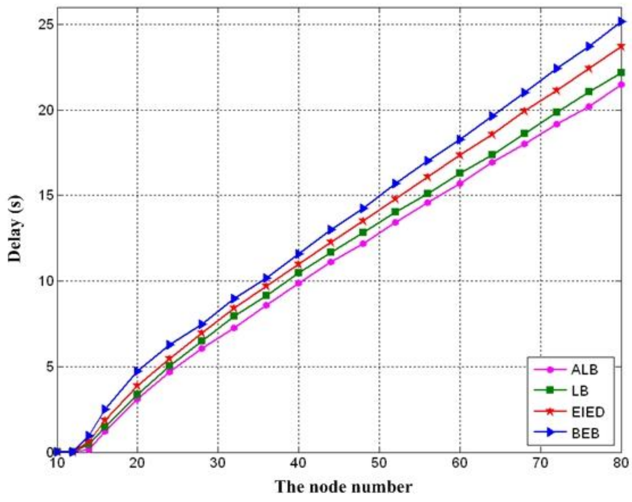

Fig. 6 The Delay Performance Comparison

By changing the number of competitive nodes, the delay performance comparison is shown in Fig. 6. The following conclusions can be obtained: (1) With the increase in the number of competitive nodes, the packet transmission delay of each algorithm gradually increases. Due to the traffic load is become heavy and the packet is accumulated, the collision probability and the packet retransmission times are increased, so the transmission delay is gradually increased. (2) With the increase in the number of competitive nodes, the media access delay of ALB algorithm is shorter than that of other algorithms. The reason is that the adaptive CW adjustment factor in ALB algorithm, which makes backoff time adapt to the change of competitive situation, reduces the packet collision probability and the packet retransmission times. The delay performance of ALB algorithm is improved 40.3% compared with BEB, 23.84% compared with EIED, and 8.32% compared with LB, respectively.

4.4 Packet loss rate performance

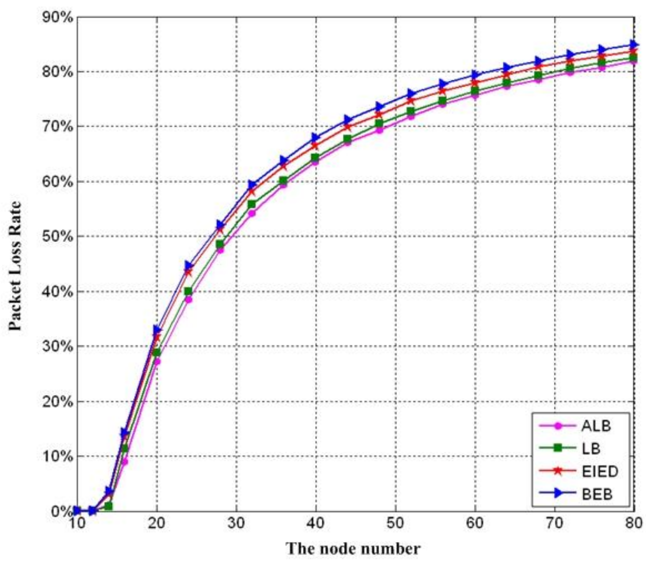

Fig. 7 The Performance Comparison of Packet Loss Rate

By changing the number of competitive nodes, the performance comparison of packet loss rate is shown in Fig. 7. The following conclusions can be obtained: (1) With the increase in the number of competitive nodes, the packet loss probability of each algorithm increases gradually. As the traffic load continues to increase, the packet loss rate is gradually increased. (2) The performance of ALB algorithm in packet loss rate is improved 36.96% compared with BEB algorithm, 24.36% compared with EIED algorithm, and 11.62% compared with LB algorithm, respectively.

5 Conclusion

Based on in-depth analysis of the related factors that affect the performance of high density WLAN, an ALB algorithm is proposed, which provides a new solution for the high throughput fairness communication in high density WLAN. The adaptive CW adjustment factor used in ALB algorithm can dynamically adjust the CW value of each network node with the channel contention, so the probability of data collisions is reduced and the network throughput, performance of fairness, delay and packet loss ratio is greatly improved.

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高密度 WLAN 中 MAC 协议的自适应对数退避算法

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摘要：在高密场景中，无线局域网面临着的各种各样的干扰，这导致了低吞吐量与人们需求之间的矛盾。随着网络通信技术的发展和应用，高密度 WLAN 中高吞吐量的公平性通信已成为亟需解决的重要问题之一。当各网络节点具有相同的发送功率和采用 WLAN 的 Ad Hoc 模式时，MAC 协议中的退避算法对 WLAN 网络性能具有重要的影响。针对现有退避算法的

不足，结合对数退避算法和竞争窗口自适应调整因子的技术优势，提出了一种自适应对数退避算法。该算法能够跟随信道的争用状况动态地改变竞争窗口，从而降低网络节点之间的冲突概率。与现有的 BEB、ELED 和 LB 退避算法相比，提出的算法可以有效提升网络公平性、吞吐量、丢包率和延时方面的性能。

关键词：通信网；高密度 WLAN；退避算法；自适应调整
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