A Novel Adaptive Backoff Algorithm Based on Active Nodesfor Flying Ad Hoc Networks

Haifeng Zhu   Yang Gao   Na Lv

Email:kunta0089@sina.com

Abstract

In order to improve the tactical coordination ability of cluster unmanned aerial vehicles, extend their application scopes and effectively enhance the reliability and survivability in flying ad hoc network, a novel adaptive backoff algorithm based on active nodes is proposed in this paper. The backoff algorithm adopts a connection window adaptive mechanism in order for adapting loads dynamic change. Therefore, nodes connection window can be adaptively adjusted for reducing collisions under heavy loads. The two-dimensional Markov chain of the backoff algorithm is established and the node state transition probability under different loads are solved. Moreover, the expression of system throughput and mean delay are also deduced. Simulations show that the algorithm not only maintains a higher information success transmission rate under light loads, but also possesses the ability to effectively resolve connections under heavy loads.

Introduction

In recent years, the unmanned aerial vehicle (UAV), which has characteristics of low cost, strong vitality and various uses, ie., becomes one of the rapidly developing technology, and has attracted wide attentions in military and civil fields[1]. Multiple UAVs which forms the flying ad hoc networks by wireless channel can quickly transmit control instructions, exchange situation awareness and intelligence information[2].The flying ad hoc networks(FANETs) combine the advantages of the UAV and mobile ad hoc network(MANET), possess some superiorities such as the reliability, invulnerability, scalability ie., and can effectively enhance the tactical coordination ability and extend the application scope of multiple UAVs system[3] [4]. However, in the practice use of FANETs, all nodes transmit information by aeronautical wireless channels with the features of large scale and high dynamic. When the network transmitted loads suddenly increase, a lot of collisions will emergence on channels, which will make the information transmission performance rapidly decline.

Introduction

The Medium Access Control (MAC) serves as the coral mechanism of data link layer and possesses the ability of controlling packets accessing the channel, so it plays an important role to network performances. In order to ensure the timeliness and reliability of information transmission, the design of MAC protocol need to consider how to resolve collisions and backoff. The design of backoff algorithms will directly affect the system throughput and mean delay, and it is an important problem to design MAC protocol by improving backoff algorithm to avoid congestion and collision caused by a large number of packets accessed to the channel [5].

At present, the research about backoff algorithms of MAC protocols in FANETs are less, however, in traditional wireless networks, Binary Exponential Back off (BEB) algorithm is widely used in MAC protocols. In BEB, the contention window (CW) of a packet is reduced to the minimum value immediately when it is sent successfully, but the CW will be doubled when collisions occur. Therefore, the serious unfairness will result when the channel is under heavy loads if the last packet accessed the channel successfully is always sent preferred, and the optimal CW size cannot be chosen quickly when network loads suddenly changes[6][7][8].

Introduction

According to above-mention problems, some related improvement mechanisms have been proposed recently. For examples, a novel exponential increases exponential decrease (EIED) algorithm is proposed in [9]. In EIED algorithm, when packets transmit successfully or failed, the CW decreases or increases exponentially. The algorithm enables all nodes to possess equal access chances to access the channel, but the appropriate index needs to be chosen according to different network environments. A Multiple Increase Linear Decrease (MILD) algorithm is also proposed in [10], and it can significantly improve the fairness of nodes accessed channels and increase system throughput under heavy loads compared with BEB algorithm, but its performance is inferior to BEB algorithm due to uncertain connection window.

According to that the performance requirements and the shortcomings of traditional backoff algorithm in scenarios of FANETs, a novel adaptive backoff algorithm based on active nodes (ANAB) is proposed. In ANAB, these nodes with packets to be sent are defined as active nodes, and the size of CW of each node in every backoff stage can be dynamically adjusted by estimating the number of active nodes in the whole network. Therefore, the packet CW can be increased under heavy loads and the optimal CW can be obtained with changes of loads. The collisions on channels can be reduced and the network performance can be improved.

Introduction

The remainder of the paper is organized as follows. In Section 2, we describe the adaptive backoff algorithm in detail. Section 3 modes the algorithm using two-dimensional Markov chain model. Simulations are performed to verify the performance of ANAB in Section 4. Finally, we conclude the paper in Section 5.

Algorithm Description

Assume that the time intervals of packets obey exponential distribution in FANETs, and packets from all nodes have the same bit length. λ is defined as the packet access rate of all nodes in the whole network and is defined is the duty cycle of a single node. C is defined as the number of channels. According to Poisson distribution and reference [11], the number of active nodes in the whole network can be calculated as

$$n = N\left(1 - e^{-\frac{2\lambda}{RC}}\right) \qquad (1)$$

According to the basic idea of ANAB, the expression of CW is calculated as

$$W_{bf} = \left\lceil -\frac{2}{\ln\frac{n}{N+1}} \right\rceil \qquad (2)$$

$$W_i = Random\left[1, \min\left(W_{bf}, W_{\max}\right)\right] \qquad (3)$$

Where $W_{\max}$ denotes the CW which increases linearly until it reaches its maximum value.

Algorithm Modeling

We use the two-dimensional Markov chain model to analyse the performance of ANAB, where (-1,0) represents a state that the service of a packet transmits successfully or failed when the backoff counter reaches the maximum value. Let $b_{i,j} = \lim_{t \to \infty} P\left\{u\left(t\right) = i, v\left(t\right) = j\right\}$ denotes steady state probabilities of every states in the Markov chain, where *i* denotes the backoff stage and *j* denotes the size of CW at present. Therefore, the backoff state linger space can be expressed as

$$\Omega = \{(i,j) | i \in \{0,1,2 \cdots m\},\ j \in \{0,1,\cdots W_i - 1\}\} \quad (4)$$

The one-step state transition probability of the backoff process is defined

$$\begin{aligned} &P\{i+1, j+1 | i, j\} = \\ &P\{u(t+1) = i+1, v(t+1) = j+1 | u(t) = i, v(t) = j\} \end{aligned} \quad (5)$$

Algorithm Modeling

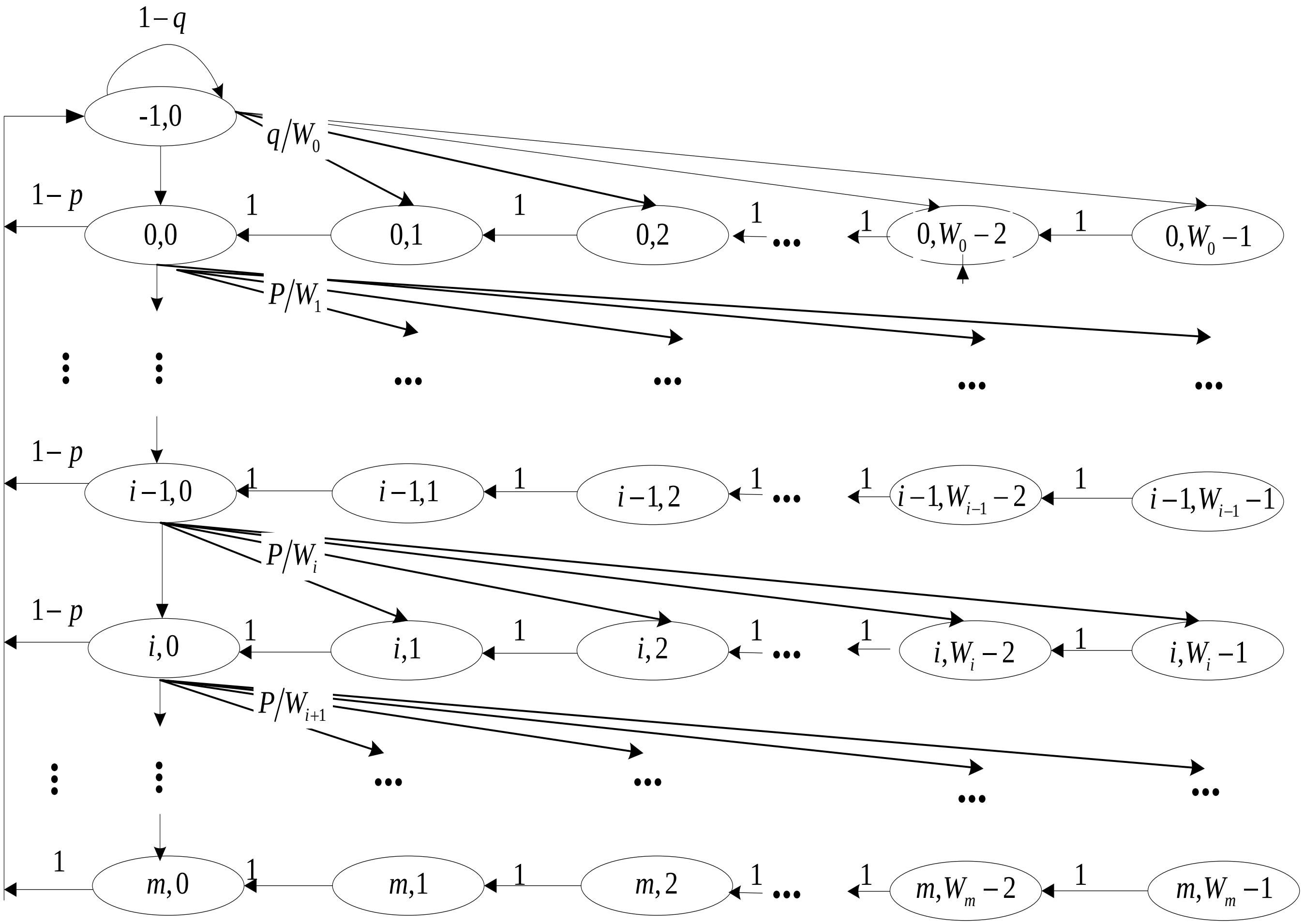


Fig. 1. Two-dimensional Markov chain model of different backoff stage

The discrete Markov chain is shown in Fig. 1.

Algorithm Modeling

We can get that

$$\begin{cases} P\{-1,0|m,0\}=1 \\ P\{-1,0|i,0\}=1-p\ ,i\in[0,m-1] \\ P\{\mathrm{i},j|i,j+1\}=1\quad ,i\in[0,m],\quad j\in[0,W_i-1] \\ P\{i,j|i-1,0\}=p/W_i\ ,i\in[1,m],\quad j\in[0,W_i-1] \\ P\{m,j|m,0\}=p/W_m,\quad j\in[0,W_m-1] \\ P\{0,j|-1,0\}=q/W_0,\quad j\in[0,W_m-1] \end{cases} \tag{6}$$

From (6) and Fig.1, we can get that

$$\begin{cases} b_{0,j}=\dfrac{W_0-j}{W_0}\cdot q\ \ ,j\in[1,W_0-1] \\ b_{i,j}=b_{i-1,0}\cdot\dfrac{W_i-j}{W_i}\cdot p_i \\ \qquad ,i\in[1,m],\ j\in[1,W_i-1] \end{cases} \tag{7}$$

From (7), the expression of $b_{i,j}$ using $b_{-1,0}$ and $b_{0,0}$ can be calculated as

$$b_{i,j}=\frac{W_i-j}{W_i}p^i b_{0,0}\ ,i\in[0,m],\ j\in[0,W_i-1] \tag{8}$$

$$b_{-1,0}=b_{0,0}/q \tag{9}$$

Algorithm Modeling

From (5)~(9), $b_{0,0}$ can be calculated as

$$b_{0,0} = \frac{1}{\frac{1}{q} + \sum_{i=0}^{m} \sum_{j=0}^{W_i - 1} \frac{W_i - j}{W_i} \cdot p^i} \qquad (11)$$

From Fig. 1, the probability of packets accessed channels is expressed as

$$p_{in} = \sum_{i=0}^{m} b_{i,0} = \frac{(1 - p) b_{0,0}}{1 - p^m} \qquad (12)$$

Let q be the packet access probability at the slot time T_σ, and it can be calculated as

$$q = 1 - e^{-\lambda T_\sigma} \qquad (14)$$

Performance Analysis

◆***Mean Delay***

Let $E[T_B]$ denotes the mean delay, and it is defined as the mean backoff time that a packet from entering the backoff stage to accessing channels, or it is discarded from send queue, so it can be calculated as

$$E[T_B] = \frac{\sum_{i=0}^{m} (1-p)^i \frac{W_i}{2} T_\sigma}{m} \tag{15}$$

◆***System throughput***

Let S denotes the system throughput, and it is defined as the whole number of packets accessed channels at the slot time. S can be expressed as

$$S = \lambda L \cdot (1-p) \sum_{i=0}^{m} b_{i,0} = \frac{\lambda L \cdot (1-p)^2 b_{0,0}}{1-p^m} \tag{16}$$

Where L represents the length of a packet.

Performance Analysis

◆ ***Fairness***

Fairness is a measure that each node in the whole network use channel resources fairly. If all nodes can used channels fairly, the fairness of an algorithm is better. According to [12], the expression of algorithm fairness proposed can be calculated as

$$F = \frac{\left(\sum_{i=1}^{N} S_i \right)^2}{N \cdot \sum_{i=1}^{N} S_i^2} \qquad (17)$$

Where N denotes the number of nodes, and S_i denotes the system throughput of the i -th node.

Simulation Analysis

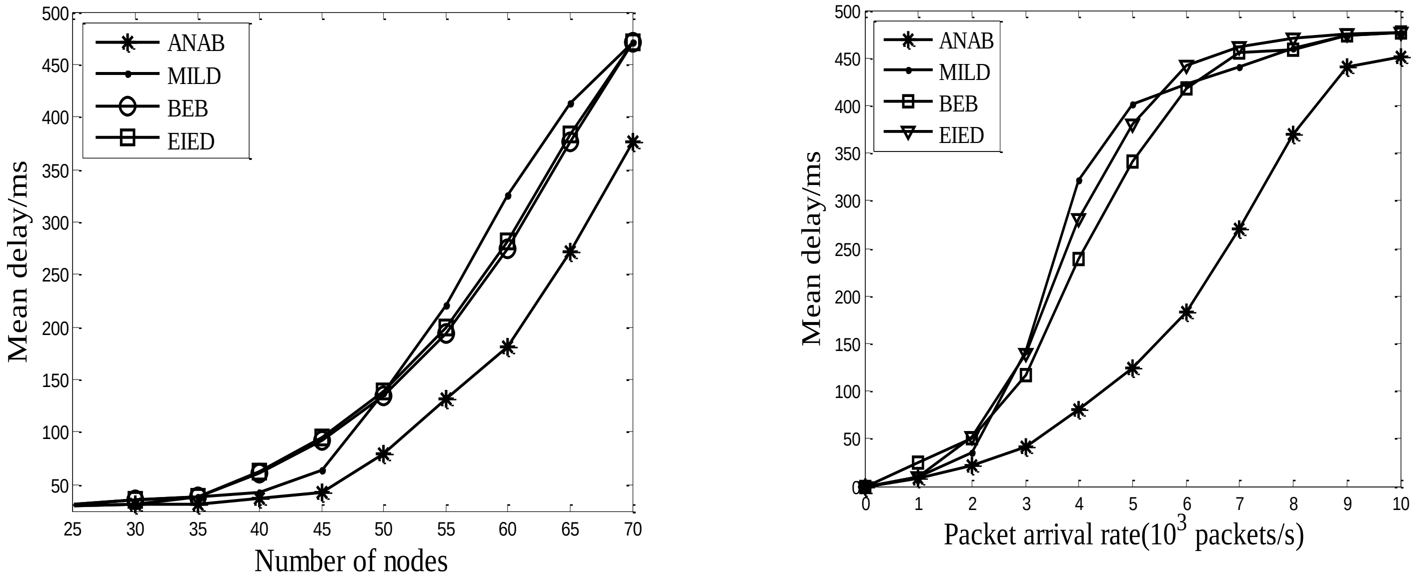
In the following, we simulate the ANAB in NS2. The simulation scenario is set as 300×300×10 km^3. All nodes are uniformly distributed in the three-dimensional space, and reside in a single-cell network. Each node can randomly choose destination nodes to communicate. The specific simulation parameters of ANAB are offered in Table I.

Table I Simulation parameters

Parameters	**Values**
Number of channels	5
Channel transmission rate	2e6bps
Single hop communication distance	250 km
Burst duty cycle	0.125
Node moving speed	1~100 m/s
Packet length	8192 bit
Slot time	50us
MAC protocol adopted	802.11b
Maxium backoff times	10

Simulation Analysis

In the same network environment, we simulate the ANAB, EIED, MILD and BEB algorithms respectively, in order for the comparison of their performances.

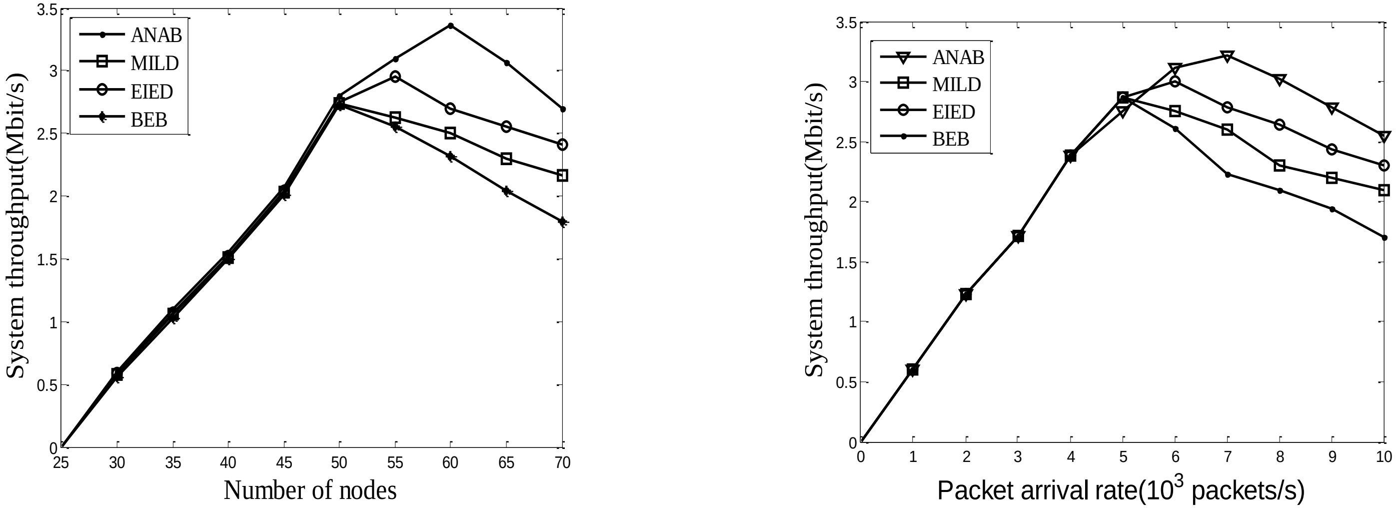


(a) Effect of nodes on mean delay (b) Effect of loads on mean delay

Fig.2. Comparison of mean delay between different algorithms

Simulation Analysis

In the same network environment, we simulate the ANAB, EIED, MILD and BEB algorithms respectively, in order for the comparison of their performances.



(a)Effect of nodes on system throughput (b)Effect of loads on system throughput

Fig.3. Comparison of system throughput between different algorithms

Simulation Analysis

In the same network environment, we simulate the ANAB, EIED, MILD and BEB algorithms respectively, in order for the comparison of their performances.

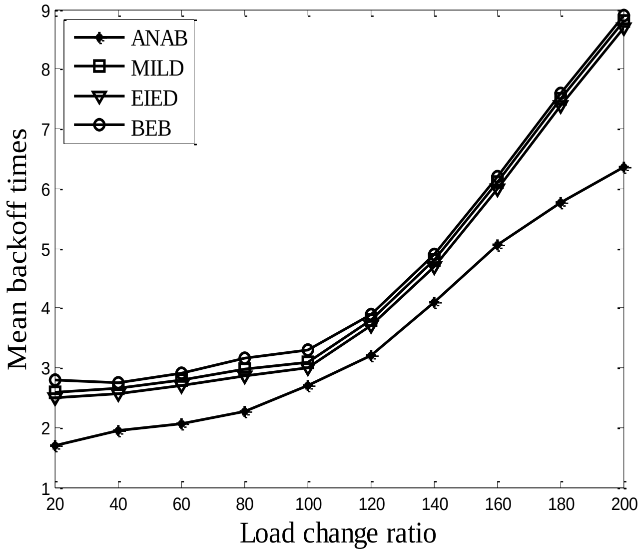


Fig.4. Effect of loads changed on different algorithms

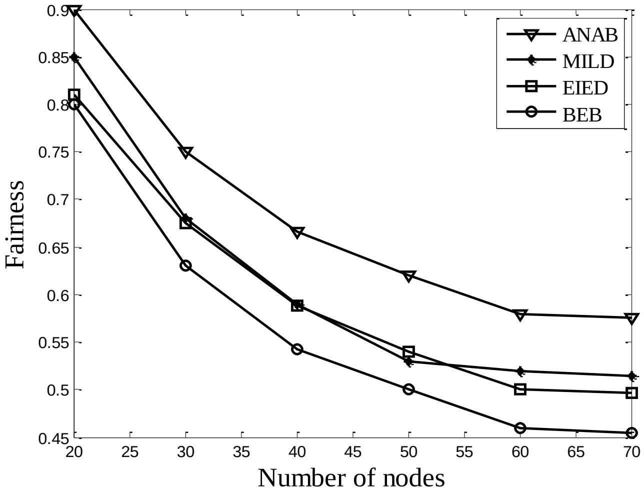


Fig.5. Comparison of fairness between different algorithms

Simulation Analysis

Firstly, the effects of nodes and packet arrival rate on different algorithm is simulated in Fig. 2. As depicted in Fig. 2 (a), the mean delay of ANAB is lowest than other algorithms with changes of loads. Fig. 2(b) shows that the mean delay of different algorithm increases quickly with change of loads, but the mean delay of ANAB rises slowly. As shown in Fig. 2, we can get that ANB can maintain a lower mean delay under heavy loads. In the following, the effects of nodes and packet arrival rate on different algorithms is shown is Fig. 3. Fig. 3 (a) shows that the system throughput for different algorithm has smaller differences when the number of nodes is less than 50, however, with increase of number of nodes, ANAB has the largest system throughput. Fig. 3 (b) shows that ANAB has a larger system throughput when loads increase larger than 7000 packets/s. As depicted in Fig. (3), ANAB has a perfect system throughput under heavy loads. The effect of loads changed on different algorithms is shown in Fig.4. Fig.4 shows that the ANAB algorithm has a better performance because of adaptive optimal connection window adjust mechanism. The Fig. 5 shows the comparison of fairness between different algorithms. As is depicted in Fig. 5, the fairness of different algorithms all decline with change of nodes, yet the fairness of ANAB has the best performance.

Based on the above simulation results, some conclusions can be draw as follows:

a) All backoff algorithms have the approximately same performance under light loads.
b) The performance of ANB algorithm is obviously better than other algorithms when load increases suddenly.
c) The fairness of ANAB algorithm is better than other algorithms.

CONCLUSIONS

In order to enhance the reliability, invulnerability and scalability, and effectively enhance the tactical collaboration ability for UAV cluster, extend the application scope of multiple UAV system, and reduce the information collision probability on channels under heavy loads, an adaptive backoff algorithm based on active nodes is proposed, which can dynamically choose the optimal connection window according to loads and effectively avoid the congestion and connection brought by a large number of packets access channels. The two-dimensional Markov chain model is established and the transition probabilities of all states under different loads are solved. The mathematical expressions of system throughput and mean delay are also deduced. The simulation results show that the algorithm has the best performance than other algorithms and can keep a stable network performance stable. Moreover, this algorithm has some reference values for the research of MAC protocols for FANETs.

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