End-to-End Throughput Optimization in Multi-hop Wireless Ad Hoc Networks

Lianghua Wu， Yuzhuo Fu，Liang Dong

***Abstract*—In this paper a simple yet efficient algorithm called Active Relinquish Scheme (ARS) is proposed to enhance the end-to-end throughput of multi-hop ad hoc networks. The principle of our scheme is to equalize the throughput of each node through a multi-hop flow thus improve the fairness of the network. The simulation results of OPNET show that our scheme works well in different kinds of topology no matter the scale of the network is small or large.**

***Index Terms*—throughput, multi-hop, ad hoc, fairness, BEB**

I. Introduction

A wireless ad hoc network consists of a collection of wireless nodes without a fixed infrastructure. Each network node serves as a router that forwards packets for other nodes. Each flow from the source to the destination traverses multiple hops of wireless links. Although IEEE 802.11 protocol is widely used in the wireless ad hoc networks, studies show that the end-to-end throughput of the network is limited because of the unfairness problem rooted in the binary exponential backoff (BEB) procedure of 802.11[5]. Previous studies are proposed to improve the fairness in multi-hop ad hoc network. However, they attempts to break each multi-hop end-to-end flow into multiple single-hop flows and they do not take into account multi-hop network whose scale is large. In many applications for ad hoc network, such as UAV (Unmanned Aerial Vehicles) [7] and VANET (Vehicular Mobile Ad hoc Networks) [9], the number of nodes varies from 50 to 100 and the number of hops differs from 3 to 10. Aiming at such network, we propose a simple yet efficient scheme to enhance the end-to-end throughput of multi-hop ad hoc network. The principle of our scheme is to equalize the throughput of each node through a multi-hop flow thus improve the fairness of the network. The simulation results of OPNET show that our scheme works well in different kinds of topology no matter the scale of the network is small or large.

The remainder of this paper is organized as follows. We analyze the unfairness problem in 802.11 protocol in section II. Next, we propose our fairness strategy to improve the end-to-end throughput of multi-hop network in III. The simulation results are shown in IV and the conclusion is drawn in V.

II. Unfairness Problem in 802.11 Protocol

A. *Basic Ideas of Binary Exponential Backoff (BEB)*

IEEE 802.11 DCF is a contention-based MAC protocol. To reduce the collision possibility, it uses carrier sense functions and binary exponential backoff (BEB) mechanism. In the BEB mechanism, each node selects a random backoff timer uniformly distributed in (0, CW-1), where CW is the current contention window (CW) size. When the transmission is successful, CW is reset to the initial value CW_{min}. When there are collisions during the transmission or when the transmission fails, the node retransmits the packet and doubles the value of CW until it reaches the maximum value CW_{max}. Then the CW ceases to grow and remains at CW_{max}. Retries for failed transmission attempts shall continue until the number of the attempts is equal to certain limit. When the limit is reached, retry attempts shall cease, and the packet shall be discarded. At this time, CW is also reset to the initial value CW_{min}.

B. *Unfairness Problem in BEB*

In a wireless network where contention of nodes is serious, nodes with a successful transmission set their contention window to minimum and are more competitive during next contention. Nodes that fail in transmission double their contention window and are impaired in their ability to access the medium. Therefore, under the procedure of BEB, successful nodes are more likely to succeed and unsuccessful nodes are more likely to fail, which causes problems of unfairness in a wireless network.[4]-[6]

C. *Validation through Simulation*

To validate the unfairness problem in wireless network, we setup a four-node scenario using OPNET as depicted in Fig.1. In this scenario, node 1 send packets to node 2 and meanwhile node 3 send packets to node 4. The smaller circle stands for transmission range and the bigger one stands for interference range. Therefore, 2 is out of the interference range of 4, which means 4 can always successfully receive packets from 3. However, 3 is inside the interference range of 2, which means packets sent by 3 will keep 2 from communicating with 1 successfully. When both 1 and 3 are heavily loaded, 1 will continue to double its CW and 3 will always keep its CW as minimum. Consequently, 3 is much more competitive than 1 and 4 will have much more throughput than 2.

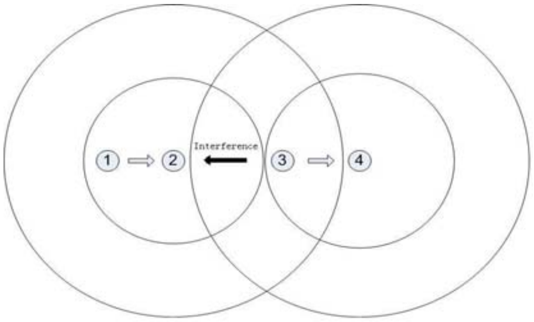

Fig. 1 Node 1 send packets to node 2 and meanwhile node 3 send packets to node 4. The smaller circle stands for transmission range and the bigger one stands for interference range.

The key parameters used in the scenario is listed in Table.I

TABLE I
THE KEY PARAMETERS USED IN THE SCENARIO

NAME	VALUE
PHY Technology	DSSS
Date Rate	2Mbps
Transmission Range	0.6 km
Interference Range	1.35 km
CWmax	1024
CWmin	32
Retransmission Limit	7

If we define the fairness index as the difference between the throughput of 2 and that of 4, then the larger the fairness index is, the more serious the unfairness of the network is. This is shown clearly in Fig.2 that depicts the fairness index against the total payload.

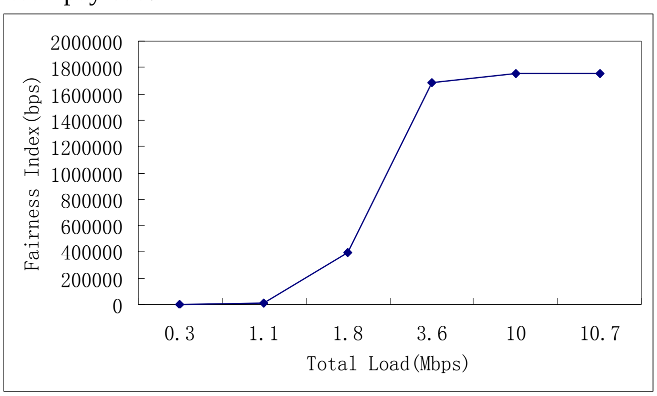

Fig. 2 The fairness index against the total payload.

D. *Situation of Multi-hop*

In wireless single hop network, BEB algorithm results in serious unfairness problem. This phenomenon also exists in a multi-hop network and reduces its end-to-end throughput. Consider a scenario in which node 1 sends packets to node 2 through node 3 and 4(Fig.3). From the analysis in the single hop scenario, we may infer that in MAC layer the throughput of 3 is smaller than that of 2 because of the unfairness of BEB. So in order to increase the end-to-end throughput of the whole system, we must increase the throughput of 3. Through solving the unfairness problem, we increase the end-to-end throughput.

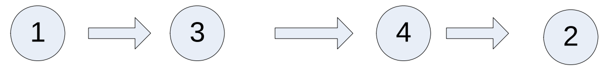

Fig. 3 A scenario in which node 1 sends packets to node 2 through node 3 and 4

E. *Related Work*

When previously proposed scheduling algorithms have been shown to perform well in providing fair shares of bandwidth among single-hop wireless flows, they do not consider multi-hop flows with an end-to-end perspective. [4] proposes a fairness backoff algorithm based on certain probability P. The node will increase its P if it is impaired by the unfairness problem. However, the five scenarios used in the paper are all based on single-hop. [6] proposes a backoff algorithm which fixes the backoff time of all nodes so that the fairness is achieved. Still it does not consider multi-hop situation. Although [1] simulates a scenario with 7-hop ad hoc network, it proposes no improvement to enhance the performance of the network. Neither does it discuss the fairness problem. [3] mentions the improvement over the total throughput of a multi-hop network, but not the end-to-end throughput. [2] proposes a new scheme to optimize end-to-end throughput significantly. Unfortunately its achievement is only limited to 2-hop network and it stops studying network with more nodes.

In this paper, we analyze the issue of increasing spatial reuse of bandwidth from an end-to-end perspective of multi-hop flows. Through analysis and simulation results, we show that our proposed algorithm is able to appropriately distribute resources among multi-hop flows, so that end-to-end throughput may be maximized in wireless ad hoc networks.

III. BASIC IDEAS OF ACTIVE RELINQUISH SCHEME

The unfairness problem results from the procedure of BEB that a node sets its CW to minimum when it transmits successfully. The node with successful transmission should actively relinquish the medium to other nodes in order to achieve fairness.

In our proposed scheme, the node who transmits successfully keep its CW to minimum for a certain time T in order to decrease the leisure time of the medium and increase the throughput of the network. However, to avoid the unfairness caused by the fact that the successful nodes access the medium for too much time, after the duration of T the node will relinquish the medium actively so that the neighboring node will have the chance to access the medium. The fairness is thus improved.

Our scheme coincide with BEB when the node fails in its transmission or when the number of its retries exceeds the retry limit. When the node fails in its transmission, we double its CW to decrease the chance of collision. If the number of the node's retries exceeds the limit, the ability of the node to access the medium is so weak that we should minimize its CW to enhance its ability.

Pseudocode: (Only one of the 3 cases will happen.)

Case 1: the transmission is successful.

```
if(ackcnt <T) //ackcnt indicates the duration a node
              //access the medium
    {
      ackcnt = ackcnt+1;
      CW = cw_min;
      // the node who transmits successfully
        keep its CW to minimum for a certain
        time T
    }
  else
    {
      ackcnt =1;
      CW=cw_max;
      // after the duration of T the node will
         relinquish the medium actively
    }
```

Case 2: the number of its retries exceeds the limit.

CW=cw_min;

Case 3: the node fails in its transmission and the number of its retries does not the limit:

CW = CW* 2;

IV. Simulation Results

A. *Simulation in Single-hop Scenario*

Our scenario to test our scheme is the same as that of BEB (depicted in Fig.1). We perform 4 simulations. In the first 3 scenarios, T is set to 100、5、2 respectively. In the 4th scenario, the backoff procedure is BEB. The key parameters are depicted in Table I. In each scenario, we compare the results of different payload. The fairness index is defined as the difference between the max throughput and min throughput of the nodes in the network.

It is clearly shown in Fig.4 that when the payload is small (lower than 3Mbps) T has little impact on the fairness index. However when the payload is heavy enough (higher than 3.6Mbps), with the increase of T the fairness index grow up and reaches the maximum when we use BEB (T is set to infinity). The graph verifies the fact that our scheme can improve fairness when the payload is heavy.

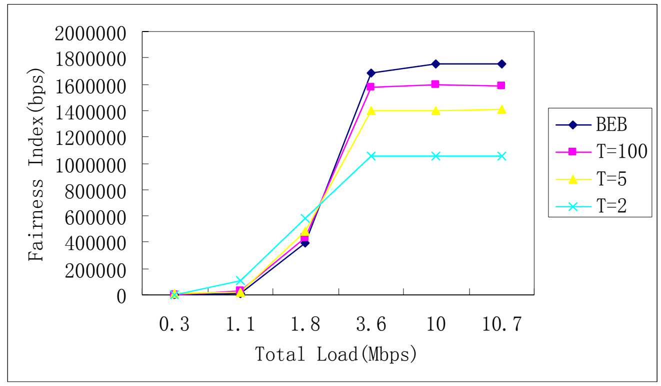

Fig.4 The fairness index against total payload in the scenario of our scheme

However, our scheme improves the fairness of the system at sacrifice of the total throughput. Fig. 5 shows that with the decrease of the T the total throughput is reduced. Later we will show that in multi-hop network our scheme will increase the end-to-end throughput.

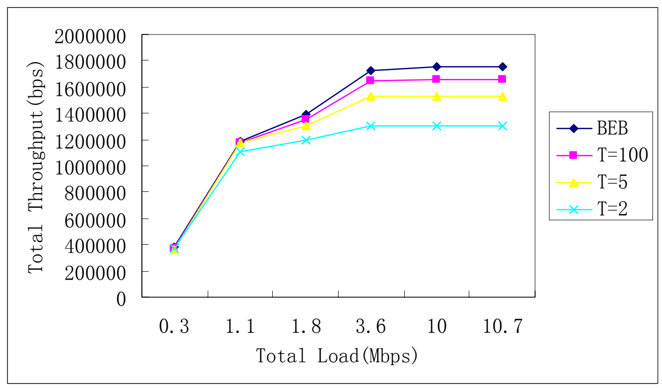

Fig.5 With the decrease of the T the total throughput is reduced.

B. *Simulation in Multi-hop Scenario*

1) *Linear Topology*

First, we setup a linear topology with 4 nodes, as depicted in Fig.7. The routing protocol is DSR. The distance between neighboring nodes is 0.5km. The MAC protocol contains our scheme in which the duration T is controllable.

We perform 6 experiments (1~6). T is set to 2, 4, 6, 8, 10, 20 respectively. If T becomes larger, the throughput of 3 is lower while the total throughput of the network (that is the sum of the throughput of 3 and 2) is higher. So there exists an optimized T which can maximize the end-to-end throughput of the network. Through our simulation result depicted in Fig.6, it is shown that when T is set to 4 the end-to-end throughput reaches its peak. We compare this value with the end-to-end throughput of BEB in the same scenario and find the former is about 10% higher than the latter, as shown in Fig.7.

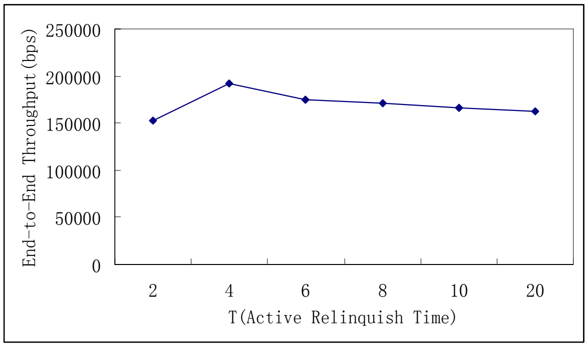

Fig.6 We carry out 6 experiments (1~6) where T(after which a node actively relinquish the medium) is set to 2, 4, 6, 8, 10, 20 respectively. When T is set to 4 the end-to-end throughput reaches its peak.

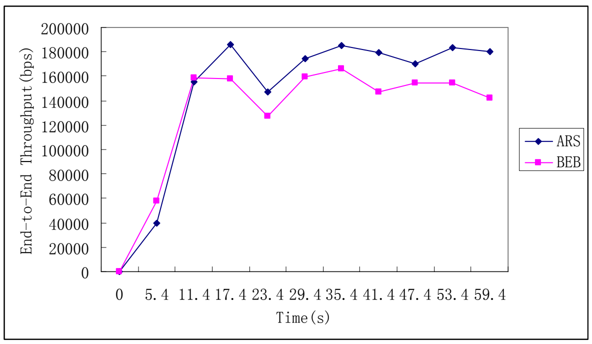

Fig.7 The end-to-end throughput of our scheme is 10% higher than than of BEB

In order to test our scheme in different scenario, we perform another 3 experiments (2~4) where the number of the nodes in the linear topology increase from 5 to 7. We find that in each experiment our scheme improve the end-to-end throughput by about 5%~10%, compared to BEB (Fig.8).

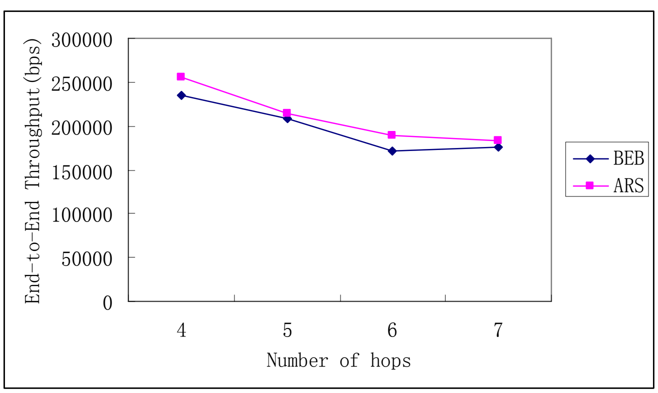

Fig.8 The number of the hops in the linear topology increase from 4 to 7 and our scheme improve the end-to-end throughput by about 5%~10%, compared to BEB

2) *Grid Topology*

This time we test our scheme in grid-topology, in which strong interference exits between flows [8]. We sum up the end-to-end throughput of 4 flows and get the total end-to-end throughput. We find that in the grid-topology of 4*4 nodes (Fig.9), our scheme improve the total end-to-end throughput by 10% (Fig.10).

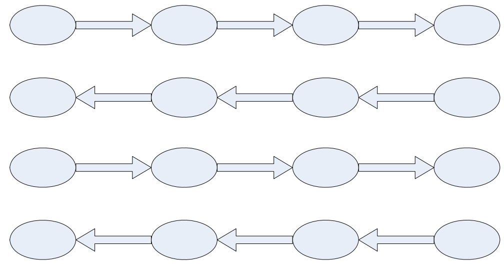

Fig. 9 16 nodes in the grid topology where 4 flows interfere with each other. All key parameters are described in Table I.

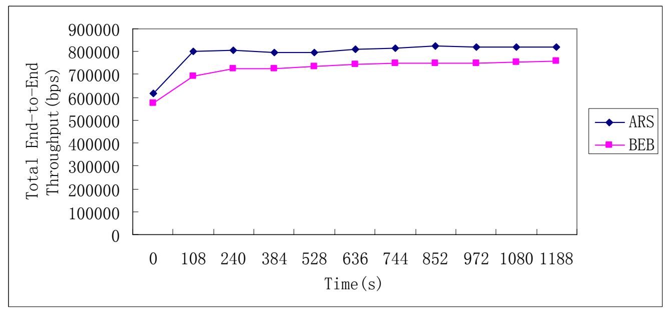

Fig. 10 Our scheme improve the total end-to-end throughput by 10%

V. Conclusion

In this paper, a simple yet efficient scheme is proposed to optimize the end-to-end throughput of multi-hop ad hoc network. The principle of our scheme is to equalize the throughput of each node through a multi-hop flow thus improves the fairness of the network. The simulation results of OPNET show that our scheme work well in different kind of topology no matter the scale of the network is small or large.

References

[1] Ping Chung Soung Chang Liew, Throughput Analysis of IEEE802.11 Multi-Hop,Ad Hoc Networks IEEE/ACM TRANSACTIONS ON NETWORKING, VOL. 15, NO. 2, APRIL 2007

[2] Hailun Xia, Zhimin Zeng, Wei Ding, Adaptive Backoff Algorithm Based on Network Congestion in Multi-hop Wireless Ad hoc Networks Eighth ACIS International Conference on Software Engineering, Artificial Intelligence, Networking, and Parallel/Distributed Computing,2007

[3] Raffaele Bruno,Claude Chaudet, Marco Conti and Enrico Gregori , A Novel Fair Medium Access Control for 802.11-based Multi-Hop Ad hoc Networks, IEEE/ACM TRANSACTIONS ON NETWORKING, VOL. 15, NO. 2, APRIL 2007

[4] C.X.Wu,Junhuan FENG and P.Z.FAN. On a new queue backoff fair algorithm for ad hoc networks. The 4th International Conference on Parallel and Distributed Computing, Applications and Technologies (PDCAT'03),2003

[5] S.Xu and T.Saadawi, Revealing the Problems with 802.11 MAC Protocol in Multi-hop Wireless Networks. Computer Networks, March 2002,Volume 38,No.4.

[6] T.Ozugur, M.Naghshineh. Optimal MAC-layer fairness in 802.11 networks. IEEE Communication Magazine,2002, pp.675~681.

[7] KE ZHANG, WEI ZHANG, JIA-ZHI ZENG, PRELIMINARY STUDY OF ROUTING AND DATE INTEGRITY IN MOBILE AD HOC UAV NETWORK IEEE. 2008

[8] Pan Li and Yuguang Fang, Saturation Throughput of IEEE 802.11 DCF in Multi-hop Ad Hoc Networks, IEEE 2008

[9] HAMID MENOUAR AND FETHI FILALI, EURECOM, A SURVEY AND QUALITATIVE ANALYSIS OF MACPROTOCOLS FOR VEHICULAR AD HOC NETWORKS, IEEE Wireless Communications October 2006