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 CWmin. 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 CWmax. Then the CW ceases to grow and remains at CWmax. 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 CWmin.

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>
<thead>
<tr>
<th>NAME</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHY Technology</td>
<td>DSSS</td>
</tr>
<tr>
<td>Date Rate</td>
<td>2Mbps</td>
</tr>
<tr>
<td>Transmission Range</td>
<td>0.6 km</td>
</tr>
<tr>
<td>Interference Range</td>
<td>1.35 km</td>
</tr>
<tr>
<td>CWmax</td>
<td>1024</td>
</tr>
<tr>
<td>CWmin</td>
<td>32</td>
</tr>
<tr>
<td>Retransmission Limit</td>
<td>7</td>
</tr>
</tbody>
</table>

Table I: The key parameters used in the scenario

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.

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.

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.

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.

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.

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).

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).

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

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