Ad hoc Networks Multi-Channel MAC Protocol Design and Channel Width Adaptation Technology

Fucai Wang, Haitao Zhao, An Song, Chunguang Shi
College of Electronic Science and Engineer
National University of Defense Technology
ChangSha, China
cswfc2005@126.com, {haitaozhao, ansong, c.g.shi}@nudt.edu.cn

Abstract— In wireless Ad hoc networks, using multi-channel technique on MAC layer to increase the network capacity is a promising technology. By extending the RTS/CTS mechanism of IEEE 802.11 standard, we propose a busy tone-based multi-channel MAC protocol, which can significantly improve the network throughput by using busy tone to distribute the multiple channels and overcome the multi-channel hidden terminal problem. On the basis of the protocol, this paper further takes the advantage of channel width adaptation technique, with which one channel can be effectively divided into several sub-channels so that the collision probability can be decreased and the network throughput can be further improved. NS2 simulation results show that, firstly, the proposed MAC protocol can significantly improve the throughput via using multiple channels and the improvement on throughput is in direct ratio to the number of channels; Secondly, without increasing the total bandwidth, dividing a channel into several sub-channels via the technique of channel width adaptation can also improve the network performance.

Keywords-Multi-Channel; Channel Width Adaptation; Hidden Terminal; Throughput;

I. INTRODUCTION

By exploiting multiple channels, we can achieve a higher network throughput than using one channel, because multiple transmissions can take place without interfering. However, the MAC protocol of IEEE 802.11 Distributed Coordinate Function (DCF) is designed for sharing a single channel between hosts. Designing a MAC protocol that exploits multiple channels is not an easy problem, due to the fact that each of current IEEE 802.11 devices is equipped with one half-duplex transceiver. The transceiver is capable of switching channels dynamically, but it can only transmit or listen on one channel at a time. Thus, when a host is listening on a particular channel, it cannot hear communication taking place on a different channel. Due to this, a new type of hidden terminal problem occurs in this multi-channel environment, which we refer to as multi-channel hidden terminal problem. Besides, deafness problem will arise in multi-channel scenario to impair the network performance. We will explain these two problems in more detail in Section II. So a single-channel MAC protocol (such as IEEE 802.11 DCF) does not work well in a multi-channel environment where nodes may dynamically switch channels.

In [1], Wu et al. proposed a so called dynamic channel allocation (DCA) scheme which one transceiver is fixed in a dedicated control channel for contention and the other transceiver is tunable among other channels for data transmission. When a node receives a request-to-send (RTS) control frame from sender in the control channel, it will scan all channels except the control channel and choose the first detected idle channel to inform sender to transmit data. Nevertheless, the requirement of dual transceivers increases both the implementation complexity and implementation cost. To use multiple channels without increasing implementation cost, Chen[2] had proposed a multi-channel access protocol by using single transceiver. But it can only be applied in the one-hop BSS of WLAN environment and needs an AP to coordinate the multi-channel transmission. In addition, all existing proposals for multi-channel MAC protocol still lack of consideration on multi-channel width adaptation technique. The channel width adaptation technique enables the end-user to separate one channel into several sub-channels or aggregate multiple sub-channels into a channel for better network performance. Channel width adaptation technique, can be used to avoid the frequency interference by adjusting the channel bandwidth when strong noise occurred in a region of the spectrum. It can also be used to divide spectrum into multiple narrow bandwidth channels in order to solve the fairness between different multi-rate network links.

In this paper, we propose a busy tone multi-channel MAC protocol which takes into consideration of channel width adaptation technique. Each mobile node equips a data interface and a busy tone interface. Busy tone interfaces are much simpler to implement than packet interfaces. The proposed protocol uses busy tone channel to solve the multi-channel hidden terminal and deafness problem by sending broadcast packets (say as BP) which can reduce the probability of packet collisions.

II. MULTI-CHANNEL MAC PROTOCOL PROBLEMS AND SOLUTIONS

A. Multi-Channel Hidden Terminal Problem

The multi-channel hidden terminal problem [3] occurs due to the fact that nodes may listen to different channels, which makes it difficult to use virtual carrier sensing to avoid the hidden terminal problem. An example to illustrate this problem is shown in Figure 1.

If sender A wants to send data to the destination node B, so A sends a RTS on the control channel 1. Destination node B
receives the RTS control packet and Node B also sends back a control packet CTS to inform A on control channel 1. By using RTS-CTS handshake, they intended chose channel 2 as data channel for the next communication, there is no conflict. However, when Node B sends CTS to A, the node C is busy on the communication on channel 3, so node C can not receive the broadcast pack CTS from node B. The node C and D will not know the channel A and B exchanging data on data channel 2. But when C communicates with D, they select Channel 2 as the data channel for communication. At the same time as they are in the same channel communication, which can lead to conflicts at the Node B.

One solution of the hidden terminal problem is to implement a “channel memory” that helps propagate the channel history (as in DCA [5]) is that the issue of busy tones [4]. The advantage of using busy tones over using a separate control channel is that the busy tone channel can be used to send or receive data packets, the other as the interface which can receive broadcast packets (say as BP). Another solution of the deafness problem is to let node B send a broadcast pack which contains the channel it uses and the broadcast packet (BP) can be received by every node in its transmitting range.

B. Deafness Problem

Deafness problem [6] arises because an intended receiver may currently be in transmitting mode, transmitting in the channel of a third node. An example to illustrate this problem is shown in Figure 2.

In Figure 2, where node A tries to communicate with node B, which is communicating with node C on a different channel.
which means successful transmission of DATA packet. Node A will close its busy tone, while the data interface switches to their data channel, and send a broadcast package to inform the waiting nodes that the data channel now is idle. If node A does not receive the busy signal that served as ACK, node A will retransmit DATA packet after a back-off process.

2) Node C to node A: In figure 3, when the data transmission between node A and B is complete, sender A and receiver B will switch to their own data channel. After an appropriate frame interval, if their channels (both busy tone channel and data channel) are free, they will send a broadcast pack which contains the information about the communication complete on their data channel. At this time, node C which is waiting on the data channel of node A, in order to communicate with node A will receive the broadcast packet (BP). The node C waiting in the back-off state will close its current back-off counter and remove all of the associated back-off and contention window state. After a DIFS, node C begins to establish communication with A. After a SIFS time, C start to send RTS to A and it will receive from C's RTS. A will also open its busy tone. If the node C gets this busy tone from A, node C will send a DATA packet to node A after SIFS. The node A will receive the DATA packet from C and close its busy tone for a proper time. After a SIFS time, node A will open this busy tone signal. Once node C senses the busy tone, it knows a successful DATA packet transmission is complete, and repeats the transfer process in 1). In this way, the use of multi-channel broadcast packet (BP) can solve the deafness problem. Conversely, if A perceives its data channel busy, the broadcast packet (BP) will be postponed until the data channel becomes idle after back-off.

3) Node D to node B: If node D wants to communicate with node B, node D will stay on the data channel of node B until D receives the broadcast which sends from node B. The process is the same as node C to node A in 2).

4) New data from node A to node B: If there are new data packets from node A to node B, after the first process of communication between node A and node B, node A must follow the IEEE802.11 back-off and contention mechanism. This is because node D also wants to establish communication with node B. In order to let every node access to the channel equally, every node must compete to use the data channel. Or else, node D will be starved. If node A’s back-off timer expires earlier than D’s, node A transmits to node B after switching to the data channel of node B.

B. Channel Width Adaptation in Data Channel Selection

For all of the nodes, a good data channel selection for improving the performance of the entire communication network plays a key role. In the more realistic case where traffic is varies dynamically, this protocol proposes a periodic quiescent channel selection mechanism using channel load as a criterion. So the channel width adaptation technique is very important for dividing the bandwidth for every sub-channel. Each node measures the load on all channels by snooping during its idle time. First, the channel which loads the least traffic is chosen as the new quiescent channel for the next transfer. Secondly, by using the channel width adaptation technique, the sender-receiver pair should get more bandwidth if their traffic more than others.

IV. SIMULATION RESULTS

A. Simulation Setup

We evaluated busy tone multi-channel MAC protocol using the ns-2 simulator. In the simulation 120 nodes comprise a grid topology (12 row × 10 column), in which the distance between two adjacent nodes is 10m. And because the transmission range is 250m, these settings assure that every two nodes will interfere with each other if they are on the same channel in the network. The 120 nodes can form 60 sender-receiver pairs which need 60 traffic flows. In each flow, a source-destination pair is randomly selected and the source node or destination node without overlap. Other simulation parameters used in our experiments are summarized in table 1. In the simulation, we measured performance by varying the number of channels and bandwidth.

<table>
<thead>
<tr>
<th>TABLE I</th>
<th>SIMULATION SETTINGS</th>
</tr>
</thead>
<tbody>
<tr>
<td>CWmin</td>
<td>15</td>
</tr>
<tr>
<td>CWmax</td>
<td>1023</td>
</tr>
<tr>
<td>SIFS</td>
<td>10 μs</td>
</tr>
<tr>
<td>DIFS</td>
<td>50 μs</td>
</tr>
<tr>
<td>Slot time</td>
<td>20 μs</td>
</tr>
<tr>
<td>No. of channels</td>
<td>C=2~6</td>
</tr>
<tr>
<td>Transmission pairs</td>
<td>N=60</td>
</tr>
<tr>
<td>Transmission range</td>
<td>250 m</td>
</tr>
</tbody>
</table>

B. Results and Analysis

First, we verify that the proposed MAC protocol can exploit well the advantage of multi-channel networks. And for each channel has the same bandwidth, increasing the number of channels will increase the network performance. These results can be easily understood, since under this case using multi-channel means using extra bandwidth resources. We set the bandwidth of each channel as 5.5Mbps. Simulation results are shown in Figure 4, where we change the number of channels from 1 to 6.

From the results in figure 4, we can obtain two conclusions:

1) While using multiple channels, the network throughput is obviously improved, which prove that multi-channel MAC protocol performs significantly better than single channel MAC protocol. This is because that multiple senders can send packets simultaneously on different channel to avoid interference under the multi-channel scenario.

2) More channels will bring more throughput improvement and the improvement is in direct ratio to the number of channels. This can be easily understood, since with the fixed width of each channel, so using more channels mean using more bandwidth resources.

Secondly, we prove that by using channel width adaptation technique to divide a channel into several sub-channels, the network performance can also be significantly improved without increasing the total bandwidth. Simulation results are shown in Figure 5.
From the results in figure 5, we can also obtain two conclusions:

1) Without increasing the total bandwidth, dividing a channel into several sub-channels via the technique of channel width adaptation can also improve the network performance. This is because that dividing a channel into several sub-channels can decrease the collision probability, see Fig. 5(b).

2) The more sub-channels a channel is divided into does not always bring the better performance. From Fig. 5 (a) we can see that the throughput in the 6-channel case is not obviously bigger that that in the 5-channel case, which implies that dividing channel is not always significantly improve the network throughput. And considering that there may exist control overhead to divide a channel, the channel bandwidth adaptation technique needs to carefully used to take into account the practical network situation.

V. CONCLUSION

We have proposed a new multi-channel MAC protocol based on the busy tone technique. We solve the channel assignment and medium access problems in an integrated manner in one protocol. Moreover, the proposed protocol supports channel bandwidth adaptation technique which can further improve the network performance. It is validated that the proposed MAC protocol can significantly improve the throughput via using multiple channels and even only dividing a channel into several sub-channels without increasing the total bandwidth can also improve the network performance.

REFERENCES


