Multichannel MAC Protocol for Ad-Hoc Wireless Networks

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Abstract

In the regular Ad-Hoc or Infrastructures wireless LANs a single channel shared among nodes in the networks. Once the number of nodes in the system increases it causes the performance of the overall system to decrease. In this paper proposes a medium access control (MAC) protocol for ad hoc wireless networks (MMAC) that uses multiple channels. We can improve throughput with multiple channels because multiple transmissions can take place simultaneously without interfering each other. This proposed protocol uses N channel where N is independent of the number of nodes in the network. We modify IEEE 802.11 DCF protocol to enable hosts to utilize multiple channels by switching channels dynamically. Our scheme requires only one transceiver for each host. The main idea is to negotiate and select channels during the ATIM windows as in power saving mechanism (PSM). And switch to reserved channel to send data in DATA windows.

Key-Words: Multichannel, MAC, PSM

1. Introduction

A mobile ad-hoc network (MANET) is a collection of wireless mobile nodes dynamically forming a temporary network without the use of any existing network infrastructure or centralized administration. MANETs have their own advantages such as high robustness and easy to set up despite resource constraints like limited bandwidth and power. A mobile node in MANETs can transmit data packets to other mobile nodes that are within its radio range. In order to transmit packets to a mobile node outside the range, the network uses a multihop store-and-forward routing.

A Medium Access Control (MAC) protocols plays an important role in the performance of the MANETs. A MAC protocol defines how each mobile unit can share the limited wireless bandwidth resource in an efficient manner. Recent researches [3][4][5][6][11] in this area have focused on designing MAC protocols with optimized performance metrics including throughput and delay, fairness, stability, support for multimedia and energy efficiency.

In a mobile ad-hoc network, node mobility, vulnerability of the radio channels, and the lack of any central coordination give rise to the following problems, which need to be taken into consideration while designing a MAC protocol.

• Hidden node problem [10]: A hidden node is a node that is out of range of a transmitter node (node A in Fig. 1), but in the range of a receiver node (node B in Fig. 1). A hidden node does not hear the data sent from a transmitter to a receiver (node C is hidden from node A). When node C transmits to node D, the transmission collides with that from node A to node B. Obviously, the hidden nodes lead to higher collision probability.

• Exposed node problem [10]: An exposed node is a node that is out of range of the receiver (node C in Fig. 2), but in the range of the corresponding transmitter (node B Fig. 2). Node C defers transmission to node D upon detecting data from node B, even through a transmission from node C does not interfere with the reception at node A. The link utilization may be significantly impaired due to the exposed node problem.

Figure 1. Illustration of the hidden node problem.

Figure 2. Illustration of the exposed node problem. (C cannot send data, even though it does not create any interference)
In this paper, we propose a MAC protocol which enables hosts to dynamically negotiate channels so that multiple communications can take place in the same region simultaneously, each in different channel. The main idea is to divide time into fixed-time intervals using beacons, and have a small window at the start of each interval to indicate the state of the channel. A similar approach is used in IEEE 802.11 power saving mechanism (PSM), which is explained in Section 3.

The rest of this paper is as follows. Section 2 describes the issues related to designing MAC protocols for MANET. Section 3 provides some background information. Our newly proposed protocol is presented in Section 4. Section 5 demonstrates the advantage of our protocol through analysis. Conclusions are in Section 6.

2. Related Work

There are many related papers that study the benefit of using multiple channels. Dual Busy Tone Multiple Access (DBTMA) [3] proposes to solve the problem by the transmission of tones on separate channels to indicate the state of the channel. A single channel is split into two sub-channels: a data channel for data frames and a control channel for control frames. In addition, two busy tones: transmit busy tone (BTt) and receive busy tone (BTr), are assigned by separate single frequencies in the control channel. A node that is transmitting/receiving data turns on a tone (BTt) and receive busy tone (BTr), are assigned by separate single frequencies in the control channel.

Multiple Access with Collision Avoidance Common-Transmitter-Based protocol (MACA-CT) and Multiple Access with Collision Avoidance Receiver-Transmitter-Based protocol (MACA-RT) [4] are two DS-SS approaches. In these approaches, a set of orthogonal codes is predefined and knows to every node. In a MACA-CT, a control and data frames are sent using common code and transmitter code, respectively. The code to be used for data frame transmission is contained in the RTS. Upon receiving RTS the receiver tunes itself to the transmitter code. Other mobile nodes that want to initiate transmission use the common code and, therefore, do not interfere with the ongoing transmissions. Collision can occur only in the common control channel and the vulnerable period is the double of the duration of a control frame.

With comparatively high persistence probability, throughput of MACA-CT can be more than six times that in the conventional CSMA approach. The system requires n + 1 codes: n codes for the n mobile nodes and one for the common control channel.

In the MACA-RT approach, each mobile node has two codes: transmitting code and receiving code. First, RTS is sent using the destination’s receiving code. Next, CTS is sent back using the transmitting code of the destination. Finally, the data transmission is conducted using the transmitting code of the originator. This approach totally eliminates collision because each mobile uses different codes to send control and data frames. This approach requires 2 x n codes two codes for each mobile. In addition, every mobile has to recognize codes of each other so as to initiate transmission using a receiver’s code. When the number of mobiles increases, available codes might not be enough for every mobile and dynamic code allocation should be used in this situation.

Multichannel CSMA with Signal Power Based Channel Selection protocol (MC-SP) [5], [6] divides the available bandwidth into N channels, the protocol assumes that each host can listen to all N channels concurrently where the transmitting station selects an appropriate channel for packet transmission. The selection criterion is based on the interference power measurements on the channels. This implies that when a node has packet to transmit, it senses the carrier on all channels, and selects the channel with the lowest sensed power. However this does not guarantee that the same channel has the least interference at the destination, it is likely to be the best channel at that location.

In the Dynamic Channel Assignment (DCA) [11] the system maintains one dedicated channel for control messages, and other channels for data. Each host has two transceivers, so that it can listen on the control channel and data channel simultaneously. RTS/CTS packets are exchanged on the control channel, and data packets are transmitted on the data channel. In RTS packet, the sender includes suggested data channel information according to the channel condition around itself. The receiver, on receiving RTS, decides which channel to communicate and includes the selected channel information in CTS packet. Then DATA and ACK packets are exchanged on the agreed data channel. This protocol does not need synchronization and can utilize multiple channels with little control message overhead. But it does not perform well in an environment where all channels have the same bandwidth.

3. Preliminaries

In this section, we present some background information on power saving mechanism that we will be adopted some idea for our designed protocol.
IEEE 802.11 Power Saving Mechanism a node can save energy by going into doze mode. In doze mode, a node consumes much less energy compared to normal mode, but cannot send or receive packets. So it is desirable for a node to enter the doze mode only when there is no need for exchanging data. In IEEE 802.11 power saving mechanism (PSM), this power management is done based on Ad hoc Traffic Indication Messages (ATIM). Time is divided into beacon intervals, periodic beacon transmissions. So every node will start and finish each beacon interval almost at the same time.

At the start of each beacon interval, there exists an interval called ATIM window, where every node should be in awake state and be able to exchange messages. If a node A has buffered packets destined for B, it sends an ATIM packet to B during this interval. If B receives this message, it will reply back by sending ATIM-ACK to A, and both A and B will stay awake for that entire beacon interval. If a node has not sent or received any ATIM packets during the ATIM window, it enter doze mode and stay until the next beacon interval. This Process is illustrated in Figure 3.

Figure 3. Operation of IEEE 802.11 PSM. Nodes are synchronized by beacons. During the ATIM window, A sends an ATIM packet to B, notifying that it has packets for B. So A and B stays awake for the whole beacon interval. Since C does not send or receive any ATIM packets, it enter doze mode after the ATIM window until the end of beacon interval.

4. Protocol Description
In this section, we present our proposed scheme. Before describing the protocol in detail, we first summarize our assumptions.
- N channel are available for use, and all channel have the same bandwidth. None of the channels is overlapped, so the packets transmitted on different channels do not interfere with each other. Hosts have earlier knowledge on how many channels are available.
- Each host is equipped with a single half-duplex transceiver. So a host can either transmit or listen at a time, but cannot perform both functions simultaneously. Also, a host can listen or transmit on only one channel at a time. So when listening to one channel, it cannot sense the carrier on other channels. Unlike our scheme, many other Multichannel MAC protocols require each host to have multiple transceivers.
  - The transceiver is capable of switching its channel dynamically.
  - Each host periodically sends out beacons to synchronize time in a distributed manner as in IEEE 802.11 power saving mechanism. When transmitting a beacon, the host includes a timestamp of its local timer. If a node receives a beacon from another node, it cancels its beacon and adjusts its timer according to the timestamp included in the beacon.
  - Each host maintains a reserved channel list that indicates which channel is preferable to use for each node.

This detail of the Multichannel MAC protocol is presented below as a variation of the IEEE 802.11 power saving mechanism channel access protocol.

In each Beacon interval, the time period it divided into ATIM window and Data window. In the ATIM window, every node must not only stay in awake state, but also must listen to control channel. The control channel is one of multiple channels available, which is selected for exchanging control packets. The nodes that have packets to transmit negotiate channels with the destination nodes during this ATIM window by exchanging control packets. Other nodes in the vicinity of the destination node, upon receiving the control packet update reserved the channel list. If other nodes have packets to send to nodes that completely reserved channel, it will not need to exchange control packets in ATIM window, it switch to this reserved channel and waits for exchange control packets in contention period on the particular data channel.

We describe the main idea of Multichannel MAC in Figure 4. Every node switches to control channel in ATIM windows for exchange control packet and reserve data channel. At the end of ATIM window, each node that received the data channel information will switch to reserved channel for send data packet.

Figure 4. Main idea of channel negotiation and data exchange in beacon interval.
The process of Multichannel MAC is illustrated in Figure 5. Suppose the scenario is as follows:

- Node A has packets for node B and node C has packets for node B.
- Each node periodically sends out beacons to synchronize time in a distributed manner as in IEEE 802.11 power saving mechanism.
- When node A is in ATIM window and has packets to transmit to node B, it sends a RTS packet to node B.
- When node B receives a RTS, it finds free data channel in reserved channel list and sends a CTS packet that contains free channel number to node A and update the reserved channel list.
- When node A receives the CTS packet, it updates the reserved channel list and waits for sending data packets in Data window.
- Other node (node C) in the vicinity of the destination node, upon receiving the control packet, updates reserved the channel list. If node C has packets to send to node B that completely reserved channel, it waits to content in Data window after node A and B completed the data exchange.

5. Performance Analysis

To analyze the performance of the proposed MAC protocol, we divide this analysis into 2 parts. We first analyze the probability that at least one station successfully transmits a control packet for the reserved channel in a given ATIM window, and then we calculate channel throughput of a single transmission area with a number of nodes using multiple channel.

5.1 Probability of success in reserved channel.

Suppose there are n stations in the network. Denote the ATIM window is divided in slot \([0,W]\), which consists of \(W+1\) slots numbered 0 through \(W\). Let \(p(n,W)\) be the probability that at least one of the \(n\) stations succeeds in control packet transmission during an ATIM window as show in [12]:

\[
p(n,W) = p_{\text{success slot } [1,W]} + p_{\text{success slot } [0]} + p_{\text{collided slot } [0]}
\]

(1)

Where \(p_{\text{success slot } [1,W]}\) is the probability that no control transmission in slot 0, but there is a successful transmission in slot \([0,W]\), \(p_{\text{success slot } [0]}\) is the probability that successful control transmission in slot 0 and \(p_{\text{collided slot } [0]}\) is the probability that unsuccessful control transmissions in slot 0, but at least one successful control transmission in slot 1 through slot \(W\). Substituting this and the above equations \(p(n,W)\) can be calculated as follows.

\[
p(n,W) = \left(\frac{W}{W+1}\right)^n p(n,W-1) + n \left(\frac{1}{W+1}\right) \left(\frac{W}{W+1}\right)^{n-1} \]

\[
+ \sum_{i=2}^{\infty} \sum_{j=0}^{\infty} \binom{n}{i-j} \left(\frac{1}{W+1}\right)^{i-j} \left(\frac{b-1}{W+1}\right)^{i-j} \left(\frac{W-b+1}{W+1}\right)^{p(n-i-j,W-b)}
\]

(2)

The boundary condition for \(p(n,W)\) is \(p(0,W) = p(n,0) = 0\) and \(b\) is the length of each control packet in form of slots.

From slot time = 20 µs and RTS = 160 bits the value of \(b\) (i.e., the length of control frames in terms of slots) is calculated to be 14 for the DSSS system. For \(b = 14\) the values of \(p(n,W)\), calculated for Eqs. 2, are plotted as curves in Fig. 6 for different value of
W. The figure shows that given $W = 30$, $p(n,W)$ is lower than 50% when $n > 80$. That means a size of ATIM window has an effect on reserving channel.

![Figure 5: The probability that at least one of n stations succeeds in control transmission during an ATIM window.](image)

5.2 Overall System Throughput.

Now we analyze channel throughput of our proposed Multichannel MAC protocol. We have the following assumptions.

There are $N$ identical nodes in the single transmission area. Each of them generates arrival data packets. The total traffic load is $\lambda$ arrivals each unit time $\delta$. Hence, the arrival rate of data packets on each node is $\lambda_i = \lambda / N$.

To evaluate the performance of Multichannel MAC protocol, we mainly used IEEE 802.11 as a reference for comparison. From the throughput show in [11] we modified the throughput calculator as follows:

$$\text{Throughput} = \frac{\text{Packet Length} \times \text{No. Successful Packs}}{\text{Average Busy Time} + \text{Average Idle Time}}$$

After one node sends an RTS packet to its intended receiver, it waits for a time long enough for the CTS, Data and ACK packet come back. So every request will block the node from accepting new arrivals for $t = \text{DIFS} + \text{Back-off} + \text{RTS} + \text{SIFS} + \text{CTS} + \text{SIFS} + \text{DATA} + \text{SIFS} + \text{ACK}$ seconds. The probability of a node being idle is:

$$P_{idle} = \frac{1}{t + 1/\lambda} = \frac{1}{1 + \lambda t} \quad (3)$$

Since all nodes are in the same transmission area, the probability of a DATA packet being successful is the probability that it is the only data transmission at the time, given that there is at least one transmission on the channel.

$$P_{\text{success}} = \frac{P_{\text{OnlyOneTransmission}}}{P_{\text{AtLeastOneTransmission}}}$$

$$= \frac{(N - 1) - P_{\text{idle}} \times (P_{\text{idle}} + P_{\text{success}})^{N-1}}{1 - (P_{\text{idle}})^N} = \frac{N\lambda t}{(1 + \lambda t)^N - 1} \quad (4)$$

Using Eqs. (4), we compute the probability of a data packet being successful plotted in Figure 6 for various value of $N$.

![Figure 6: The probability of data packet successful transmits vs. Arrival Rate.](image)

We defines parameters used in our analysis are listed in Table 1.

<table>
<thead>
<tr>
<th>Number of mobile</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slot time</td>
<td>20 $\mu$s</td>
</tr>
<tr>
<td>Channel Bit Rate</td>
<td>2 Mbps</td>
</tr>
<tr>
<td>Beacon Interval</td>
<td>10 ms</td>
</tr>
<tr>
<td>ATIM Window</td>
<td>2 ms</td>
</tr>
<tr>
<td>Length of DIFS</td>
<td>50 $\mu$s</td>
</tr>
<tr>
<td>Length of SIFS</td>
<td>20 $\mu$s</td>
</tr>
<tr>
<td>Back-off slot time</td>
<td>20 $\mu$s</td>
</tr>
<tr>
<td>PHY header</td>
<td>128 bits</td>
</tr>
<tr>
<td>RTS</td>
<td>160 bits</td>
</tr>
<tr>
<td>CTS</td>
<td>112 bits</td>
</tr>
<tr>
<td>ACK</td>
<td>112 bits</td>
</tr>
<tr>
<td>DATA</td>
<td>512 byte</td>
</tr>
</tbody>
</table>

Table 1. Analysis parameter.

Analysis results re presented in this Figure 7, the curves labeled as “802.11” refer to original IEEE 802.11 single channel MAC and MMAC.

![Figure 7: Average Throughput vs. packet Arrival Rate.](image)
Figure 7. Shows the average throughput of different protocols as the network load increases. When the network load is low all protocols perform similarly. As the network load increases, MMAC performs significantly better than IEEE 802.11. Multichannel MAC improves performance over IEEE 802.11, but it has overhead for channel negotiation. The throughput of multichannel over our multichannel protocol may not be dramatic, but it is important that Multichannel MAC achieves this throughput using only a single transceiver for each host. Thus, the important is achieved using simpler hardware.

6. Conclusions and Future Work

In this paper, we have presented a Multichannel MAC protocol that utilizes multiple channels to improve throughput in wireless networks. The proposed scheme requires only one transceiver for each host, while other multichannel MAC protocols require multiple transceivers for each host. The nodes in the network are synchronized by beacons, and the channels are negotiated in the ATIM window using control packet. After ATIM window, node switch to their selected channel and exchange messages on the channel for the rest of the beacon interval. Since multiple transmissions occur at the same time. Analysis results show that Multichannel MAC performs significantly better than IEEE 802.11 and use simpler hardware than other Multichannel MAC protocol.

7. References


