New Multichannel MAC Protocol for Ad Hoc Networks

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Abstract—Since wireless ad hoc networks require a distributed multiple access protocol, the medium access control (MAC) layer can be seen as the bottleneck for the throughput in wireless 802.11-based ad hoc networks. In this paper, we develop a new MAC protocol for multichannel operation in wireless ad hoc networks. The proposed protocol is based on the code division multiple access (CDMA) technique where each spreading code represents one channel. However, the proposed MAC protocol is not limited to CDMA systems. It can be applicable within frequency division multiple access (FDMA) systems (with one radio transceiver) or multi radio systems. We show through computer simulations that our proposition of multichannel MAC protocol significantly improves the communication performance in wireless ad hoc networks.

Index Terms—Medium access control, multichannel protocols, ad hoc networks, CDMA.

I. INTRODUCTION

It is widely accepted that ad hoc networks are at the leading edge of the innovative wireless networking technologies. This type of networks consists of nodes connected together without infrastructure and hence, it has to be self configured, self organized and the resources have to be allocated in a distributed manner. Two important phenomena limit the MAC protocol design in these networks: namely, the hidden and exposed nodes. The first one increases the rate of packet collisions; whereas, the second phenomena causes a loss in the resources.

Many MAC protocols are proposed to overcome these problems. However, the proposed solutions are in general of high cost and complex and they haven’t completely eliminated these problems.

Different proposed MAC protocols are based on the code division multiple access (CDMA) technique for wireless ad hoc networks. The early work realized by Sousa and Silvester in [1] includes two new MAC protocols. In these protocols, the data packets are transmitted on a transmitter-based code, but the packet header is either transmitted on a common code (the first protocol) or on a receiver-based code (the second protocol). Hence, the number of used spreading codes relies completely on the network size. Even though the rate of occurred collisions is reduced, the collisions still happen for the packets transmitted on the common code in the first protocol and the ones transmitted on the receiver code in the second protocol.

A pairwise code assignment has been proposed in [2]. It assigns in a centralized manner one of the available codes to each transmitter-receiver pair (link) such that no two adjacent edges use the same code. Accordingly, each node has to maintain many codes to connect with the neighbored nodes. The major drawback of this proposed protocol is that the overhead, caused by code assignment signaling messages, is relatively high. The number of used codes have been minimized in [3] where the authors have shown that the minimization problem is NP-complete.

Another way of thought is to make use of handshaking control packets to sense the channel. The handshaking packets were first introduced by MACA (multiple access with collision avoidance) protocol in [4]. The sender and receiver nodes exchange two control packets, namely ready-to-send (RTS) and clear-to-send (CTS) before sending the data packet. Two protocols based on common-transmitter based (MACA/C-T) and receiver-transmitter based (MACA/R-T) are proposed in [5]. These protocols can be considered as variants to the ones presented in [1] except that the new proposed protocols take into consideration the RTS/CTS packets. Thus, collisions occur only at the level of the control packets exchange. On the other hand, sending the data with the receiver’s code was investigated in [6]. However, the disadvantage of this kind of protocols is that it does not support multicast services.

The authors of [7] have proposed a distributed algorithm of code assignment in which the number of available codes is at least $d \times (d - 1) + 2$ where $d$ is the maximum number of one-hop neighbors any node can have. An important characteristic of this protocol is the existence of a common channel that is used to exchange the code assignment information between the nodes. In [8], the authors have proposed a dual reservation MAC protocol in which $N + 2$ codes are used ($N$ codes for data, one common code for control messages and one code for broadcasting). Each node has three lists: the available codes list, the occupied codes list and the forbidden codes list. The code used for transmitting data packets between two nodes is dynamically assigned after negotiations using the control messages.

A. Muqattash and M. Krunz have proposed a multichannel MAC protocol in [9], in which the bandwidth is divided into two frequency channels. One channel is used to exchange control messages and the other one is used for the data transmission. All nodes use the common code on the control channel; whereas, on the data channel, only one code is assigned to each node for data transmission. Although the
The proposed solution reduces the number of occurred collisions, the hardware implementation is complex and of high cost. In [10], two phases coding multichannel MAC protocol was proposed. It assumes that one node has to take the responsibility of assigning the codes to the other nodes in the same cell. In fact, this protocol will be more suitable to wireless LAN 802.11 DCF. In [11], asynchronous multichannel coordination protocol (ACMP) is devised. It uses a dedicated control channel on which nodes contend to reserve data channel by exchanging RTS/CTS packets according to 802.11 DCF.

In this paper, we propose a new MAC protocol based on multichannel operation in wireless ad hoc networks. The proposed protocol is based on CDMA technique to identify the different channels. However, the method considered in this protocol for identifying channel allows us to utilize other multiple access technique such as FDMA technique where each channel is represented by a frequency bandwidth or the multi-radio systems where each radio transceiver may correspond to one channel.

We consider in this proposed protocol one common channel on which RTS and CTS control packets are exchanged, and several data channels used for transmitting the data packets. Time is divided into frames. The synchronization among the nodes is established by inserting a synchronization interval at the beginning of each frame in the control channel. The reservation of a particular data channel for one transmission is realized by the control channel. Obviously, all the nodes have to monitor the common channel in order to obtain the identification of the assigned data channel.

Contrary to many distributed multichannel MAC protocols for wireless ad hoc networks proposed in the literature, our proposed protocol is simple since it requires a limited amount of signalling exchange. Our protocol is able to be extended in order to include more complicated functions such as multiple frame reservation. The information about the channels (corresponding to different codes in CDMA systems) reserved for a particular node for data transmission can be provided implicitly to the corresponding node.

The rest of this paper is organized as follows. Section II details the proposed multichannel MAC protocol for wireless ad hoc networks. Simulation results are presented in Section III showing the improvement of the performance realized. A discussion about the simplicity, efficiency and flexibility of our protocol is given in Section IV. Finally, we conclude this paper in Section V.

II. MULTICHANNEL MAC PROTOCOL PROPOSITION

In this section, we detail the functionality of the proposed MAC protocol. We describe the operations of this protocol considering a CDMA multiple access technique, although the proposed protocol can be easily extended to different multi-channel ad hoc networks. We assume no transmission errors, so a RTS packet is lost only if it suffers from a collision with another RTS packet. CTS, data and acknowledgment packets do not suffer from any error.

The proposed protocol assumes \( N + 1 \) codes corresponding to \( N + 1 \) independent and orthogonal channels. One common code is used by RTS and CTS packets whereas \( N \) codes are used by data and acknowledgement packets. Time is divided into frames. The frames on the data channel (data frames) and the ones on the control channel (control frames) are equal in length and synchronized.

Each control frame is divided into one synchronization interval (denoted by SYN) and eight slot intervals. Each slot in the control channel is divided into two fields. The first one is assigned to transmit RTS packets whereas the second field may transmit CTS packets.

The synchronization is achieved by using the SYN interval available at the beginning of each control frame. As the number of slots in one control frame is eight, the number of data codes has to be eight too. Thereby, the number of the slot in which RTS and CTS packets are exchanged between two nodes identifies those two transmitting nodes as well as the data code corresponding to the data channel. The procedure of medium access contention is described in the following.

Every node listens to the common channel during the SYN interval for the synchronization and during the RTS fields unless that node has data to transmit or it is concerned by a received RTS packet. When a node has data to transmit, it waits until the next slot in the control channel and then it transmits a RTS packet during the RTS field. If this node is the only transmitting node in that RTS field, the destination node will receive correctly the RTS packet and will then respond with a CTS packet during the corresponding CTS field. Otherwise, if two or more RTS packets are transmitted in one RTS field, a collision will obviously occur and the collided nodes have to back-off and retransmit their RTS packets after many slots.

Upon receiving the CTS packet, the sender node switches to the corresponding data channel and starts transmitting data at the beginning of the next slot in the control channel. The destination node receives data and replies with an acknowledgment packet on the same data channel. Thus, each successful RTS/CTS exchange reserves only one frame in the data channel. If the sender node has more than one data frame or the receiver node has data for the sender node, they have to contend in order to reserve another frame on a data channel.

The procedure is illustrated in figure ?? where we give an example of different successful and unsuccessful RTS/CTS exchanges. When a RTS packet is not transmitted or a RTS collision is occurred (denoted by unsuccessful RTS/CTS exchange) during one slot of the common channel (slots \( S_1 \) and \( S_{N-1} \) in the first frame), the next immediate frame in the corresponding data channel of that slot will be idle. When RTS/CTS exchange is successful as in slots \( S_2, S_3 \) and \( S_N \), one data frame is reserved on the corresponding data channel for that transmission. In this way, the reservation of data channels is simply achieved.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic rate</td>
<td>2 Mbps (RTS/CTS)</td>
</tr>
<tr>
<td>Data rate</td>
<td>2 Mbps (DATA/ACK)</td>
</tr>
<tr>
<td>SYN</td>
<td>144 usec (36 bytes)</td>
</tr>
<tr>
<td>Packet size</td>
<td>986 bytes</td>
</tr>
<tr>
<td>RTS/CTS header</td>
<td>20/14 bytes</td>
</tr>
<tr>
<td>DATA/ACK header</td>
<td>28/14 bytes</td>
</tr>
<tr>
<td>Channel switching delay</td>
<td>0 sec</td>
</tr>
<tr>
<td>Scenario</td>
<td>50 nodes</td>
</tr>
</tbody>
</table>

III. SIMULATION RESULTS

In this section, we evaluate the performance of our proposed multichannel CDMA-based MAC protocol and we compare it with 802.11-based ad hoc network with one channel. The performance evaluation is achieved with computer simulations using NS-2 network simulator. In our simulations, we assume up to eight flows simultaneously. This presents the maximum number of flows during one frame. In other words, sixteen nodes can be connected one-to-one without any interference between them. When the number of flows is less than or equal to the number of slots, the maximum throughput can be achieved if we consider no RTS packets collision. We consider eight slots per frame, corresponding to eight data channels. We also assume that the RTS/CTS/DATA/ACK packets have the same structure as in 802.11 standard. The simulations results show the throughput versus the number of flows and versus the number of nodes. Intuitively, we expect that our proposed MAC will improve considerably the total throughput in the system compared to standard IEEE 802.11 MAC due to the utilization of multi channels.

We notice from figure 1 that our proposed MAC protocol gives higher throughput in function of number of used channels. In fact, the throughput (defined by the rate of packets correctly transmitted) of 802.11-based ad hoc network is almost fixed since only one channel is used. On the other hand, the throughput increases linearly with the number of channels using our MAC protocol.

The results depicted in figure 2 provides the throughput in versus the packet arrival rate. We notice that our MAC protocol provides similar throughput for low packet arrival rate since for the most of the time, only one channel is used. When the packet arrival rate is used, the performance of 802.11 gets saturated. We even notice a slight decrease in 802.11 throughput due to the increases rate of packet collisions. When our MAC protocol is used, the throughput increases when the packet arrival rate increases since more channels are used. In fact, our proposition performs the aggregate throughput for ad hoc networks.

In the next section, we provide some discussion about the flexibility, simplicity and efficiency of multi-channel MAC protocol based on CDMA technique.

IV. DISCUSSION

Our proposed scheme is efficient, simple and flexible. It is efficient because $N$ connections at most can be achieved at the same time. Hence, as shown in the simulation results, a significant increase in the throughput can be achieved. We consider $N$ spreading codes and the number of codes is equal to the number of slots in one frame.

The scheme is simple because it uses a simple algorithm of code allocation in a distributed manner where the number of the slot represents the number of the corresponding data channel. Moreover, the proposed scheme is flexible because its structure is open for future developments. For example, a node with one simple transceiver can have only one connection during one frame but if this node has multi-transmitter and multi-user detection receiver, it can have up to $N$ connections during one frame assuming only one pair of nodes in the geographic zone i.e., this node can use all data codes at the same time.

Our proposition can be improved by adding the possibility of reserving more than one frame by only one RTS/CTS exchange. This allows the transmission of large data packets in
one frame. A data channel can be simply reserved by adding busy tone at the beginning of the corresponding slot in the control frame. The busy tone will prevent the other nodes from contending on this channel.

V. CONCLUSION

In this paper, we presented a new multichannel MAC protocol and its use in wireless ad hoc networks to improve network performance. Our protocol allows several connections to occur concurrently using multiple channels without interference. The channel allocation and identification are simply achieved by transmitting RTS/CTS packets in one slot on a control channel. The slot’s number represents the number of a corresponding data channel. By this, the hidden and exposed terminal are eliminated. Using the ns-2 simulator, we show that multichannel MAC protocol provides higher network throughput.

REFERENCES


