

Enhanced multi-channel MAC protocols in Wireless Ad hoc Networks

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Abstract

This paper proposes a multi-channel MAC protocol with directional antennas (MMAC-DA). Each node pair exchange control packets on the control channel during the control window to determine the beam's direction and negotiate the data channel. By exploiting multiple channel resources and improving the spatial reuse of wireless channel, MMAC-DA can improve the network performance.

Key word: Multi-channel MAC, directional antennas, wireless ad hoc networks.

1. Introduction

IEEE 802.11 provides multiple channels for wireless communications at Physical layer, but the MAC protocol is designed for a single channel. By exploiting the multiple channel resources through multi-channel MAC protocols, many concurrent transmissions on different channel are supported. Moreover, by using the omnidirectional antennas, the spatial reuse of wireless channel is improved and thus the network performance is increased.

The SINR-based transmission power control (STPC-MAC) [1] can help to improve the spatial reuse. The Multi-channel MAC (MMAC) [2] and Hybrid Multi-channel MAC (H-MMAC) [3] protocols adopt IEEE 802.11 Power Saving Mechanism (PSM) in which the ATIM window is used for nodes to exchange control packets for channel negotiation. However, H-MMAC allows nodes to exchange data packets during the ATIM window.

The Directional Virtual Carrier Sensing (DVCS) [4] employs a steerable antenna system. The Directional Network Allocation Vector (DNAV) is used instead of NAV. The circular directional RTS in CDR-MAC [5] helps the intended receiver to identify the direction toward the sender. The Dual Sensing Directional MAC (DSDMAC) [6] employs an additional busy tone with continuous and ON/OFF patterns to avoid the hidden terminal problem and solve the deafness problem.

2. The proposed MMAC-DA protocol

In this protocol, the antennas are assumed to operate in either omnidirectional mode or directional mode (Fig. 1). The antenna can beamform to one of M fixed directions in directional mode. The antenna gain in directional mode is higher than in omnidirectional

mode. We assume that there are N non-overlapping channels in the system: one control channel and $N-1$ data channels. All nodes are time synchronized.

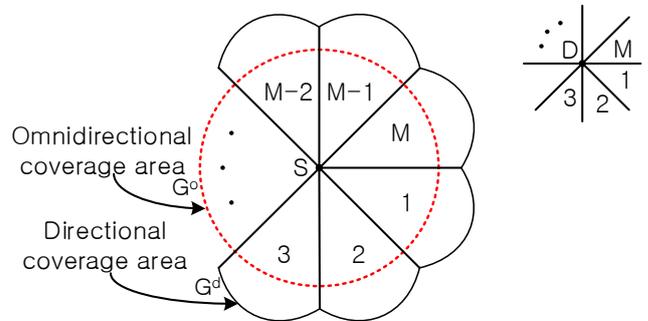


Fig. 1. Antenna model.

Adopting the IEEE 802.11 PSM, time is divided into beacons. Each beacon consists of a control window and a data window. During the control window, all nodes have to be on the control channel to exchange control packets for Channel Beam Negotiation (CBN): Request to Negotiate (RTN), Channel Beam Acknowledgement (CBA), Channel Beam Reservation (CBR) and Directional Channel Beam Reservation (DCBR). After the control window, node pairs switch to negotiated channels to exchange data packets in determined directions.

Each node maintains two data structures, Neighbor Information List (NIL) and Channel Usage List (CUL) to keep track of the status of neighbor nodes and channels.

Node C's NIL		Node C's CUL	
Neighbor	Status	Channel	Beam
B	1	CCH	1, M
D	1	DCH_1	2, 3, M-2
...	...	DCH_2	3, M

Table. 1. Data structures in MMAC-DA

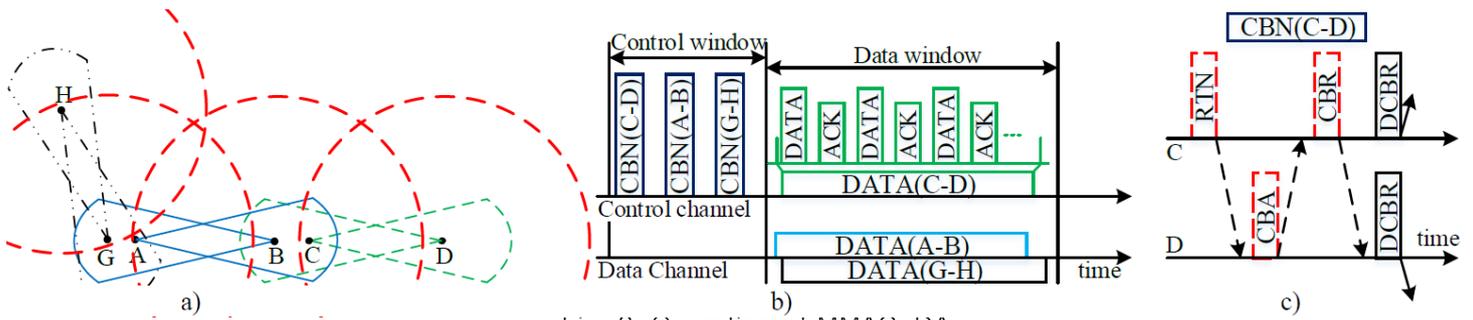


Fig. 2. Operation of MMAC-DA

In the NIL (Table. 1a), the status of each node can be Busy (1) or Available (0). Busy means that neighbor already performed a handshake successfully and it is going to exchange data packets during the data window. A node only can communicate with the neighbor node which is in Available state. The CUL (Table. 1b) stores the available beam's direction of each channel. During the data window, the control channel (CCH) can be used for data transmissions. Both the NIL and CUL are updated through the overheard CBA, CBR or DCBR packets.

Now, we explain the operation of MMAC-DA. Assuming that node C has data packets for node D.

1. In the control window, node C checks the status of node D in its NIL. If node D is available, it transmits an RTN packet including its CUL to node D in omnidirectional mode. Otherwise, it has to wait for the next beacon.
2. Upon receiving the RTN, node D determines the beam's direction toward node C and converts node C's CUL into its point of view. Based on the determined beam, node C's converted CUL and its CUL, node D selects a channel which has an available beam to node C. Then, node C sends the CBA packet including the selected channel with determined beam's direction.
3. Node C confirms the selected channel and beam's direction by sending CBR packet in omnidirectional mode. Note that the beams from source node and destination node are in opposite directions.
4. Then, both nodes C and D transmit DCBR packet in directional mode to the opposite direction of destination and source node, respectively. This helps to warn the hidden neighbor nodes in directional mode. In Fig. 2, node B cannot overhear the CBA and CBR, nodes A and B may

use the same channel and same direction with nodes C and D, and cause the collision in directional mode at node A or node D.

5. Neighbor nodes which overhear the CBA, CBR or DCBR packets update their NIL and CUL.
6. After the control window, nodes switch to selected channel to exchange data packets in determined beam directions.
7. Nodes which do not exchange CBN messages in the ATIM window go to doze mode to save energy.

3. Simulation Results

In this section, we evaluate our proposed HER-MAC protocol on the event-driven simulation program in Matlab. Some simulation parameters are given in Table. 2. The simulation results are shown in Fig. 3.

Parameter	Value
Number of channels	3 channels
Beacon interval	100 ms
Control window	20 ms
RTN/CBA/CBR/DCBR	28/ 16/ 16/ 16 bytes
Data packet	512 bytes
Basic rate/ Data rate	1 Mbps/ 2 Mbps
Transmit power consumption	1.65 W
Receive power consumption	1.4 W
Idle power consumption	1.15 W
Doze power consumption	0.045 W

Table. 2. Simulation parameters.

Fig. 3 shows the performance comparison of different protocols. As shown in Fig. 3(a), the multi-channel MMAC and MMAC-DA protocols, give the higher aggregate throughput than single channel IEEE 802.11 MAC. Moreover, MMAC-DA employs directional antennas to improve the spatial reuse, thus more concurrent data transmissions are provided. MMAC-DA also reduces the overhead of control packets

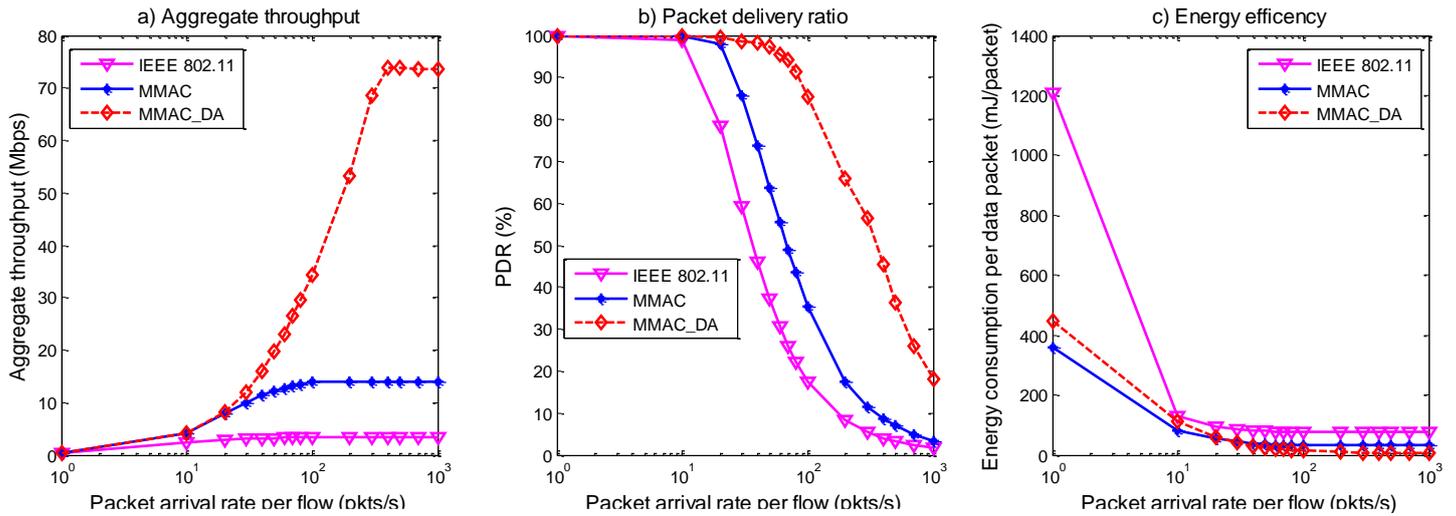


Fig. 3. Performance comparison of different protocols.

during the data window compared to MMAC. After nodes negotiate the data channel successfully, they switch to selected data channel to exchange data packets without any contention. Therefore, MMAC-DA has higher aggregate throughput than MMAC.

When the packet arrival rate increases, more nodes try to access channel and the collision probability increases. It leads to packet loss. Also, the data packets are dropped due to the limited queue size. The packet delivery ratio decreases as the packet arrival rate increases, as shown in Fig. 3(b). By providing more concurrent data transmissions, MMAC and MMAC-DA protocols have higher packet delivery ratio than IEEE 802.11.

Since both MMAC and MMAC-DA protocols adopt IEEE 802.11 PSM, they gain the efficiency of energy consumption as shown in Fig. 3(c). During the data window, if nodes do not have any data packet to exchange, they go to doze mode to save energy and wake up at the beginning of the next ATIM window. In IEEE 802.11, nodes have to stay awake even though they do not have any data packet to exchange. By exploiting the multiple channel resources and employing the directional antennas to provide more concurrent data transmissions; adopting IEEE 802.11 PSM to save energy, MMAC-DA consumes less energy to transmit a data packet in average.

4. Conclusion

In this paper, we propose a multi-channel MAC protocol with using directional antennas, named MMAC-DA. By exploiting the multiple channel resources and improving the spatial reuse, MMAC-DA can improve network performance. The analysis of the MMAC-DA is left as our future work.

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