# A Novel Multi-channel MAC Protocol for Ad hoc Networks

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Abstract

The medium access control (MAC) protocol is designed only for single channel in the IEEE 802.11 standard. That means the throughput of the network is limited by the bandwidth of the single channel. The multiple channels can be exploited to get more concurrent transmission. In this paper, we propose a novel Multi-channel MAC that utilizes the channel more efficiently than other Multi-channel MAC protocols.

Key word: Multi-channel, MAC protocol, Ad hoc networks.

## 1. Introduction

The performance of the ad hoc network is limited by the bandwidth of single channel. Although the IEEE 802.11 provides multiple channels for wireless communications at Physical Layer, the MAC layer is designed only for a single channel. However, it is not easy to design the MAC protocol that can exploit multiple channels with a single half-duplex transceiver. Since transceiver cannot sense all channels simultaneously, it may lose the channel reservation messages from its neighbors on another channel. This leads to the new type of hidden terminal problem in a multi-channel environment, referred as *multi-channel hidden terminal problem* [2].

In Dynamic Channel Allocation (DCA) [3], each node is equipped with two transceivers. One is the control transceiver used by node to perform RTS/CTS/RES handshake for data channel negotiation. Other is the data transceiver which is used to transmit DATA and ACK packets on agreed data. In the other way, the Signal to Noise Ratio based multi-channel MAC protocol (SNRMP) [5] proposed the criterion for receiver to choose the "best" data channel in terms of the lowest interference power. The performance of both DCA and SNRMP are affected by the ratio of $T_d/T_c$, where $T_d$, $T_c$ are the transmission durations of data packet and control packet, respectively. Using single transceiver, Asynchronous Multi-channel MAC (AM-MAC) [4] targets low-cost and low-power while the collision-free is guaranteed.

The Multi-channel MAC (MMAC) [2] uses one transceiver and the common control period, called the ATIM window, to negotiate the data channel. After the ATIM window, nodes switch to agreed data channel for data transmission. Since all nodes have to be on a certain channel during the ATIM window, the resource of other channels is wasted during this period. To avoid that, the Traffic Aware Multi-channel MAC (TAMMAC) [6] proposes a mechanism to adjust the ATIM window dynamically according to the traffic of the network.

In this paper, we propose a Novel Multi-channel MAC protocol, named H-MMAC. H-MMAC protocol uses the common control period like MMAC, but the enhancement of the H-MMAC protocol compared to the MMAC protocol is that the H-MMAC protocol allows some nodes to transmit data packets while other nodes are exchanging ATIM messages during the ATIM window. For $N$ channels, the H-MMAC protocol utilizes $(N-1)$ channels in the ATIM window. The H-MMAC protocol can improve the throughput significantly compared to the MMAC protocol.

$$Improvement = (\frac{N-1}{N})\frac{ATIM\_window\_size}{Data\_window\_size}$$

## 2. The Proposed H-MMAC protocol

First, we summarize our assumptions as below:

1) There are N non-overlapping channels.
2) Nodes have prior knowledge of how many channels are available.
3) Each node is equipped with a single half-duplex transceiver, and it is capable of switching its channel dynamically.
4) All nodes are time-synchronized and applied the IEEE 802.11 DCF mechanism.

Next, we define two transmission modes (Tx mode):

1) Normal Transmission (N-Tx) is the transmission performed within the data window.
2) Extended Transmission (E-Tx) is the transmission performed within the data window and also the next beacon. The E-Tx is longer than the N-Tx.

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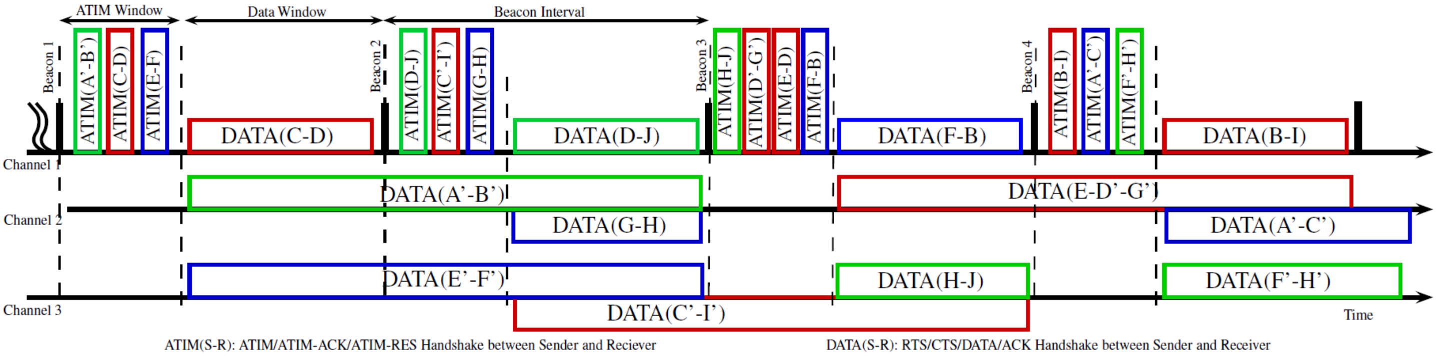

Fig. 1. The operation of H-MMAC protocol.

The neighbor node can be one of four types: Normal, Ongoing, Limited and Unknown.

1) Normal: nodes have up-to-date information of their neighbor nodes.
2) Ongoing: nodes are exchanging data during the current ATIM window because of the E-Tx mode.
3) Limited: nodes which lost their neighbor's status since they are Ongoing in last beacon.
4) Unknown: if node does not know about its neighbor, the neighbor node is Unknown node.

A. Neighbor Information List – NIL

Each list entry keeps the information of neighbor nodes: Channel, Type and Tx mode. Channel field shows which channel the node is going to switch to in the data window and the channel 0 means it is idle node. There are four types for neighbor nodes: Normal, Ongoing, Limited and Unknown and two Tx modes: Normal (N-Tx) or Extended (E-Tx). Table I shows the NIL of node A.

TABLE I. Node A's NIL

| Node | Channel | Type | Tx mode |
|---|---|---|---|
| B | 0 | Limited | N-Tx |
| C | 1 | Unknown | N-Tx |
| D | 1 | Normal | E-Tx |

TABLE II. NIL's Update

| Node A's Type | Before update | | | After update | | |
|---|---|---|---|---|---|---|
| | State | Type | Tx mode | State | Type | Tx mode |
| Normal | – | Unknown | N-Tx | Idle | Normal | N-Tx |
| Normal | – | Unknown | E-Tx | – | Unknown | N-Tx |
| Normal | Idle | Limited | E-Tx | Idle | Normal | N-Tx |
| Normal | Busy | Ongoing | E-Tx | Idle | Limited | E-Tx |
| Any | Busy | Normal | E-Tx | Busy | Ongoing | E-Tx |
| Ongoing | – | Ongoing | – | – | Unknown | E-Tx |
| Normal | Busy | Normal | N-Tx | Idle | Normal | N-Tx |
| Any: Normal or Ongoing type node<br>Ongoing: not Ongoing type node | | | | | | |

A node needs to know the current status of it neighbor node in order to exchange data. It is therefore very important for a node to keep its NIL to be updated. A node updates its type itself (Normal or Ongoing) and then updates its NIL before each beacon as the Table II. Whenever it overhears ATIM messages from the neighbor node, the State changes from Idle to Busy and Tx type is updated to corresponding transmission mode for that neighbor node's record in the NIL.

B. Preferable Channel List – PCL

Each channel in the PCL has the state either Selected or Not_Selected state. Selected channel means that this channel has already been chosen by the node to use in the current beacon, otherwise Not_Selected channel. So, at most one channel can be Selected at each node for each beacon. The counter of a channel shows how many node pairs already reserved that channel. A Not_Selected state and zero counter channel means an idle channel. Table III is the node A's PCL after node A finished exchanging ATIM messages with node B at the fourth ATIM window.

TABLE III. NodeA's PCL

| Channel | State | Counter |
|---|---|---|
| 1 | Not_Selected | 1 |
| 2 | Selected | 1 |
| 3 | Not_Selected | 0 |

C. The operation of H-MMAC protocol

In the ATIM window, there are four types of node: Ongoing, Limited, Normal and Unknown. The node must be Normal or Limited type in order to be a receiver.

1) When a node has data to send, it checks the receiver's type in its NIL. If the receiver's type is Ongoing or Unknown, it has to wait for next beacon to try again.
2) The sender checks the receiver's channel in its NIL and its channel from its PCL. If the Selected channel of sender and receiver are different, the sender also has to wait for next beacon.
3) Based on the traffic load, the sender decides which transmission mode is used.

4) The sender attaches its PCL and transmission mode into ATIM packet and sends to the receiver.
5) Upon receiving ATIM, the receiver selects the best channel from its PCL and the sender's PCL by using Algorithm 1. Then the receiver sends ATIM-ACK indicating the selected channel to the sender.
6) The sender sends ATIM-RES to confirm the data channel selected by the receiver.
7) After the ATIM window, the sender and receiver switch to agreed channel for exchanging data.

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**Algorithm 1:** Algorithm to select the "best" channel

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**If** There is a Selected channel in destination's PCL **then**
    This channel is selected.
**else if** There is a Selected channel in source's PCL **then**
    This channel is selected.
**else**
    The channel which has the least counter value is selected.
**end if**

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## 3. Performance Evaluation

In this section, the performance of H-MMAC is evaluated compared to IEEE 801.11, DCA and MMAC. The simulation has been established with the following parameters (Table IV).

TABLE IV. Simulation's Parameters

| Parameters | Value |
|---|---|
| Transmission range | 250 m |
| Beacon interval | 100 ms |
| ATIM window | 20 ms |
| Number of channels | 12 channels |
| Number of nodes | 60 nodes |
| Data packet size | 512 bytes |

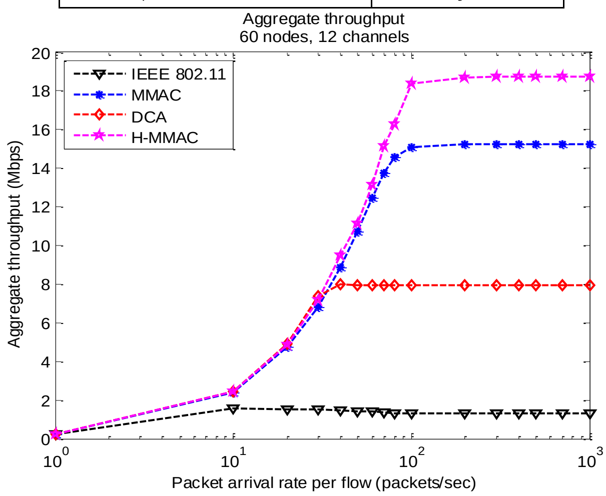


Fig. 2. The throughput of different protocols.

Fig. 2 shows the aggregate throughput of different protocols. By exploiting the multiple channels, the multi-channel MAC protocols offer more data packets transferred than IEEE 802.11 MAC protocol. That leads the higher throughput of multi-channel MAC protocols than IEEE 802.11 MAC protocol designed for single channel. As we mentioned above, the performance of the DCA protocol is affected by the $T_d/T_c$ ratio. If the number of channels is larger than $T_d/T_c$, the DCA protocol cannot utilize the multiple channel fully. The more channels MMAC uses, the more channel resources are wasted during the ATIM window. Although the ATIM window impacts the performance of the H-MMAC protocol on default channel, the other channels are fully utilized when the traffic load is high. Therefore, H-MMAC can achieve almost 12 times as much throughput compared to IEEE 802.11 MAC.

## 4. Conclusions and Future work

In this paper, we have proposed a hybrid multi-channel MAC protocol, named H-MMAC, which utilizes almost all of the entire channel resources to improve the network performance. By allowing nodes to transmit data during the ATIM window, H-MMAC achieves higher performance than other multi-channel MAC protocols.

## 5. Reference

[1] IEEE 802.11 Working Group. *Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specification*, 1997.

[2] Jungmin So, Nitin H. Vaidya. *Multi-Channel MAC for Ad hoc Networks: Handling Multi-channel Hidden Terminals Using A Single Transceiver*, Proceeding MobiHoc '04 Proceedings of the 5th ACM international symposium on Mobile ad hoc networking and computing *(Mobihoc'04)*, 2004.

[3] Hyu-Chee Tseng; Shih-Lin Wu and Chih-Yu Lin; Jang-Ping Sheu. *A multi-channel MAC protocol with power control for multi-hop mobile ad hoc networks*, 2001 International Conference on Distributed Computing Systems Workshop, 2001.

[4] Duy Nguyen; J. J. Garcia-Luna-Aceves and Katia Obraczka. *Collision-Free Asynchronous Multi-Channel Access in Ad Hoc Networks*, Proc. IEEE conference on Global telecommunications GLOBECOM'09, 2009.

[5] Sarkar M., Nagaraj S and Balsania I.H. *A SINR based MAC layer protocol for multi-channel ad-hoc networks,* 2011 International Conference on Wireless Communications and Mobile Computing (IWCMC), 2011.

[6] Wen-Tsuen Chen, Jen-Chu Liu, Ting-Kai Huang and Yu-Chu Chang. *TAMMAC: An Adaptive Multi-Channel MAC Protocol for MANETs*, IEEE Transactions on Wireless Communications, Nov 2008.