# An Enhanced Multi-channel MAC Protocol for Wireless Ad hoc Networks

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***Abstract*—In the wireless ad hoc network, utilizing the multiple channels at Medium Access Control (MAC) layer is on of the key techniques to improve the network performance. It can be done by multi-channel MAC to utilize the channels resource as much as possible. Wireless nodes are usually powered by battery and thus are limited in power capacity. The IEEE 802.11 Power Saving Mechanism (PSM) is used to conserve energy for the ad hoc networks by allowing nodes to enter doze mode when there is no need for data exchange. In this paper, we propose a hybrid and adaptive protocol, named H-MMAC, by adopting IEEE 802.11 PSM. In H-MMAC, nodes exchange control messages on default channel to negotiate the data channel during the ATIM (Ad hoc traffic Indication Message) window. The difference of H-MMAC compared to other multi-channel MAC protocols is that the other nodes can transmit data packets on data channels based on the network traffic load. This means H-MMAC can utilize the channel resources more efficiently. The simulation results show that our proposed H-MMAC improves the network performance significantly in terms of aggregate throughput, average delay and energy efficiency.**

***Index Terms*—Multi-channel, MAC protocol, Ad hoc networks.**

## I. Introduction

There are 3 non-overlapping channels in the IEEE 802.11b,g and 12 non-overlapping channels in the IEEE 802.11a. However, the IEEE 802.11 MAC protocol is designed only for a single channel. If multiple channels are exploited, we can achieve a higher network throughput than using single channel. It is not easy to design the MAC protocol that can exploit multiple channels with a single half-duplex transceiver because of a *multi-channel hidden terminal problem* [7].

The rest of the paper is organized as follows. Section II reviews the related work of Multi-channel MAC protocol in ad hoc networks. Our proposed protocol is described in details in section III. We evaluate the proposed protocol through extensive simulations in section IV. Finally, we conclude our work in section V.

## II. Related work

There are five main challenges for multi-channel MAC: multi-channel hidden terminal problem, deafness problem, broadcast problem, channel access problem and channel switching delay problem [3]. Recently, many multi-channel MAC protocols have been proposed and they can be classified into the following categories [2]: Dedicated Control Channel, Split Phase, Common Hopping and Parallel Rendezvous.

In Dedicated Control Channel approach, each node has two radios: one radio is tuned to the channel dedicated to control packets and another one can switch to any other channels for data transmission. The performance of Dynamic Channel Allocation (DCA)[4] and Dynamic Channel Assignment with Power Control (DCA-PC)[5] are affected by the ratio of the transmission duration of the data packet and control packets. The Asynchronous Multi-channel MAC (AM-MAC)[6] targets low-cost and low-power while guaranteeing the collision-free.

Each node has only one radio in Split Phase approach. Time is divided into beacons with control interval and data interval. One of the disadvantages of MMAC [7] is the wastage of bandwidth of data channel in the control interval. Traffic Aware Multi-channel MAC (TAMMAC) [8] proposed a mechanism to adjust the control interval dynamically according to the traffic of the network. The Multi-channel MAC with Channel Distribution (CD-MAC) [9] is another scheme which tries to utilize the channel during the control interval.

Nodes also have one radio in Common Hopping approach. Nodes that do not exchange data hop through all channels synchronously. The switching channel time affects the performance of this approach. Channel Hoping Multiple Access (CHMA) [10] is an example of this approach. Pipelining Multi-channel MAC ($\pi$-Mc) [11] is similar to pipeline technique. The transmission task is divided into many subtasks. If the first subtask is transmitted successfully, all the other subtasks also succeed in transmission.

Parallel Rendezvous protocols are proposed to make multiple agreements at the same time, such as: Slotted Seeded Channel Hopping (SSCH) [12] and Multi-channel MAC (Mc-MAC) [13]. The Fast and Slow Hopping MAC protocol that is proposed in [14] is based on frequency hopping and parallel rendezvous approaches.

The detail of the H-MMAC protocol is described in the following section.

## III. The Proposed H-MMAC protocol

First, we summarize our assumptions as follows:

- Time is divided into beacon intervals which contain two sub-intervals called ATIM window and data window.
- There are $N$ non-overlapping channels which can be used. One channel is predefined as a default channel which is used for nodes to exchange control messages during the ATIM window.

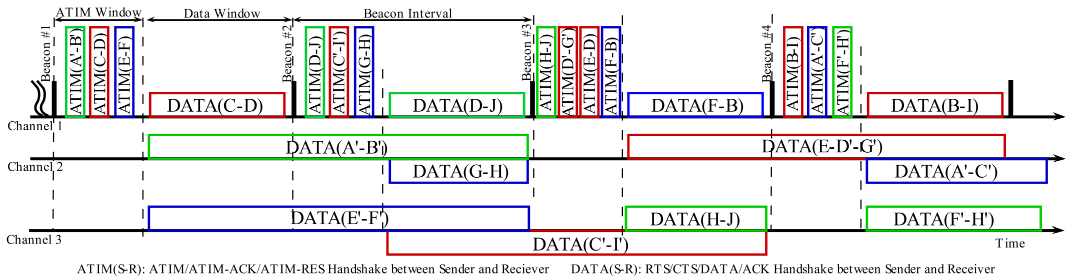


Fig. 1. The operation of H-MMAC protocol

- All nodes are time-synchronized and operate the IEEE 802.11 DCF mechanism.
- Nodes have prior knowledge of how many channels are available.
- Each node has a single half-duplex transceiver such that it can either transmit or listen but not both simultaneously.

For the completeness of our proposal, we define two transmission modes (Tx mode): Normal Transmission (N-Tx) and Extended Transmission (E-Tx) as the transmission performed within the data window and within the data window and also the next beacon, respectively. The E-Tx is obviously longer than the N-Tx. We use the E-Tx_Node_Threshold to limit the number of node in E-Tx mode on each channel. A node chooses which transmission mode based on the network load by using the E-Tx_Retry_Threshold.

Next, we classify the neighbor node into four types: Normal, Ongoing, Limited and Unknown used in the Neighbor Information List (NIL).

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

Now, we describe our proposed protocol in detail.

### *A. Neighbor Information List and Preferable Channel List*

Each node maintains its data structures called the Neighbor Information List (NIL) and Preferable Channel List (PCL). The NIL stores the information of neighbor nodes such as: channel, type and transmission mode while the PCL stores the information about channels such as: state, node counter and E-Tx counter.

*1) 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. 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.

It is 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, it updates its NIL.

TABLE I
NODE A'S NIL

| Node | Channel-CHNL | Type-TYP | Tx mode |
|---|---|---|---|
| B | 0 | Limited | N-Tx |
| C | 0 | Unknown | N-Tx |
| D | 2 | Normal | E-Tx |
| E | 3 | Unknown | N-Tx |
| ... | ... | ... | ... |

TABLE II
NIL'S UPDATE

| Node A's Type | Before update | | | After update | | |
|---|---|---|---|---|---|---|
| | CHNL | TYP | Tx | CHNL | TYP | Tx |
| Normal | - | Unknown | N-Tx | 0 | Normal | N-Tx |
| Normal | - | Unknown | E-Tx | - | Unknown | N-Tx |
| Normal | 0 | Limited | E-Tx | 0 | Normal | N-Tx |
| Normal | X | Ongoing | E-Tx | 0 | Limited | E-Tx |
| Any | X | Normal | E-Tx | X | Ongoing | E-Tx |
| Ongoing | - | $\overline{\text{Ongoing}}$ | - | - | Unknown | E-Tx |
| Normal | X | Normal | N-Tx | 0 | Normal | N-Tx |

Any: Normal or Ongoing type
X: Non-zero channel
$\overline{\text{Ongoing}}$: node that is not Ongoing type

TABLE III
NODE A'S PCL

| Channel | State | Node counter | E-Tx counter |
|---|---|---|---|
| 1 | Not_Selected | 3 | 1 |
| 2 | Selected | 1 | 0 |
| 3 | Not_Selected | 0 | 0 |

*2) Preferable Channel List - PCL:* Each channel in the PCL has the state either Selected or Not_Selected state. The Selected channel means that this channel has already been chosen by the node to use in the current beacon, otherwise the Not_Selected channel. So, at most one channel can be Selected at each node for each beacon. The Node_counter of a channel shows how many node pairs already reserved that channel. The E-Tx_counter of a channel is used to count how many nodes perform E-Tx transmission on that channel. The E-Tx_counter is used to update Node_counter at the beginning of each beacon. Table III is the node A's PCL after node A finished exchanging ATIM messages with node B at the fourth ATIM window (Fig. 1).

The PCL is updated whenever the node overhears ATIM-ACK/ATIM-RES messages or when the node selects a channel to use in the data window.

- All the channels are reset to Not_Selected state at the start of each beacon interval.
- Since E-Tx node is on a data channel for the data transmission, the node counter is updated from E-Tx counter.
- If the source and destination nodes reserve a channel to exchange data, this channel is changed to Selected state in both source and destination's PCL.
- When a node knows that its neighbor node plans to use a channel through ATIM-ACK/ATIM-RES packet, it increases the counter of that channel by one.

### *B. The operation of H-MMAC protocol*

In the ATIM window, there are four types of node: Ongoing, Limited, Normal and Unknown but 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 the 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 the next beacon.
3) Based on the traffic load, the sender decides which transmission mode is used (N-Tx or E-Tx).
4) The sender attaches its PCL and transmission mode into the 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, both sender and receiver switch to agreed channel for exchanging data.
8) Both sender and receiver go to doze mode after finishing their data transmission to save energy.

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

```
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
```

## IV. Performance Evaluations

In this section, the performance of H-MMAC is evaluated compared to IEEE 801.11 [1], DCA [4], MMAC [7] and $\pi$-Mc [11] in terms of the aggregate throughput, the average delay and the energy efficiency.

TABLE IV
SIMULATION'S PARAMETERS

| Parameters | Value |
|---|---|
| Transmission range | 250 m |
| Number of channels | 12 channels |
| Basic rate / Data rate | 1 Mbps / 2 Mbps |
| Data packet size | 512 bytes |
| ATIM window / Beacon Interval | 20 ms / 100 ms |
| SIFS / DIFS / Slot time | 16 $\mu$s / 34 $\mu$s / 9 $\mu$s |
| ATIM / ATIM-ACK / ATIM-RES | 27 bytes / 16 bytes /16 bytes |
| Retry limit | 7 |
| Transmit/Receive power consumption | 1.65W / 1.4W |
| Idle/Doze power consumption | 1.15W / 0.045W |
| E-Tx_Retry_Threshold | 4 |
| E-Tx_Node_Threshold | 2 nodes |

### *A. Simulation Model*

The network consists of 50 nodes in a 250m x 250m area. Each node generates and transmits constant-bit-rate (CBR) traffic. The other simulation parameters in our simulations are listed in Table IV. Each simulation was performed for 5 seconds and the simulation results are the average of 30 runs.

### *B. Simulation Result*

The aggregate throughput, the average delay and the energy efficiency comparisons are shown in Fig. 2. The multi-channel MAC protocols have higher throughput than the IEEE 802.11 MAC. Although the multi-channel MAC protocols can exploit multiple channels, but some of them cannot utilize all channels resources due to their characteristics. The DCA protocol cannot utilize the multiple channels fully because of congestion on control channel. The overhead of channel switching time affects the performance of $\pi$-Mc. The more channels MMAC uses, the more channel resources are wasted during the ATIM window. Although the ATIM window also impacts the performance of the H-MMAC protocol on default channel, the other channels are fully utilized when the traffic load is high. That is the reason that H-MMAC achieves almost 12 times as much throughput compared to IEEE 802.11 MAC and about 22% throughput higher than MMAC protocol. Since more data packets are transmitted, the average delay of H-MMAC protocol is low as shown in Fig. 2(b). By adopting the IEEE 802.11 PSM, both MMAC and H-MMAC can save the energy by allowing nodes to go to doze mode if they do not need to exchange data. With higher throughput and less energy consumption, H-MMAC protocol has higher energy efficiency as shown in Fig. 2(c).

Fig. 3 shows the impact of the number of channels on the performance of different multi-channel MAC protocols. Since H-MMAC can utilize all data channels during the ATIM window, the throughput increases likely linearly with the number of channels. As the result, H-MMAC protocol has the higher throughput, lower delay and higher energy efficiency compared to other multi-channel protocols.

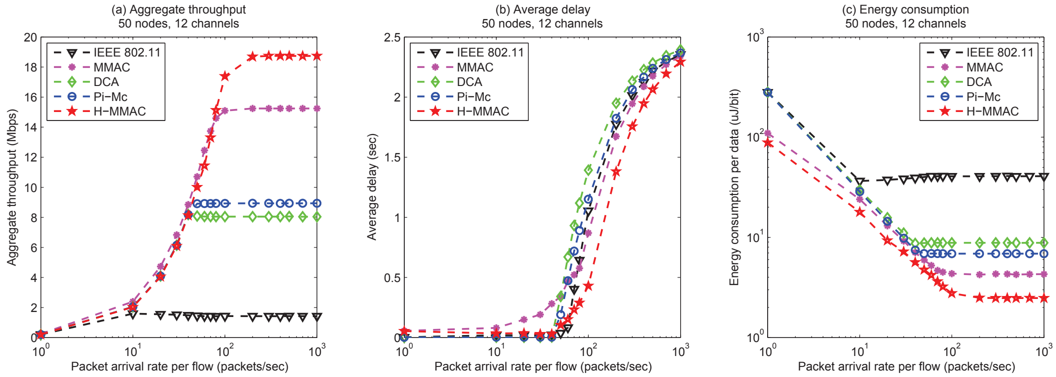


Fig. 2. Performance comparison of different protocols vs. packet arrival rate.

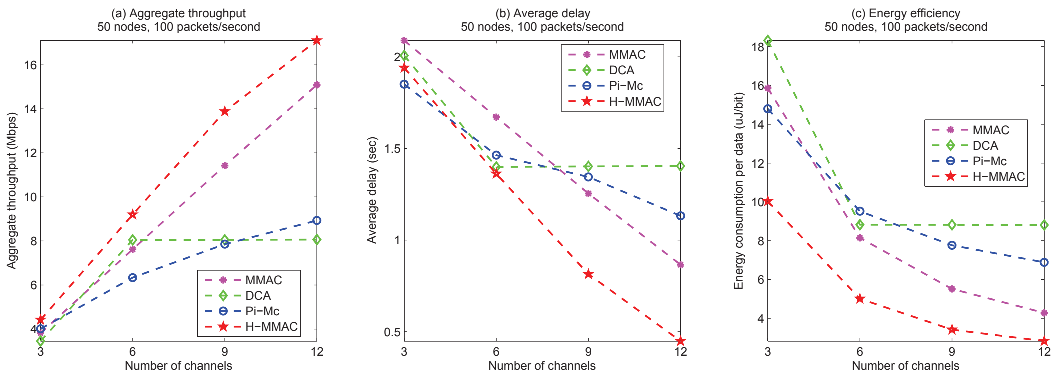


Fig. 3. The impact of number of channels on the performance of different multi-channel MAC protocols.

## V. Conclusions

In this paper, we have proposed a hybrid multi-channel MAC protocol, named H-MMAC, that utilizes almost all of the entire channel resources to improve the network performance. By using the PSM and allowing nodes transmit data during the ATIM window, H-MMAC achieves higher performance than other multi-channel MAC protocols. Simulation results showed that the H-MMAC's performance is increased significantly when the number of channels is large.

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## References

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

[2] Jeonghoon Mo, So H.-S.W. and Walrand J. *Comparison of Multichannel MAC Protocols*, IEEE Transactions on Mobile Computing, Jan 2008.

[3] M. Wang, L. Ci, P. Zhan, Y. Xu. *Multi-channel MAC Protocols in Wireless Ad Hoc and Sensor Networks*,ISECS Int. Colloquium on Computing, Communication, Control, and Management (CCCM 08), 2008.

[4] Shih-Lin Wu, Chih-Yu Lin, Yu-Chee Tseng and Jang-Laing Sheu. *A new multi-channel MAC protocol with on-demand channel assignment for multi-hop mobile ad hoc networks*, Proceedings. International Symposium on Parallel Architectures, Algorithms and Networks, 2000. I-SPAN 2000.

[5] S.-L. Wu, Y.-C. Tseng, C.-Y. Lin and J.-P. Sheu. *A multi-channel MAC protocol with power control for multi-hop mobile ad hoc networks*, The Computer Journal vol. 45, no. 1, p. 101-110, 2002.

[6] 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.

[7] Jungmin So and Nitin H. Vaidya. *Multi-Channel MAC for Ad hoc Networks: Handling Multi-channel Hidden Terminals Using A Single Transceiver*, Proc. of *(Mobihoc'04)*, 2004.

[8] 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.

[9] Liao W.-H., Shih K.-P. and Chung W.-C. *Multi-channel medium access control protocol with channel distribution for mobile ad hoc networks*, IET communications, 2009.

[10] A. Tzamaloukas A and J.J. Garcia-Luna-Aceves. *Channel-hopping multiple access*, IEEE International Conference on Communications (ICC 2000), 2000.

[11] Kuei-Ping Shih, Yen-Da Chen and Shu-Sheng Liu. *A Collision Avoidance Multi-channel MAC Protocol with Physical Carrier Sensing for Mobile Ad Hoc Networks*, IEEE WAINA 2012, 2010.

[12] Bahl Paramvir, Chandra Ranveer and Dunagan John. *SSCH: slotted seeded channel hopping for capacity improvement in IEEE 802.11 ad-hoc wireless networks*, In Proc. of *(MobiCom '04)*, 2004.

[13] Hoi-Sheung Wilson So and Jean Walrand. *McMAC: A Multi-Channel MAC Proposal for Ad-Hoc Wireless Networks*, In Proc. of IEEE WCNC 2007, Hongkong, 2007.

[14] Almotairi K.H. and Xuemin Shen. *Fast and Slow Hopping MAC Protocol for Single-Hop Ad Hoc Wireless Networks*, 2011 IEEE International Conference on Communications (ICC 2011), 2011.