A Multi-channel MAC Protocol with Power Control 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 channel. The multi-channel can be exploited to get more concurrent transmission. Our new scheme of Multi-channel MAC protocol with Power Control named MMAC-PC can avoid the multi-channel hidden terminal problem as well as improve the performance of the network.

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

1. Introduction

The performance of the ad hoc network is affected by the hidden terminal problem as well as the limited bandwidth of single channel. To avoid the hidden terminal problem, IEEE 802.11 DCF [1] uses the channel reservation technique by exchanging "Request to Send" (RTS) and "Clear to Send" (CTS) messages before data packets are sent. In addition to the RTS-CTS-DATA-ACK handshake, the IEEE 802.11 DCF employs a Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) technique.

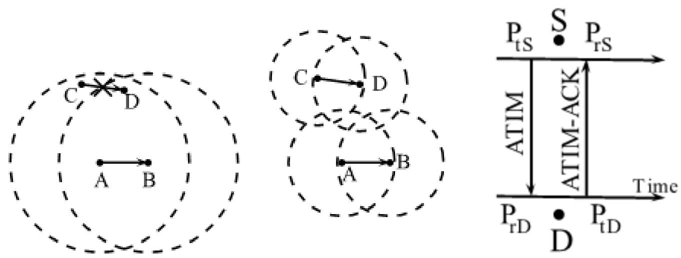
Although the IEEE 802.11 provides multiple channels for wireless communications at Physical Layer, the MAC layer is designed only for a single channel. However, it is not easy to design the MAC protocol that can exploit multiple channels with a single half-duplex transceiver. Transceiver cannot sense 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, we refer as *multi-channel hidden terminal problem* [2].

In this paper, we propose a Multi-channel MAC protocol with Power Control. The main idea is using small interval in each beacon to negotiate channels for using during the remaining beacon interval. In addition, a simple power control algorithm is used to reduce the interference to a neighbor by adjusting the transmission power in each beacon interval.

2. The Proposed MMAC-PC protocol

First, we summarize our assumptions as below:

1) There are N non-overlapping channels can be used. All channels have the same beacon interval. The beacon interval is divided into two sub-intervals: ATIM window, Data window as shown in Fig. 2. One channel is defined as a Control Channel (CH0) in the ATIM window.
2) Nodes have prior knowledge of how many channels are available.
3) All control messages in ATIM windows are transmitted with the maximum power while the others in Data windows are sent with negotiated power.
4) Each node is equipped with a single half-duplex transceiver, and it is capable of switching its channel dynamically.
5) All nodes are time-synchronized and applied the IEEE 802.11 DCF mechanism.



a) b)

Fig. 1. Simple Power Control Mechanism

A. Power Control

Transmit power control is a technical mechanism to improve frequency utilization efficiency (see Fig. 1a) by preventing co-channel interference as well as to save the energy of a mobile device with limited battery. We use the simple power control [3]. Let P_{ti}, P_{rj} be the transmit power from node i and the received power of node j respectively. The receive power is calculated as [4]:

$$P_{rj} = P_{ti}(\frac{\lambda}{4\pi d})^n G_t G_r \quad (1)$$

where

λ carrier wavelength;

d distance between transmitter and receivers;

n path loss coefficient, typically 2;

Gt, Gr antenna gains of transmitter and receiver.

Now, we consider the Fig. 1b with source S and destination D.

$$P_{rD} = P_{tS}(\frac{\lambda}{4\pi d})^2 G_t G_r$$
$$P_{rS} = P_{tD}(\frac{\lambda}{4\pi d})^2 G_t G_r \quad (2)$$

Dividing these above equations, we have:

$$\frac{P_{rD}}{P_{rS}} = \frac{P_{tS}}{P_{tD}} \quad (3)$$

Now, we can determine the transmit power P_{tD} if the other powers are known. All control messages like ATIM, ATIM-ACK and ATIM-RES are transmitted with the maximum power P_{max} and the minimum received power that mobile nodes can distinguish signals from noises is P_{min}. So, when node S sends ATIM message with P_{tS}=P_{ATIM}=P_{max}, node D receives with power P_{rD}. Node D can determine which value of P_{tD} so that the expected receive power level at node S P_{rS}=P_{min}. On the other hand, node S can determine the transmit power P_{tD} after receiveing ATIM-ACK from node D.

B. Channel Usage List and Neighbor Information List

Each node maintains its data structure called the Channel Usage List - CUL(see Table I) and Neighbor Information List - NIL (see Table II). In CUL, each channel has a counter. The counter equals zero that means no node reserves this channel for data transmission; this channel is idle. These counters are used in CUL to balance the channel load as much as possible, the same mechanism like in [2].

TABLE I

NODE A's CUL

Channel	Counter
CH1	1
CH2	0
CH3	1
CH4	2
...	...

TABLE II

NODE A's NIL

Node	Channel	Power	Status	Interference
B	2	3	Idle	0
C	4	4	Busy	1
D	1	7	Busy	0
E	3	1	Idle	0
...	...	...	...	...

Each entry in NIL has 4 fields that contain all information about neighbor nodes as below:

1) Channel: which channel that node switches to after ATIM window;
2) Power: the required power level for transmiting to neighbor node. It is updated when a node overhead any control messages of neighbor in ATIM window. A timeout mechanism is used to keep this value up-to-date. When a node does not hear any communication from its neighbor, it sets power = ∞.
3) Status: Busy if this node is going to exchange data and Idle otherwise;
4) Interference: the power transmitted in data window by neighbor node can be overheard or not.

At the beginning of each beacon, nodes set value of counter to zero for all channel in CUL; set status to Idle, interference to zero in NIL. Nodes overhear control messages in ATIM window update all fields of their CULs and NILs.

C. Rules for creating Preferable Channel List

Each node has to create Preferable Channel List (PCL) when it wants to communicate with another. The channel CH_i is added to PCL when it is a free channel (CH_i.counter = 0 in CUL) or the transmit power on that channel CH_i to destination does not interfere with other transmissions in data window.

For example, node A wants to send data to node B. We consider the CUL and NIL of node A are shown in Table I and II:

• From CUL: Channel 2 is added to PCL because its counter is zero.

• From NIL: Channel 1 is added because it satisfies two conditions: node D is going to use this channel but it does not interfere with node A; the transmit power to B is less than to D, that means node A does not interfere with node D.

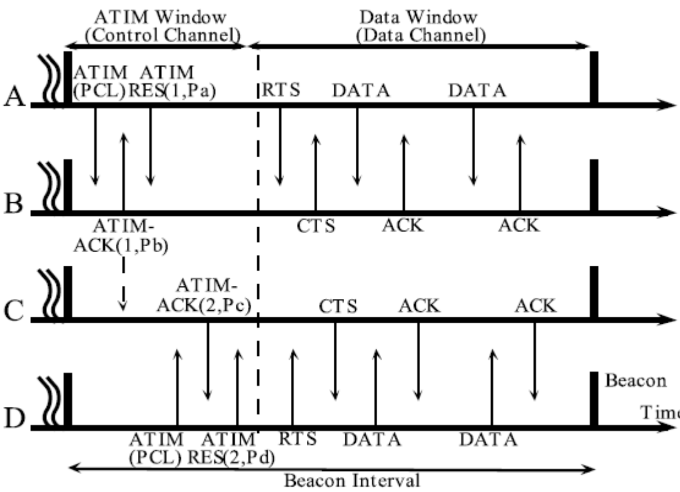


Fig. 2. Negotiation and data exchange in MMAC-PC

D. ATIM windows

The ATIM window has the role as in IEEE 802.11 PSM. All nodes have to switch to control channel and use the 3-way handshake (ATIM/ATIM-ACK/ATIM-RES messages) to select a data channel in ATIM window. Both ATIM-ACK and ACK-RES messages require the transmit power level and information of channel. The transmit power level can help neighbor nodes determine they are interfered or not. After a sender-receiver pair finishes channel negotiation, they stay awake for entire beacon interval. If a node has no data packet in its buffer or does not receive any ATIM message, it goes into doze mode after ATIM window to save energy. All ATIM, ATIM-ACK and ATIM-RES messages are transmitted with the maximum power.

E. Algorithm of MMAC-PC protocol

The main idea is the sender-receiver pair try to contend the channel on the control channel in ATIM window. Sender sends ATIM message, including PCL to a receiver. Receiver chooses the "best" channel and calculates the transmit power of the sender, then sends this information through ATIM-ACK message. Sender confirms the selected channel and calculates the transmit power of the receiver, then replies with ATIM-RES message.

The example of MMAC-PC is illustrated in Fig. 2. Suppose node A has some data for node B and node D wants to send data to node C.

1. Node A checks the status of node B in its NIL. If node B is Busy, node A has to wait for next beacon interval. If node B is Idle, node A includes its PCL in ATIM message and sends to node B.

2. After receiving ATIM(PCL) message from node A, node B compares its PCL and the PCL from node A to choose the free common data channel CH_i. Base on the receive power of ATIM message, node B calculates the transmit power PWR_B that should be used when transmit data to node A in Data window. Now, node B sends ATIM-ACK(CH_i,PWR_B) to node A with two information: which data channel will be used and which power level that node B uses in next data window.

3. In the reception of ATIM-ACK, node A also calculate its transmit power PWR_A to node B and confirms the data channel CH_i selected by node B by replying with ATIM-RES(CH_i,PWR_A).

4. Node D has data for node C. Node D sends ATIM(PCL) to node C. By overhearing ATIM-ACK from node B, node C may choose another data channel.

5. After ATIM window, node A, B and node C, D switch to corresponding data channels to exchange data by using RTS/CTS/DATA/ACK handshake.

When the network load is low, the above algorithm is similar to MMAC [2] except power control to save energy. In this case, the number of sender-receiver pairs is less than or equal to the total number of channel, the first condition of rules for creating PCL is always satisfied. That leads to a sender-receiver pair uses one of N data channels in Data window. But when the network load increases, the number of data channel is not enough, nodes use the second condition to create PCL. More than one sender-receiver pair use the same data channel because of their transmit power are controlled so that their signal do not interfere with each others.

3. Conclusions and Future work

Although a lot of multi-channel MAC protocols for Ad hoc networks have been proposed, design of efficient enough multi-channel MAC has a still long way to go. In this paper, we have proposed the Multi-channel MAC protocol with Power Control that can improve the performance of Ad hoc networks. For the future work, we will conduct extensive simulations to compare the performance of our protocol with IEEE 802.11 and previously proposed multi-channel MAC protocols based on various performance metrics: aggregate throughput, average packet delay and, etc.

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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; 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] Wesel, E. K. *Wireless Multimedia Communications: Networking Video, Voice and Data*, Addison-Wesley, 1998.