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Hop-Reservation Multiple Access with Variable Slots

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Abstract

Hop-reservation multiple access control protocols in Ad Hoc networks are widely researched for its virtue in anti-jamming. Several typical such protocols are introduced and compared. Based on the analysis about their performance on anti-jamming and ability to serve upper protocols, a hop-reservation multiple access protocol with variable slot (HMAVS) is proposed. By the adaptation of variable length slots, the hop speed of control channel can be supported to the largest extent while diverse applications can be served without additional cost. Simulation results demonstrate the preference of HMAVS to other existing protocols.

Keywords: Ad hoc networks; multiple access protocol; hop-reservation; variable slot; anti-jamming

1. Introduction

Ad hoc networks are temporarily deployed multi-hop networks composing of mobile terminals with wireless radios, in which communications are executed through retransmitting of the terminals. This kind of networks does not rely on infrastructures such as base stations and routers. Thus Ad hoc networks are very suitable for the applications in Tactical Internet, fleet communications, disaster relief, temporary conference networking, and other infrastructure-less scenarios. As distributed multi-hop networks, the transmitting range of terminals in Ad hoc networks is limited. As a result, the spectrum can be reused if the terminals are apart from each other. Meanwhile, the determination and avoidance of message collisions are pivotal for the performance of the network. The difference of the sensed channel conditions and message collisions results in exposed terminal problems and hidden terminal problems which degrade the spectrum efficiency a lot.

As direct controllers of the transmitting and receiving of messages in Ad hoc networks, multiple access control (MAC) protocols lie in the ground floor of the protocol stack, control the channel access, schedule the potential competition and collision, and play a key rule in the efficient usage of spectrum and network performance guarantee. According to the usable channel numbers in the network, MAC protocols can be classified into single channel protocols, double channel protocols, and multiple channel protocols. Single channel MAC protocols can not eliminate exposed terminal problems and hidden terminal problems completely. Double channel MAC protocols can solve the two problems with proper interaction on control channel. Yet there is only one usable data channel which restricts the communication capacity of the network. Meanwhile, the development of wireless terminals makes the multiple channels MAC protocol feasible, in which the users can communicate through multiple channels and the network

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capacity can be enhanced remarkably. To achieve multiple channel access, we can either equip a user with multiple transceivers or make one transceiver switch on different channels. The former method facilitates the channels allocation and management, but the power consumption is high and the inter-node interference of different transceivers is serious. The latter method uses one transceiver to switch on different channels and the controlling is complex relatively, but the power consumption is much less, which is preferable in the mobile applications. Meanwhile, the switching delay has been decreased to 80 μs [1] as the advancement of hardware. Thus most multiple channel MAC protocols are based on single transceiver. In this paper, we focus on the multiple channels MAC protocols with one transceiver.

According to the control and allocation strategies, existing multichannel MAC protocols can be divided into four categories. The first kind is dedicated control channel protocols, i.e., CMCT [2], which assign a dedicated channel as control channel to exchange control message. These protocols do not require strict synchronization, but the control channel is easy to be congested or jammed and become a bottleneck of the network. The second kind is split phase based protocols which require the terminals switch bask to a control channel periodically to exchange control message and reserve channels. Thus strict synchronization is critical for the coordination. A reprehensive such protocol is MMAC in [3]. The third kind protocols are multiple rendezvous based, following which each terminal hold several hopping sequences and the working channel is exchanged with neighbors through sequence seed broadcasting [1]. The forth kind is hop-reservation based protocols which take a common hopping sequence as control channel. Two reprehensive such protocols are RICH-DP [4] and HRMA [5]. The control channels of the forth kind protocols are more robust, but broadcast can not be well sustained.

The open feature of wireless environment makes the wireless communication sufferable to man-made or natural interference and jam. Especially in the complex spectrum environment of tactical internet, the jamming, wiretapping, and attack from adversary threaten the network seriously. The hop-reservation MAC protocols incorporate frequency hopping, main technique for anti-jamming, anti-intercept, and secure transmission in wireless communications [6], into the channel design to solve the robustness problems in ad hoc networks, being an important research direction.

In this paper, we firstly analyze the existing hop-reservation MAC protocols. Based on the analysis, a new hop-reservation protocol with variable slots reservation is proposed and simulated to evaluate its performance.

2. Analysis of Several Hop-reservation MAC Protocols

Incorporating frequency hopping into control channel design of ad hoc networks, hop-reservation MAC protocols have great potential in refraining control channel congestion and anti-jamming. Their application perspective in tactical internet is expansive. In this section, we introduce several representative hop-reservation MAC protocols and analyze their performance in both control channel robustness and support ability for upper layer protocols.

2.1. Several Representative Hop-reservation MAC Protocols

Tzamaloukas al. [4] propose a receiver-initiated channel-hopping with dual pooling protocol (RICH-DP), following which users hop usually on a common hopping sequence. When a user *i* want to initiate a session with node *j*, it transmits a ready-to-receive (RTR) message o the current channel and waits for the reply from j. Successfully received a RTR, *j* begins to transmit data to *i* on current channel directly if it has data for user *i*. Otherwise, it sends a clear to send (CTS) message to *i* to notify *i* that it can send data on the channel. Meanwhile, other users continue to hop on the common hopping sequence. And when the data exchange between *i* and *j* ends, they join the common hopping sequence again. This protocol reserves channels on common hopping sequence while other users normally hop, thus the hidden terminal problem is solved. There will no data collision if the data exchange time is shorter than frequency hopping cycle. Furthermore, the receiver-initiate design reduces the control overhead, especially for the reactive routing strategy where the destination can directly reply RREP message when receiving a RREQ message rather than reserve channel through RTR/CTS exchange.

A hop-reservation multiple access protocol (HRMA) is proposed in [5]. Let L denote the number of available channels. In these channels, one channel f_0 is assigned for synchronization and the rest are divided into (L-1)/2 channel f_i^* couples (f_i, f_i^*) with f_i for hop-reservation (HR) packets, RTS/CTS packets and data packets and f_i^* for ACK packets. Each frame begins with a synchronization slot, which is followed by a synchronization period, a HR slot, and RTS/CTS slot. HR slot is used for reserving a period longer than a frame and all users should stop competing and wait for the next frame if they sense HR packets. Otherwise, users compete for (f_i, f_i^*) through RTS/CTS packets to avoid hidden terminal problem. This protocol can provide distributed synchronization through synchronization slot and synchronization period, but the special ACK channels limit the improving of spectrum efficiency.

To improve the robustness of the channels in HRMA and RICH-DP, the hopping sequences are used for data channel in the FHMCRMA [7]. In this protocol, all available channels are used to create an orthogonal hopping map, in which one sequence is used for control message exchange and others for data transmission. To support broadcast, the broadcast messages are given priority on the common hopping sequence.

2.2. Robustness of the control channel

The control channel is the foremost element for the robustness of the network. In the frequency hopping system, the hopping speed is the most important indication of the system performance and the high hopping speed is taken for more robustness [6]. In the hop-reservation MAC protocols, hopping sequence is taken as control channel, thus being the key of the system. In practice, the hopping speed is constrained by the processing speed of control channel, the reactive speed of frequency synthesizer, the process speed of CPU, physical channel characteristics and the cost of the facility.

Let the hopping speed be n hops/s, channel switching time is Δ and the data rate of user is a hops/s. Then the data length on each slot is given by

$$L = (\frac{1}{n} - \Delta)a \tag{1}$$

If the shortest data length needed to be sent on each slot is l bit, we have

$$n \leq \frac{a}{l + a\Delta} \tag{2}$$

It can be inferred from (2) that the hopping speed n is in inverse proportion with the shortest data length l and in direct proportion with data rate a. Given a, the supported hopping speed n is bigger with a smaller l. In RICH-DP, the length of l is equal to the transmission time of RTS and a propagation delay; in HRMA, the length of l is equal to the transmission delay of RTS and CTS with two propagation delay. Thus, the hopping speed of RICH-DP can be two time as that of HRMA, indicating a robustness preference. The robustness of FHMCRMA is the same with RICH-DP.

For data channels, FHMCRMA is preferable for the frequency hopping data channels with some anti-jamming ability.

2.3. Support ability for upper layer

Ad hoc networks are packet networks based on TCP/IP protocol stack. Thus the design of MAC protocols should considers the support ability for upper layer. The overhead of the protocol stack includes transport layer (8 byte for UDP), routing layer (12 byte at least for AODV and DSR) and MAC layer (at least 12 byte), sum up to 32 byte at least when a packet comes to the physical layer. Since RICH-DP and HRMA stay on the current channel at least one frame for data transmission after successful reservation, the protocol overhead is relative small. In contrast, a hopping sequence is reserved for data transmission in FHCRMA and the supported packet on each slot is relatively small. Taking the parameters n=2000hops/s, a=2Mbps, $\Delta = 80\mu s$ as an example, it is easy to compute that the data length which can be transmitted on each slot is only 125 byte. Thus the data channel robustness of FHCRMA is at the cost of protocol efficiency. Possible solutions to the inefficiency include amending physical layer and splitting long data packet at MAC layer, but the protocol complexity would be increased a lot.

For broadcast messages, RICH-DP and HRMA take them as normal data packets. On the other hand, highest priority is given to broadcast messages by FHCRMA and the routing protocols can be well supported.

3. Hop-reservation Multiple access with Variable slots

Based on the analysis of existing hop-reservation MAC protocols, we propose a Hop-reservation Multiple access with Variable slots (HMAVS) in this section to accommodate to the channel robustness and supporting upper layer requirements in the ad hoc protocol stack.

3.1. Description of the protocol

Similar to FHCRMA, HMAVS also make a hopping sequence map using all the available channels in the network. In the N constructed sequences, one is assigned as common control sequence and the others are for data transmission. For descriptive convenience, we use channel to denote the hopping sequences hereafter. Some integral time slot length data channels are constructed based on the orthogonality rule. For synchronization, all users go back to f_0 to exchange synchronization messages in the first slot of the frame.

The framework of the protocol is given in figure 1. All the nodes hop on the common hopping sequence. If a node has packets to send, it reserves the data channel on the current channel through RTS/CTS messages. If success, the sender and the receiver switch to data channel (a hopping sequence) for data transmission. If the reservation fails because of collision or broadcast massage reservation, the sender waits for a random number slot for another reservation attempt.

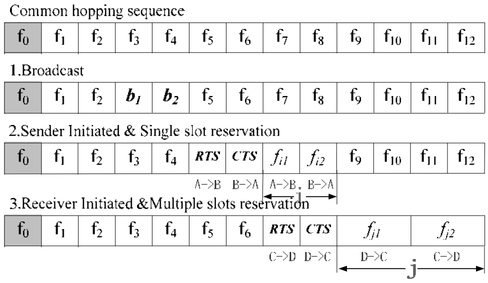

Fig.1. Frame structure of HMAVS

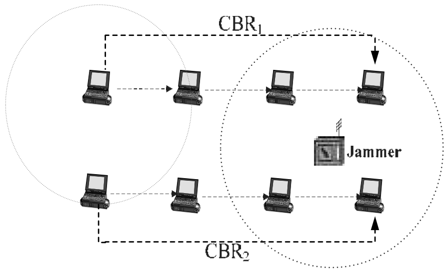

Fig. 2. Simulation scenario

Before reservation, nodes select transmission strategies based on the data types. Broadcast has the highest priority and can be sent on the common hopping sequence directly. For unicast messages, the sender or the receiver chooses to reserve different slot length data channels according to the packet length, details of which are as follows.

(1). Broadcast messages

Broadcast messages are given highest priority and the sender can send on common hopping sequence directly if the channel is sensed to be free at the start of the slot.

(2). Sender initiated single slot length channel reservation

When a node A wants to send data to node B, it senses the channel at the start of the slot. If no broadcast messages sensed, it send RTS on the current channel (f_5) to node B. If B successfully receives RTS and it does not in the data transmission process with other nodes, B firstly checks whether it has messages for node A. If there is, it choose the strategy in (3). Otherwise, node B chooses an available channel (a hopping sequence), elapses the chosen channel in CTS message, and sends CTS to node A on the current channel. After that, node B switches to the chosen channel on the start of the next slot and waits for data from node A. Node A also switches to the chosen channel on the next slot after receivers the CTS. The reservation time of a channel is one frame, before the end of which no further reservation of the channel is allowed.

(3). Sender initiated multiple slots reservation

If node B finds that it has length packets for node A after receiving RTS (as the condition of node C and D in figure 1), it chooses a long slot channel and notifies node A by CTS. In the next slot, B switches to the chosen channel and starts transmitting directly to A. The reserved time of the channel is also one frame time.

Beside the after mentioned three patterns, sender initiated multiple slots reservation and receiver initiated single slot reservation are also supported, details of which is similar to that of the described three patterns.

3.2. Analysis of the protocol

The slot length of HMAVS is constrained by the transmission time of RTS/CTS. Since the two control message are rather short, the hopping speed can be increased to the most extent and the robustness of the common hopping sequence is ensured. Furthermore, the data channels are constructed by the orthogonal hopping sequences. When the data packets can be transmitted within one slot, the robustness of data channels can be same with that of control channels. Meanwhile, packets with different length are supported with variable length slots and the long packets need not to be divided in upper layer. Thus the complexity of the protocol is decreased.

For broadcast messages, HMAVS assigns highest propriety to ensure the rapid efficient transmission of broadcast messages which is essential for the route establishment and update.

4. Performance Evaluation

We simulate the protocol with the network simulator Qualnet 3.7 in this study. The network topology is described in figure 2. There are two CBR flows in the network, whose packet sizes are 256 byte and 512 byte respectively. DSR protocol is adopted in the network layer. In the 2.4Ghz band, 16 channels with 25M interval and 2Mbps data rate are selected. These channels are orthogonalzed to create hopping sequences which are taken as channels in the network. There are variable numbers of jammers in the network, transmitting interference on the channels. The performance of HMAVS, HRMA, and RICH-DP is evaluated in different jammer numbers environment.

Figure 3-1 compares the throughput of the protocols with the variation of the number of jammers n. From the figure, it can be observed that when there is no jammer, the performances of the protocol are almost the same and degradation is obvious then the jammers are more. However, the decrease of the performance of the network using HMAVS is much slower, indicating its adaption of the complex interference environment.

Figure 3-2 compares the average end to end delay of the three protocols. It can be observed from the figure that the end to end delay of HMAVS is much less than the two counterparts, which results from the flexible channel reservation scheme and the anti-jamming ability of the data channels.

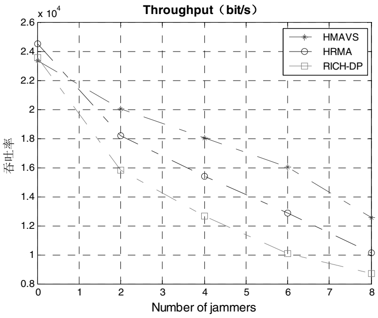

Fig 3-1. Network throughput

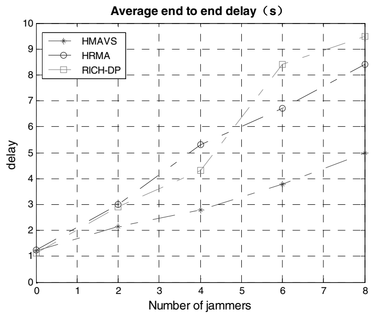

Fig 3-2. Average end to end delay

5. Conclusions

In this paper, the hop-reservation MAC protocols are analyzed and variable slot hop-reservation MAC protocol is proposed. The analysis and simulation demonstrate the obvious preference of the proposed protocol on both throughput and end to end delay.

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