A Survey on Multiple Channel protocols for Ad Hoc Wireless Networks

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Abstract

Wireless ad hoc networks often suffer from rapidly degrading performance with the number of user increases in the network. One of the major reasons for this rapid degradation of performance is the fact that users are sharing a single channel. Obviously, the problem of using single shared channel schemes is that the probability of collision increases with the number of nodes. Fortunately, it is possible to solve this problem with multi-channel approaches. Due to the especial properties of multiple channels, using the multiple channels is more efficient than single channel because it enhances the capacity of the channel and reduces the error rate during data transmission. Some multi-channel schemes us one dedicated channel for control packets and one separate channel for data transmissions. On the other hand, another protocols use more than two channels for data transmissions. This paper summarizes six multiple channel protocols based on these two kinds of schemes. Then we compare them and discuss the research challenge of multiple channel protocols.

1. Introduction

In the ad hoc wireless networks, the MAC layer takes the responsibilities for the data transmission. However, in real world, the wireless channel is susceptible to a variety of transmission impediments such as path loss, interference, and blockage. These transmissions impediments often influence the throughput of wireless network. What is more serious, the collision is another problem which due to the increasing of number of nodes and influences the throughput dramatically. It is well know that ad hoc networks suffer from rapid degrading performance as the number of users increases in the network. One of the major reasons is that all users in the network share a single channel. However, most of protocols for wireless ad hoc networks are designed to work in a single channel environment. This is because most current devices are equipped with a single transceiver, and only listen to one channel at a time. This constraint complicates the protocol design, which discourages the use of multiple channels in ad hoc networks. Wireless networks follow a different mechanics than wired networks. Lower channel bandwidth and faster propagation speed typically result in a much smaller normalized propagation delay. Collisions occur for a very different reason. Signal strength reduces with distance and thus it is possible that some nodes in the network cannot hear each other sufficiently well, the single strengths being below the carrier-sensing threshold. This cause transmitting nodes to be “hidden” form other nodes, and still can cause sufficient interference at the receiver for packets to be lost due to collisions. Using multiple channels, two transmissions take place simultaneously without interfering each other. In IEEE 802.11 infrastructure mode, neighboring *access points (APs)* often operate on different channels to reduce interference between cells.

The Problem in utilizing multiple channels is that current devices are often equipped with a single transceiver. Thus, a node can only transmit or receive on one channel at a time, although nodes can switch channels in a short time. If two nodes are on different channels, they cannot communicate with each other. So they need to agree on a common channel and switch to that channel in order to communicate. Recently, more and more MAC and routing protocols are proposed in the context of multi-channel networks. In this paper, we focus on some multiple channel protocols. A comparative table is depicted and the pros and cons will be compared with key performance metrics. The rest of this paper is organized as follows: in the following section 2, the description of several multiple channel protocols are given and the key properties of multiple channel protocols are briefly reviewed. Section 3 is the enhancement of our comparison. Finally, the conclusion of this paper covered in section 4.

2. Multiple Channel Protocols

In the classification, some multi-channel schemes use a specific channel for control packets and one separate channel for data transmission. They set up busy tones on the control channel, albeit one with small bandwidth consumption, so that nodes are aware of ongoing transmission for avoid the collision. These protocols only use two channels in MAC layer. Other approaches use multiple channels for data packet transmissions. It means that there will be more than two channel used in these protocols. These approaches have the following advantages. Using more channels appropriately can potentially increase the throughput. Data transmitted on different channels does not interfere with each other, and multiple transmissions can take place in the same region simultaneously. This leads to significantly fewer collisions. It is easier to support QoS by using multiple channels. We summarize some multiple channel protocols that proposed so far in following part, and these protocols belong to two approaches we described before. Some issues of medium access still need to be resolved.

2.1 Dual Busy Tone Multiple Access (DBTMA)

In the presence of hidden terminals, there remains a risk of subsequent data packets being destroyed because of collisions. RTS/CTS schemes were proposed for these problems. However, it still degrades the utilization in the cases in which the propagation and transmission delays are long. The DBTMA [1] scheme split the single common channel into two channels. One is data transmission channel; the other is transmission control channel. Subsequently, two different busy tones on a separate narrow channel are used to protect the transfer of the RTS and data packets. They are *transmission busy tone (BTs)* and *receiving busy tone (BTr)*. The function of BTs shows that a node is transmitting on the data channel, and the BTr shows that a node is receiving on the data channel. DBTMA decentralizes the responsibility of managing access to the common medium and does not require time synchronization among the nodes. After sending RTS packets on data channel to set up transmission requests, the sender of RTS sets up a transmit-busy tone (BTt). Then the receiver sets up a receive-busy tone (BTr) in order to acknowledge the RTS without using CTS packet. Any node that senses an existing BTr or BTt defers from sending its own RTS over the channel. Through the use of the BTt and BTr in conjunction, exposed terminals are able to initiate data packet transmissions and hidden terminals can reply to RTS requests as simultaneous data transmission occurs between the receivers and senders. That means with this design, exposed terminals are able to initiate new transmission, because they do now need to listen to the shared channel to receive the ACK from their intended receivers. Instead, the ACK of the successful channel request will be sent by means of receive busy tone. Furthermore, the hidden terminals can reply to RTS requests by simply setting up it's receive busy tone. The analytical and simulation results show that the DBTMA protocol is superior to some schemes that relay on RTS/CTS dialogues on a single channel or those that rely on a single busy tone.

2.2 Multi Channel CSMA MAC protocol

The multi-channel CSMA [2] protocol proposed by Nasipuri et al. divides the total available bandwidth into N distinct channels of W/N bandwidth for each. Here N may be lower than the number of nodes in the network. CSMA protocol can gain distinct advantages in throughput by segregating the available bandwidth into multiple channels, and using the carrier sense information for selecting idle channels with a “soft” channel reservation. This reservation based scheme will perform better than a multichannel scheme with random selection of idle channels. The channels may be divided based on FDMA and CDMA. However, the TDMA is not used in this approach because of the absence of network-wide synchronization in such networks. A transmitter or receiver at every host would use carrier sensing to see if the channel last used is free. Otherwise, another free channel is chosen at random. If no free channel is found, the node should back off and retry later. Typically, a transmitter tries to reuse the channel it used in its last successful transmission. In this novel approach, there are five steps in this protocol operation. First is that each node monitors the N channels while detects whether or not the *total received signal strength (TRSS)* in the channels are above or below its *sensing threshold (ST)*. Then the channel for which the TRSS is below the ST, are marked as IDLE. These channels are free channel which can be used for data transmission. Second, if there no free channel, the node have to wait until the first channel to be idle. It will waits for a *Long Inter-frame Space (Long IFS)*, and a random access back off period before the transmitting. On the other hand, if there have free channels, the node checks the channel whether can be used successfully. Then the node chooses this channel for data transmission. Third, before the transmission, the node checks TRSS on the chosen channel has remained below ST for at least a long IFS period. Fourth, any back off is canceled when the TRSS on the chosen channel goes above the ST at any time during the back off period. Last step is that after successful transmission last-channel is undefined and a random channel will be chosen from the free-channel list for the retransmission. This protocol has been shown to be more efficient than single channel CSMA scheme is lower than that of the single channel CSMA scheme at lower traffic load or when there are only a small number of active nodes for a long period of time.

2.3 Hop-reservation Multiple Access(HRMA)

Zhenyu Tang et al. propose a novel multiple channels protocol named Hop-reservation multiple access (HRMA) [3]. HRMA allocates frequency bands to nodes using a common frequency-hopping pattern. Data and ACKs are transmitted without hidden-terminal interference. It allows systems to merge and nodes to join existing system. It is based on a common hopping sequence for the entire network and requires half-duplex slow frequency-hopping radios with no carrier sensing to operate. It is an efficient MAC protocol based on FHSS radios in the ISM band. HRMA uses time-slotting properties of very-slow FHSS such that an entire packet is sent in the same hop. It allows a pair of nodes to reserve a frequency hop for communication without interference from other nodes. A frequency hop is reserved by contention through a request-to-send/clear-to-send exchange between a sender and receiver. After a successful exchange, a reservation of a frequency hop will be remaining reserved with a reservation packet from the receiver to the sender, which prevents those nodes that can cause interference from attempting to use the reserved frequency hop. When a hop is reserved, a sender can transmit data beyond the normal frequency-hop is used to permit nodes to synchronize with one another.

HRMA guarantees that no data or acknowledgement packets from a source or a receiver collide with any other packets in the presence of hidden terminals. HRMA shows that it achieves every high throughput for the range of traffic load within which the network is stable, which can be enforced in practice with simple back off strategies.

2.4 Multi-channel Medium Access Control (MMAC)

Vaidya et al. proposed Multi-channel medium access control (MMAC) [4], which utilizes multiple channels by switching among them dynamically. The proposed scheme requires only one transceiver for each host, while other multi-channel MAC protocols require multiple transceivers for each host. The nodes in the network are synchronized by beacons, and the channels are negotiated in the ATIM window using ATIM packets. After the ATIM window, nodes switch to their selected channel and exchange message on that channel for the rest of the beacon interval. MMAC is an adaptation to the DFC in order to use multiple channels. Time is divided into multiple fixed-time beacon intervals. The beginning of every interval has a small ATIM window. These window ATIM packets are exchanged among nodes so that they can coordinate the assignment of appropriate channels for use in the subsequent time slots of that interval. MMAC needs only one transceiver, and every node synchronizes itself to all other nodes by tuning in to a common synchronization channel on which ATIM packets are exchanged. Every node maintains a preferred channel list that stores the usage of channel within its transmission range, and also allows for marking priorities for those channels. The simulation results show that, first, MMAC performs significantly well in aggregate throughput. MMAC achieves throughput using only a single transceiver for each host. Thus, the improvement is achieved using simpler hardware. Second, MMAC does not have the problem of suffering from high contention at the control channel which results in high packet delay because it does not maintain a separate channel for control messages. Third, by using the different packets size, MMAC does not have the problem which using large packets, larger amount of data is transmitted for one RTS/CTS exchange and thus contending over the channel occurs less frequently. Moreover, MMAC gains significant benefit from not having a dedicated control channel.

2.5 Dynamic Channel Assignment With Power (DCA-PC)

DCA-PC [5] is proposed by Tseng et al., which is an extension of their DCA protocol that did not consider the issue of power control. It combines concept the issue of power control and multiple channel medium access in the context of MANETs. DCA-PC assigns channels to mobile hosts in an "on-demand" manner. If a host needs a channel, it will go through a RTS/CTS/RES dialogue to grab a channel. After the transmission completed, the include the channel code in the RTS header. When some station receives the RTS, it will check if the channel channel will be released for future using. Because of this on-demand feature, the authors assume that the number of channels given to the network is a fixed number, which is independent of the network size, topology, and degree. In DCA-PC, every node is equipped with two half-duplex transceivers and the bandwidth is divided into a control channel and multiple data channels. Every node keeps a table of power levels to be used when communicating with any other node. These power levels are calculated based on the RTS/CTS exchanges on the control channel. DCA-PC is a novel protocol, which attempt at solving dynamic channel assignment and power control issues in an integrated fashion. The simulation results of DCA-PC show that the effect of power control is less significant as the number of channels is too large because the control channel is overloaded. Under the same fixed-channel bandwidth model, the throughput DCP-PC will keep on improving as more channels are used. What's more, when the mobile hosts maximal speed, DCA-PC protocol will degrade slightly fast.

2.6 Dynamic Private Channel (DPC)

Wing Chung Hung et al. proposed a protocol named Dynamic private Channel (DPC) [6], which is to maintain good system performance and enhance ad hoc network connectivity. In Fig1:

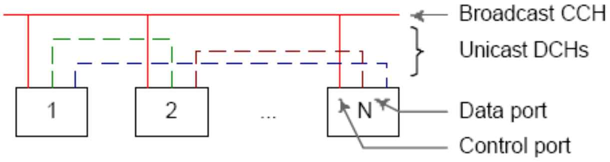

Fig1: Multi-channel system used in DPC

DPC has one multicast control channel (CCH) and multiple unicast data channels (DHCs). The CHH is shared by all stations and can be heard by all stations within the transmission range. On the other hand, DCHs are either free or busy depends on whether it is being used. If a station A need a channel for communicating with station B, one free DCH will be assigned to the pair for a limited duration time. When A and B do not need the channel anymore, the DCH will become free again for future using. Each DPC station is equipped with Nr+1 radio ports where Nr=1. One is the control port and can become to the CCH at all times while the others are the data ports which will be used dynamically for data communication using the DCHs. Every station maintains three queues: data queue Qd, incoming Qi and outgoing Qo RTS queue. After data arrives from the higher layer, data will be queued in the data queue. When RTS is received from CCH, it will be stored in the incoming RTS queue for future process. If a RTS is waiting to be sent out, it will be kept in outing RTS queue. DPC is connection-oriented. If a station A has data packet to send. A will initiate the setup process by sending an RTS to other station through CHH. A also reserves one of its data ports for communicating with other station. Before sending out the RTS, station A choose a free DCH and

chosen by A is acceptable. If so, it returns a Reply to RTS (RRTS) to station A with same channel code in the header.

Else, other station will suggest another one and put the new channel code in the RRTS header. When the code negotiation comes to end, both stations will tune one of their data ports to the select DHC and start exchange data packets. When there are no more data sending or the reservation period Td is expired the communication will end.

3. Comparison

We compare the state-of-art multiple channel protocols proposed so far in the literature. First, we evaluate DBTMA, which divided into two channels. It may be the basic approach to implement the idea of multiple channels. It is easy to accomplish because it only require two channels. One is control channel, and the other is data transmission channel. Then more novel protocols such as CSMA, HRMA divide channels more than two channels. These protocols make sure the data transmission success ratio by use more channels in the contention situation. DCA-PC does not consider the issue of power control and it designed for mobile host. So, this novel multiple channel protocol maybe perfect for Vehicular ad hoc networks (VANET) and vehicular sensor networks (VSV). RTS/CTS scheme still be used in these protocols for enhancing the performance on avoiding collision. Additionally, using the carrying sensor is also an important way to avoid collision by detecting the channels situation, because only the free channel can support the data transmission. Table 1 summarizes the simple comparison of properties of all multiple channel protocols proposed in the paper.

Table1: Comparison of multiple channel protocols.

Multiple Channels	Channel No.	RTS/CTS	Carrying Senor	Perpofmance on Avoid Collision	Simulation Scenario	Key Point
DBTMA	2 Channels	Yes	Yes	Normal	6Km*6Km / 400 nodes	BTt/BTr
CSMA MAC	N Channels (N=5,10,20)	Yes	Yes	Good	200m*200m/225 nodes	TRSS/ST/IFS
HRMA	N Channels, 1 SYN Channel, (N-1)/2 Frequency pairs	Yes	No	Good	_	Half-duplex/FHSS
MMAC	N Channels (N>2)	Yes	Yes	Good	250m*250m/6,30,64 nodes	ATIM
DCA-PC	1 Control Channel, N Data Transmission Channels	Yes	Yes	Good	100m*100m/200 nodes	RTS/CTS/RES
DPC	1CHH, N DHCs	Yes	_	Good	2 to 20 stations	CHH/DHCs

4. Conclusion

IEEE 802.11 standard for wireless LAN has a medium access control protocol designed for sharing channel between hosts. When hosts are communicating, all other hosts within the range of the two hosts must defer their communication in order to avoid collision. This results in significant throughput degradation as the number of active hosts increases. A lot of work has been done to improve the throughput of wireless networks, multiple channels protocols, definitely, are available to reduce this problem. However, the current MAC protocol is designed for sharing a single channel. The main reason for this is that each IEEE 802.11 host is equipped with one half-duplex transceiver. It can only transmit or listening on one channel at a time. So when a host is listening on a particular channel, it cannot hear communication taking place on a different channel. If a single-channel MAC protocol is applied in a multi-channel environment wherein each node may dynamically switch channels, performance degradation may occur. In other word, MAC multiple channel protocols we summarized are taken to manage dynamic channel selection by using FDMA, CDMA and TDMA schemes for reducing the degradation. They divide single channel into many channels and use different channel working corporately to actualize the data transmission. We have to face drawbacks of data transmission in MAC layer. Collision, throughput, packets delivery rate are still crucial issues what need more novel approaches to handle in the future works.

5. References

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