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A brief study on Contention Based Multi-Channel MAC Protocol for MANETs

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ABSTRACT

Mobile ad hoc networks (MANETs) are useful in environment where fixed network infrastructure is unavailable. MANETs demand an efficient and distributed Medium Access Control (MAC) protocol to effectively reduce collisions and thus becomes a key issue for MAC design in MANETs. Several mechanisms have been proposed to avoid collisions, achieve fairness with the help of carrier sensing, handshaking, and back-off mechanism. The use of multiple channels in wireless networks could provide performance advantages in reducing collisions and enabling more concurrent transmissions. This paper provides a brief study on two popular Contention based MAC protocol - BTMA and DBTMA.

Keywords: MANET, MAC, BTMA, DBTMA

1. INTRODUCTION

In mobile ad hoc networks (MANETs), mobile hosts can transmit messages directly to each other within their radio transmission range without any infrastructure devices. The bandwidth of wireless links is so precious that there are a number of medium access protocols [1,2,3] proposed to maximize the utilization of bandwidth. Using a single channel to transmit packets, the throughput of a wireless network is limited by the bandwidth of the channel. In order to increase the throughput of the network, multiple channels can be exploited to transmit packets simultaneously .Since all the mobile nodes in MANETs use the same frequency spectrum (or physical channel), medium access control (MAC) and it plays an important role in coordinating channel access among the nodes so that information gets through from one node to another. First, wireless channels are not as reliable as wired ones, suffering from path loss, fading, and collisions could take place when several nodes simultaneously access the shared medium. Also, the usable bandwidth is limited. Second, by its name, a MANET is composed of a number of nodes that can move around. Consequently, the network topology may experience continuous change and cause frequent route breakages and re-routing activity as a node cannot immediately detect collisions during its transmission, which leads to channel inefficiency. Third, in MANETs, mobile nodes are typically computationally limited and battery powered, which means they cannot afford complex and energy intensive computation. Last, but not least, MANETs by nature are self-organized, self-controlled, and distributed. In other words, there is no centralized controller that has perfect knowledge of all the nodes in the network. Instead, each node can only have incomplete or sometimes skewed view of the network. As a result, it has to make decisions with imperfect information. Due to all these complication posed by MANETs, achieving simple, efficient, fair, and energy-efficient MAC, is highly desirable, and challenging.

2. CONTENTION BASED MAC PROTOCOLS FOR MANETs

The primary goal of MAC is to coordinate the channel access among multiple nodes to achieve high channel utilization. In other words, the coordination of channel access should minimize or eliminate the incidence of collisions and maximize spatial reuse at the same time. The basic components of contention-based MAC are Sender Initiated and Receiver Initiated protocols. Here will focus on sender initiated protocol where the two-way DATA/ACK and four-way RTS/CTS/ DATA/ACK handshake of the IEEE 802.11 MAC protocol are sender-initiated. The sender has full knowledge of packets in its queue and it initiates the handshake only when there are pending packets. The exchange of short RTS and CTS frames in a four-way handshake between a transmitter and a receiver serves as a channel reservation that notifies overhearing nodes to defer their access to the shared channel so as to avoid collisions. Some solutions to the classical hidden terminal and exposed terminal problem are sender initiated protocol over MANETs. Sender Initiated protocol is also classified into two types: Single channel and multi-channel protocol. A single channel was available for data transmission (a separate channel for the transmission of the busy tone was also assumed to be available). For single hop networks, it has been shown that multiple channel schemes outperform their single channel counterparts. Multichannel schemes for multi-hop networks have not been considered. In this paper, we analyze the performance of multichannel BTMA and DBTMA schemes in large multi-hop networks and determine the achievable performance enhancement when multichannel scheme are used. The results have shown that the throughput of networks increases when the bandwidth is split into several narrow band sub-channels. An important advantage of the multichannel mode is that the network can increase or decrease its capability by adding or deleting channels, and channels can be allocated to a network on a demand assignment basis. Another advantage of the multichannel mode is that each sub channel can be utilized better than in the single composite channel [2], especially when they use CSMA protocols. This is due to the well known property of CSMA protocols that their efficiency increases as the ratio of propagation delay to packet transmission time decreases. In the multichannel mode, each user transmits on a slower speed channel, thereby increasing the packet transmission time. The ratio of propagation delay, which is only a function of the distance, to packet transmission time is, therefore, smaller on each of the sub channels than it is on the wide bandwidth channel.

3. RELATED WORK

Since the hidden terminal effect is the key problem for the application of CSMA protocols in multi-hop networks, we consider the use of the multichannel scheme as another approach to solve the hidden terminal problem in addition to the busy tone mode. There have been numerous MAC protocols that attempted to solve the hidden- and the exposed-terminal problems. Examples of such protocols are: Busy Tone Multiple Access (BTMA) [1], Multiple Access Collision Avoidance (MACA) [2], and MACA for Wireless networks (MACAW) [3]. In BTMA, a busy tone is emitted by the base station to notify terminals about the on-going channel use. In MACA [2], Karn originally proposed the use of short control packets, the Request-To-Send (RTS) and Clear-To Send (CTS) packets, for collision avoidance on the shared channel. A ready node transmits an RTS packet to request the channel. The "receiver" replies to the "transmitter" with a CTS packet. All other nodes that hear the RTS packet back-off for a time long enough for the "transmitter" to receive the CTS packet. All nodes that hear the CTS packet back-off for a time long enough for a DATA packet reception. MACA reduce the probability of data packet collision caused by hidden terminal through the use of RTS/CTS dialogue. In MACAW, additional control packets are introduced to improve the performance of the scheme and to reduce unfairness among the nodes in accessing the channel [6]. Since DATA packets are long, collision and corresponding destruction of DATA packets can be very costly in wireless resources. In [4], we proposed the Dual Busy Tone Multiple Access (DBTMA) protocol, a scheme that eliminates DATA packet collisions in a practical wireless communication environment. In DBTMA, in addition to the use of the RTS/CTS dialogue, there are two out-of-band busy tones, whose purpose is to notify neighbor nodes of the on-going transmission. Nodes sensing the busy tones defer from using the channel in the "direction" species by the type of the busy tone. The scheme provides means for continuous channel monitoring and does not require successful reception of the RTS/CTS dialogue by the potentially interfering nodes to prevent collisions.

4. BTMA (BUSY TONE MULTIPLE ACCESS)

The protocol, named busy tone multiple access (BTMA), relies on a centralized network operation; i.e., a network with base stations. When a base station senses the transmission of a terminal, it broadcasts a busy tone signal to all terminals, keeping them (except the current transmitter) from accessing the channel. The original BTMA was proposed to be used in a network with a base station and the scheme uses the busy tone in a centralized manner. Although the protocol could be used in ad hoc networks with distributed control, to our knowledge, the performance of the scheme has not been investigated in such networks. Busy tone multiple access protocols have been used in multi-hop networks to reduce the effect of the hidden terminal problem. The transmission channel is split into: Data Channel and Control Channel. The data channel is used for data packet transmission whereas control channel is used to transmit the busy tone signal. When a node is ready for transmission, it senses the channel to check whether the busy tone is active. If not, it turns on busy tone signal and starts data transmission. Otherwise, it reschedules the packet for transmission after some random rescheduling delay. When a node is transmitting, no other node in the two-hop neighborhood of the transmitting node is permitted to simultaneously transmit.

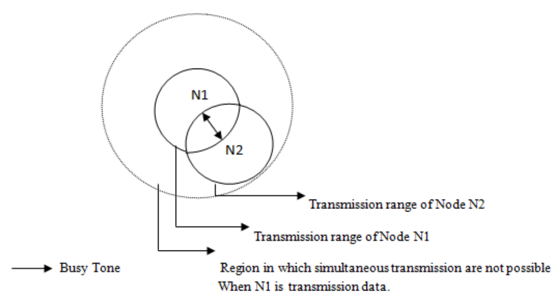

Figure 1: Transmission in BTMA

In the Receiver-Initiated Busy-Tone Multiple Access scheme (RI-BTMA) proposed by Wu and Li [9], a packet preamble is sent to the intended receiver by the transmitter. Once the preamble is received correctly, the receiver sets up an out-of-band busy tone and waits for the data packet. The transmitter, upon sensing the busy tone, sends the data packet to the destination. The busy tone serves two functions: to acknowledge the channel access request and to prevent transmissions from other nodes. RI-BTMA was proposed to be used in the slotted manner. The correct operation of

RI-BTMA depends largely on the synchronization of slots, which is usually difficult to achieve globally in a distributed ad hoc networking environment, especially of the mobile type. In multiple access collision avoidance (MACA) [5], Karn originally proposed the use of short control packets, the request-to-send (RTS) and the clear-to-send (CTS) packets, for collision avoidance on the shared channel. A ready node transmits an RTS packet to request the channel. The receiver replies with a CTS packet. The reception of the CTS packet acknowledges that the RTS/CTS dialogue has been successful and starts the transmission of the actual data packet. All other nodes that hear the RTS packet back off for a time long enough for the transmitter to receive the CTS packet. All other nodes that hear the CTS packet back off for a time long enough for the receiver to receive the data packet. However, when hidden terminals are present, the MACA protocol degenerate to ALOHA. MACA was proposed to address the hidden/exposed terminal problems, but, in fact, these problems are not fully solved by the scheme. Bharghavan [7] suggested the use of the RTS-CTS-DSDATA-ACK message exchange for a data packet transmission in the MACAW protocol. The DS (Data Sending) packet was added to notify all nodes in the transmitter's range of its following use of the shared channel. The ACK packet was included for immediate acknowledgment and for fast retransmission of collided data packets. A new back-off algorithm, the multiple increase and linear decrease (MILD) algorithm, was also proposed in the paper to address some of the unfairness problems in accessing the shared channel. Additional features of the MILD algorithm, such as back-off interval copying and multiple back-off intervals for different destinations, further improve the performance of MACAW. However, similar to MACA, MACAW solves neither the hidden- nor the exposed-terminal problems.

5. DBTMA (DUAL BUSY TONE MULTIPLE ACCESS)

In DBTMA Scheme, the single shared channel is split into two sub-channel. One is data channel and other control channel. Data channel is used for the data packet transmissions, and a control channel is used for control packet transmissions (RTS and CTS packets) and also for transmitting the busy tones. RTS packet is used to initiate channel request. Two busy tones are used to protect the RTS and CTS. One of the busy tones is set by the sender and is used to protect the RTS packet. And another busy tone set by the receiver is used to protect the CTS of the receiver and to provide the protection for the incoming data packets. Other nodes in the neighborhood that overhears any of these busy tones defer their transmission [4] [8].

In the DBTMA protocol, two narrow-bandwidth tones are implemented with enough spectral separation on the single shared channel. BT_t (transmit busy tone) and BT_r (receive busy tone), indicate whether the node is transmitting RTS packets or receiving data packets, respectively. The transmit busy tone (BT_t) provides protection for the RTS packets to increase the probability of successful RTS reception at the intended receiver. We use the receive busy tone (BT_r) to acknowledge the RTS packet and provide continuous protection for the transmitted data packets. All nodes sensing any busy tone are not allowed to send RTS requests. When the start of the signal is sensed, a node sending the RTS packet is required to abort such transmission immediately. Indeed, the RTS packets and the receive busy tone solve the hidden- and the exposed-terminal problems [8].

A node implementing the DBTMA protocol can be in one of the following seven states: IDLE, CONTEND, S_RTS, S_DATA, WF_BTR, WF_DATA, and WAIT. Fig. 2 depicts the finite state machine (FSM) of the DBTMA scheme.

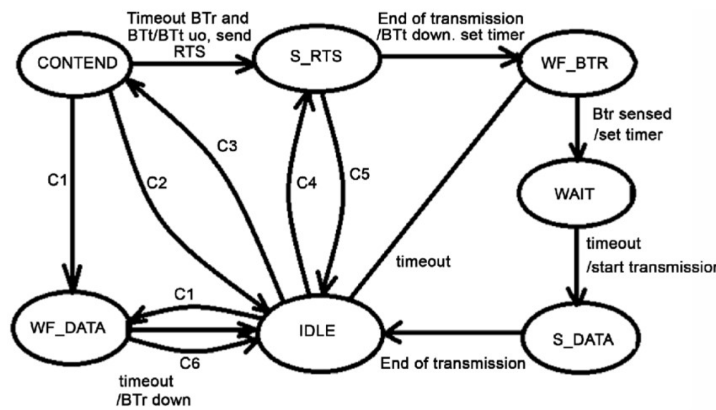

Figure 2: Finite State Machine of DBTMA

Source: Z. J. Haas, and J. Deng, "Dual busy tone multiple access (DBTMA)-a multiple access control scheme for ad hoc networks." Communications, IEEE Transactions, vol. 50, no. 6, pp. 975-985, 2002

A node without packets to send stays in the IDLE state. When a node has a packet to send, but it is not allowed to send the RTS packet, then it stays in the CONTEND state. Nodes sending RTS or DATA packets are in the S_RTS or S_DATA states, respectively. The RTS packet sender waits for the acknowledgment from its intended receiver in the WF_BTR state. The receiver waits for the data packet in the WF_DATA state.

When node A has a data packet to send while it is in the IDLE state, it tries to sense the BT_t and the BT_r busy tone signals. If none of the busy signals is present, it turns on its BT_t signal, sends an RTS packet to node B, and goes into the S_RTS state. Otherwise, it sets a random timer and goes into the CONTEND state. By the end of the RTS transmission, node A turns off its BT_t signal, sets a timer, and goes into the WF_BTR state. When node B receives the RTS packet, it turns on its BT_r signal, replying to node A and announcing that it is waiting for the incoming data packet. Then it sets up a timer and goes into the WF_DATA state. Node A continuously monitors the BT_r signal when it is in the WF_BTR state. When a BT_r signal is sensed, it knows that its channel request has been successful. Before node A sends the data packet, it waits a mandatory waiting time (t_{mw}=2r) in the WAIT state [10]. This mandatory waiting time is meant to allow all possible RTS transmissions in the range of the receiver to be aborted. Upon timeout in the WAIT state, node A goes into the S_DATA state and sends the data packet. By the end of its transmission, node A goes into the IDLE state. Upon successful reception of the data packet, node B turns off the BT_r signal and goes into the IDLE state, ending the communication. If, for any reason, node B does not receive the data packet before the time expires, it turns off the BT_r signal and goes into the IDLE state. Upon timeout in the CONTEND state, node A turns on its BT_t signal and sends its RTS packet if no busy tone signal is sensed. Otherwise, it goes back into the IDLE state [4].

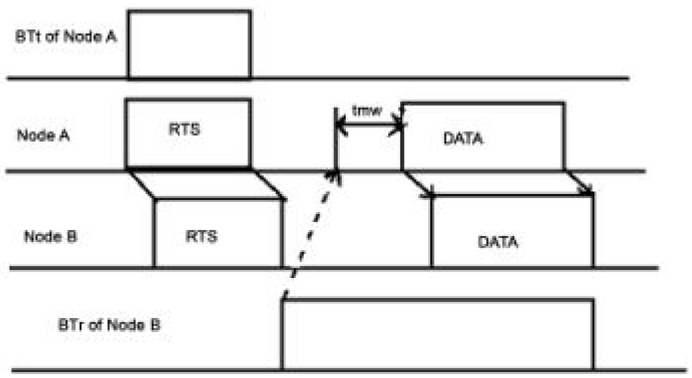

Figure 3: Time Diagram of DBTMA

Source of the above figure is from paper: Dual Busy Tone Multiple Access (DBTMA) — A Multiple Access Control Scheme for Ad Hoc Networks by Zygmunt J. Haas, Senior Member, IEEE, and Jing Deng, Student Member, IEEE

6. COMPARISON BETWEEN BTMA AND DBTMA

DBTMA is the extension of the BTMA scheme [4]. In both the protocols, two channels are used. One is data channel and other is control channel. But in DBTMA, two narrow-bandwidth tones are implemented with enough spectral separation on the single shared channel. BT_t (the transmit busy tone) and BT_r (the receive busy tone), indicate whether the node is transmitting RTS packets or receiving data packets, respectively. While in BTMA, the data channel is used for data transmission and the control channel is used for busy tone signal only. If a node wants to transmit data to another node, it firstly senses the medium and check whether the busy tone is active. If busy tone is inactive, it will turn on the busy tone signal and sends the data. But if it is active, it will wait for some random time and then will retry which may leads to collision. However in DBTMA, if the RTS or CTS is sensed when BT_t or BT_r is active then it will defer their transmission. So, there will be no chances of collision because of these two narrow-bandwidth tones and it solves both the hidden and exposed node problem.
The BTMA Protocol is simple as compared to DBTMA Protocol. Though the BTMA protocol has low probability collision while DBTMA protocol is collision free. The bandwidth utilization of BTMA protocol is low (blocked in two-hop neighbor).

7. CONCLUSION

As per the various literature review, DBTMA Protocol shows better performance than other protocol. As the carrier sensing schemes evaluate the state of the channel at the transmitter only, rather than at the receiver, some researchers have proposed to rely on a reservation dialogue (the RTS/CTS dialogue) among the communication nodes. However, some of these schemes, e.g., MACA and MACAW, solve neither the hidden-node problem nor the exposed-terminal problems. In this paper, we have analyzed the performance of DBTMA Protocol under various network conditions. In the proposed DBTMA scheme, in addition to the use of the RTS request, two out-of-band busy tones are used. One busy tone, generated at the receiver, serves two functions: 1) notifying the RTS sender that the channel has been successfully acquired and 2) announcing to its neighbor nodes that it is receiving data packet and that they should refrain from accessing the channel. The other busy tone, generated at the transmitter while it is sending the RTS packet, provides protection for the RTS packet. With this design, exposed terminals are able to initiate new transmission, because they do not need to listen to the shared channel to receive the acknowledgment from their intended receivers. Instead, the acknowledgment of the successful channel request will be sent by means of the receive busy tone. Furthermore, the hidden terminals can reply to RTS requests by simply setting up its receive busy tone. When RTS/CTS dialogues are used on the single channel, such as in the MACA, MACAW, and FAMA-NCS schemes, the hidden terminals cannot send their replies. Our analytical and simulation results show that the DBTMA protocol is superior to other schemes that rely on RTS/CTS dialogues on a single channel or those that rely on a single busy tone.

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