MCDA:An Efficient Multi-Channel MAC Protocol for 802.11 Wireless LAN with Directional Antenna

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***Abstract*—IEEE 802.11 provides a contention based MAC protocol for single channel wireless environment. Extending IEEE 802.11 to a multi-channel environment will not only exploit the bandwidth utilization but also reduce the degree of contentions. Involving directional antenna in designing multi-channel MAC protocol additionally increases the spatial reuse, allowing more communications proceeding in parallel. This paper proposes an efficient 802.11 Multi-Channel MAC protocol with Directional Antenna (MCDA). Since each station is only equipped with a single antenna, communicating pairs that progress their communications on data channels will unable to maintain the channel usage information which is only obtained from the control channel, raising the channel collision problem. The proposed protocol adopts mechanism of channel switch sequence (CSS) to resolve the channel collision problem and reduce the overhead in message exchange for switching channel. According to the state management, MCDA then controls directional antenna transmitting data on a selected channel to exploit the opportunities of spatial reuse and maintain the fairness among communicating pairs. Simulation results show that the proposed MCDA protocol can largely improve the bandwidth utilization and throughput while the fairness could be maintained.**

Keywords- Ad Hoc Network; IEEE802.11; MAC protocol; Multi-channel; directional antenna.

I. INTRODUCTION

IEEE 802.11 defines a contention based MAC protocol that adopts techniques including CSMA, RTS/CTS, Random Backoff, and Priority Scheme to avoid transmission collision, maintain fairness among wireless stations in communication, and make good use of bandwidth resources. However, 802.11 MAC protocol was originally designed for single channel environment. Extending 802.11 MAC to multi-channel environment will improve the channel utilization and distribute stations that compete for channel access over several channels, reducing the overhead of data retransmission due to failure in competition for channel access. Moreover, a multi-channel communication environment, which allows multiple communicating pairs to transmit data simultaneously, can improve the throughput and fairness.

A number of MAC protocols [1][2][3][4][5] have been proposed for extending the 802.11 MAC to multi-channel communication environment. In [5], simulation results depicts that multi-channel takes advantage of distributing stations over different channels and alleviates the phenomenon of transmission collision. In [2], an on-demand channel assignment protocol is proposed for multi-channel environment. A station that uses an antenna to communicate with another station on specific data channel will unable to overhear the channel usage information from control channel. Therefore, two antennas are applied for communication and maintaining channel usage information at the same time, resulting overhead in hardware cost. Some other researches [3][4] use busy tone to resolve the hidden terminal and exposed terminal problems, enhancing the channel utilization. In [4], the bandwidth is divided into one control channel and one data channel. As a station intends to use one antenna to transmit packet on data channel, another antenna should transmit busy tone to prevent interference from other stations.

Moreover, J. So and N. H. Vaidya propose a MMAC[1] protocol with considering the power saving mode in multi-channel environment. MMAC uses ATIM/ATIM-ACK/ATIM-RES negotiation to inform the neighbors of communicating pair the information regarding the selected data channel. Multiple communicating pairs that are located in the nearby area thus can use different channels for communication without interference. Although the existing MAC protocols provide multiple pairs of wireless stations with simultaneous transmission on multi-channel and increase throughput and channel utilization, however, they use omni-directional antenna for RTS/CTS negotiation, remaining improved dimension in exploiting spatial reuse.

Directional antenna provides more opportunities for spatial reuse. Furthermore, directional antenna concentrate its power in transmitting signal in a specific direction, thus it has longer transmission distance than omni-antenna under the condition of the same power dissipation. Previous researches [6][7][8][9][10] incorporate directional antenna in the design of MAC protocol to increase spatial reuse, reduce end-to-end transmission delay, and save power consumptions in data transmission. However, degree of exploited spatial reuse is constrained in single channel environment. Taken into consideration both the directional antenna and multi-channel in exploiting opportunities of spatial reuse will increase the utilization of bandwidth resource, reduce the degree of contention, and thus improve the overall performance for data transmission.

This paper proposes an efficient multi-channel MAC protocol with considering directional antenna. The proposed protocol takes advantages of parallel transmission from multi-

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channel and spatial reuse opportunities of directional antenna. Performance results reveal that the protocol efficiently explores the spatial reuse opportunities, increases the bandwidth utilization, and reduces the packet lost rate, thus improves the network throughput.

The remaining part of this paper is organized as follows. Section 2 introduces the protocol environment and presents an overview of the proposed protocol. In the section 3 presents the detail of the proposed multi-channel MAC Protocol with directional antenna. Section 4 reveals a series of simulation analysis and efficiency evaluation of the proposed MCDA protocol. Finally, a conclusion is drawn.

II. BACKGROUNDS AND BASIC CONCEPTS

In wireless network, three resources make great impact on network performance, namely time, space, and bandwidth. Providing multiple pairs of sender and receiver communicating on different channels simultaneously will make good use of wireless resources. Exploiting the capacity of data transmission in time and spatial dimensions will enable more wireless stations in simultaneous transmission, thus conducing to increase throughput, reduce the waiting time for data transmission, and have better transmission fairness. This paper proposes an efficient 802.11 multi-channel MAC protocol with considering directional antenna to exploit the bandwidth utilization on multi-channel and makes good use of directional antenna to avoid the interference from mobile stations in communication.

2.1 Environment

The proposed protocol operates in a multi-channel communication environment that contains a control channel and *n-1* data channels. Each mobile station is equipped with 180° directional antenna so as to exploit opportunities of spatial reuse in wireless network environment. The operations of directional antenna are described in the following. Each station could choose to receive data from omni-direction, but packet collision might occur when receiving different signals from various directions at the same time. Moreover, each station can optional block its transmission in a specific direction if necessary such that data cannot be received or transmitted using its antenna in that direction.

2.2 Basic Concepts

This paper considers a control channel and *n*-1 data channels. A narrowband control channel is utilized for RTS/CTS negotiation such that each mobile station in communication has the opportunity of competing for data channel access. Then several data channels are used for senders and their receivers to transmit Data/Ack packets. The developed multi-channel MAC protocol will incorporate with directional antenna to exploit spatial reuse. Each mobile station is equipped with 180° directional antenna. The protocol takes advantages from multi-channel environment to arrange different communicating pairs on different data channels and uses the characteristics of directional antenna to exploit the spatial use, maximizing the network throughput for 802.11 WLAN.

III. MULTI-CHANNEL MAC PROTOCOL WITH DIRECTIONAL ANTENNA

This section proposes the detailed operations of MCDA. The proposed protocol operates in multi-channel environment, containing one control channel and *n-1* data channels. Each station is equipped with 180° directional antenna. MCDA tries to sufficiently exploit the utilization of multi-channel and directional antenna in time and space domain and maintain the transmission fairness in the network. Initially, all stations stay in control channel. In MCDA protocol, stations that intend to communicate should firstly compete for RTS/CTS negotiation on control channel using omni-directional antenna according to CSMA and random backoff rules that are similar to rules defined in 802.11 MAC protocol. Then, the pairs of stations, which get the opportunity RTS/CTS negotiation, will derive a data channel switch sequence based upon the 48-bit MAC address of sender and receiver, and switch to a data channel according to the channel switch sequence to compete for the opportunity of transmitting data packet.

MCDA mainly consists of two Phases, namely the *Negotiation Phase* and *Communication Phase*. In the Negotiation Phase, sender and receiver exchange RTS/CTS packet on control channel and data channel to compete for the opportunity of mutual communication. In Communication Phase, *pair*(s_i, r_i), which succeeds in RTS/CTS negotiation on both control channel and data channel, will utilize the data channel for data transmission.

The protocol mainly consists of two phases, namely Negotiation Phase and Communication Phase.

A. Negotiation Phase

In Negotiation Phase, stations that intend for communication should stay on control channel, trying to access the channel for RTS/CTS negotiation in a contention based manner. The competition rules for sender to send RTS packet is similar with ones defined in 802.11 DCF. One difference in design of RTS packet is that the duration defined in RTS packet will be the number of slots that required for RTS/CTS negotiation. Since the Data packet will be transmitted in data channel, the time for data transmission will not be taken into account in the duration field of RTS. Since sender has no information about receiver's location, sender that has the right of control channel access will use omni-directional antenna to transmit RTS packet (OS/RTS). Receiver then uses directional antenna to send CTS packet (DS/CTS) on control channel in prevention of hidden terminal problem. At last, sender and receiver will derive a data channel switch sequence (CSS) based on their IDs, as a basis of switching to different data channels sequentially. This implies that different communicating pairs will select different data channel for communication, avoiding collision occurred in multiple data channels. After the RTS/CTS negotiation is completed, the other senders can compete for their RTS/CTS negotiation on control channel.

After the RTS/CTS negotiation on control channel, an additional RTS/CTS negotiation on data channel is also involved in the design of Negotiation Phase. Although channel switch sequence has largely reduced the probability of collision in channel selections from different communicating pairs, however, preventing data transmission from any possible interference on data channel is required. Therefore the RTS/CTS negotiation is required on data channel.

As the communicating pair completes the RTS/CTS negotiation on control channel, they will switch to a data channel according to the channel switch sequence. This pair will wait for a DIFS duration on data channel to ensure the medium is idle. Then sender will use directional antenna to send a RTS packet to receiver (DS/RTS). However, if medium is at busy state during carrier sense period, sender immediately use directional antenna to send a warning packet to its receiver, notifying receiver about switching to the next data channel in the switch sequence immediately. Then sender and receiver will switch to another data channel and compete for the opportunity of transmitting Data/Ack again.

In the Negotiation Phase, sender and receiver will execute RTS/CTS negotiation on both control and data channels so that the data transmission can be prevented from interference. After executing the Negotiation Phase, the communicating pair will select a channel that is idle for communication. Sender and receiver then will execute the operations illustrated in Communication Phase.

B. Communication Phase

Communicating pair that completes the Negotiation Phase will obtain the opportunity of data transmission on the data channel. Thus, sender and receiver will use directional antenna for transmitting Data and Ack and block the directional antenna in the unused direction.

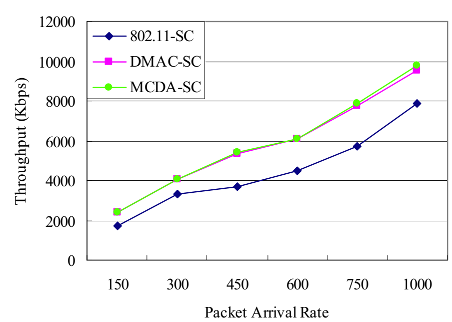
The proposed protocol arranges sender and receiver transmission on data channel in order of priority. To maintain the fairness, the first-come-stay policy is applied. More specifically, communicating pair that earlier switches to data channel will stay on the channel if there is a collision. Communicating pair that later switches to data channel will select another channel according to their channel switch sequence. The assignment of priority is according to the order of packet types transmitting on data channel. As there is a collision in access of data channel, pairs with lower priority will switch to other data channel to again compete for opportunity of communication under the condition of non-interfering with the pairs which have higher priority.

IV. PERFORMANCE STUDY

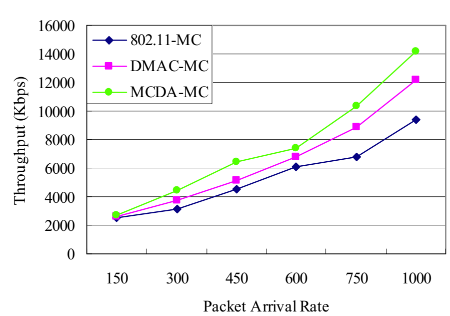
This section proposes the performance investigation of the proposed MAC protocol in terms of throughput, packet delay, and channel utilization. The size of network is set by 1000m × 1000m, while the radio transmission range of a station is set at a constant 250 and the bandwidth of each channel is set at 2Mbps. The size of each packet is 512 bytes, and memory buffer can be filled with 50 packets to the full capacity. Performance is evaluated in both single-channel and multi-channel environments. In a single-channel environment, there is only one channel to be used in control and data transmissions whereas a multi-channel model with one control cannel and three data channels will be applied in multi-channel environment. In Multi-channel environment, stations applying IEEE 802.11 and D-MAC protocols randomly select a data channel for communication. In case that a channel is selected by more than one communicating pairs, these pairs will compete for channel access.

The proposed protocol (labeled by MDMAC) is compared with IEEE 802.11 (labeled by 802.11) and D-MAC(labeled by DMAC) protocol[6]. In [6], *n* directional antennas are applied. Herein, D-MAC with *n*=2 is used as comparison with the proposed protocol. Performance is evaluated in both single-channel (denoted by SC) and multi-channel (denoted by MC) environments. In single-channel environment, there is only one channel to be used in data transmission whereas a channel modal with one control cannel and three data channels will be applied in multi-channel environment. The number of pairs of stations is controlled ranging from 5 to 30 whereas the packet arrival rate is controlled ranging from 150 to 1000 packets per second.

Figure 1 investigates the impact of packet arrival rate on throughput. Herein, we set the number of stations are 25 pairs. The packet arrival rate is controlled ranging from 150, 300, 450, 600, 750, and 1000 packets/second separately. Figures 1(a) and 1(b) discuss the throughput in single-channel and multi-channel environments, respectively. In general, the throughput increases with the packet arrival rate. Both D-MAC and MCDA protocols have a better throughput than IEEE 802.11, and D-MAC has similar performance to MCDA in single channel environment. Figure 1(b) depicts the throughput in multi-channel environment. The MCDA outperforms D-MAC in throughput efficiency because that MCDA uses channel switch sequence to keep stations in channel switching avoid the packet collision and scatter the traffic of the entire network, exploiting opportunities of spatial reuse.



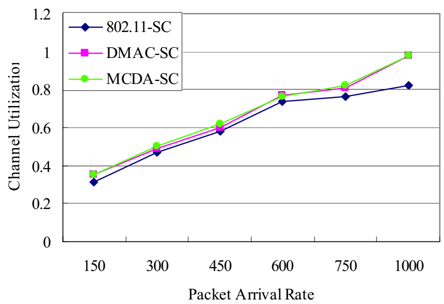
(a)Single Channel Environment.



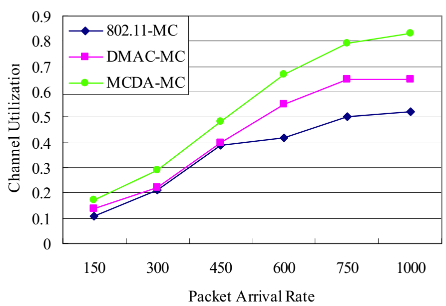
(b)Multi-channel environment.

Figure 1: The impact of packet arrival rate on network throughput.

Finally, Figure 2 discusses the channel utilization in different packet arrival rate. The increasing of packet arrival rate improves the channel utilization. Figure 2(a) and 2(b) respectively reveal the channel utilization in single channel and multi-channel environments. In Fig. 2(a), the performances of three protocols in channel utilization are similar as packet arrival rate is smaller than 600 packets/second. However, as packet arrival rate is higher than 600 packets/second, D-MAC and the proposed MCDA improves 802.11. In a multi-channel environment, the proposed MCDA protocol improves D-MAC and 802.11 significantly. As the packet arrival rate is higher than 450 packets/second, 802.11 and D-MAC protocols a randomly select data channel on which it is possible that the same channel are chosen by many communicating pairs but some channel is not used by any communication pairs, resulting low channel utilization.



(a) Single channel environment



(b) Multi-channel environment

Figure 2: The impact of packet arrival rate on channel utilization.

V. CONCLUSION

This paper proposes a MCDA protocol, incorporating multi-channel and directional antenna into protocol design. Applying the proposed MCDA, stations that are located at the nearby locations but intend to access same channel will use directional antenna for transmitting data simultaneously, exploiting opportunities of spatial reuse. In case that some stations using directional antenna also exist packet collision problem, a channel switch sequence will be used as the policy for selecting different data channels without additional negotiation. The proposed MAC protocol analyzes possible collisions and appropriate controls the directional antenna to exploit the spatial reuse and avoid the collisions. The use of channel switch sequence also provides a good policy for distributing stations over multiple channels to increase the channel utilization and maintain the fairness without addition negotiation. Performance study shows that the proposed MCDA protocol significantly increases the throughput and channel utilization and reduces the packet transmission delay in situation of high packet arrival rate or large number of stations.

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