Flexible Multi-channel Access and Channel Width Adaptation in Wireless Networks

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***Abstract*—This research proposes a flexible framework for fine-grained multi-channel access scheme in wireless networks based on non-contiguous orthogonal frequency division multiplexing. This framework allocates the frequency resource in the granularity of sub-carrier, which brings more flexibility and higher frequency utilization efficiency. The framework also adopts a frequency-time domain backoff scheme to decrease the access collision.**

***Index Terms*—Multi-channel access, Wireless channel width adaptation, Fine-grained channel allocation, frequency-time domain backoff.**

The prevailing of the wireless broadband services calls for a significant improvement on throughput performance, but it is difficult to satisfy the increasing demand with limited bandwidth. The newly proposed IEEE 802.11n standard employs 40MHz bandwidth and 802.11ac even doubled this bandwidth. Therefore, increasing the bandwidth efficiency is significant for broadband access technology. Because of the broadcast nature of wireless media, the traditional single channel media access control (MAC) protocols work inefficiently while taking all available wireless media as one channel. However, by dividing the wireless media into several orthogonal channels, multi-channel MAC and bandwidth adaptation can improve the wireless network performance by increasing the bandwidth efficiency. In this paper, we will investigate the issues of multi-channel MAC and bandwidth adaptation protocols design in wireless networks.

This paper proposes a flexible framework for fine-grained channel width adaptation and multi-channel access in wireless networks based on non-contiguous orthogonal frequency division multiplexing (NC-OFDM). And it is superior to the other multi-channel MAC protocols in the following aspects. (i) All users contend in the granularity of sub-channels, which can be of different width and depend on the number of contending users. (ii) Various bandwidth adaptation principles can be utilized, aiming at different optimization targets such as maximizing the aggregate throughput or fairness, providing services with distinguishing priority level and so on. (iii) The proposed framework utilizes a combined frequency-time domain backoff, which increases the successful access probability significantly. (iv) Multiple users can utilize orthogonal sub-channels which contain different number of sub-carriers to perform parallel data transmissions, which can further improve the bandwidth utilization. Simulation results validate the high bandwidth efficiency of our proposed framework.

Consider a wireless network composing of several users and one access point (AP), and NC-OFDM is enabled in each side. The basic idea of the channel width adaptation is that variable numbers of sub-carriers compose a sub-channel without changing the framework of NC-OFDM. The power saving mechanism (PSM) of IEEE 802.11 is used as reference in our proposal. We first consider the uplink transmission. Beacon frames periodically transmitted by AP divide the time axis into a sequence of consecutive transmission procedures. And each transmission procedure is divided into a control phase and a data exchange phase. During the control phase, through RTS/CTS handshake, all users contend for sub-carriers to be used during the following data phase. And in the data phase, users aggregate the assigned sub-carriers as one sub-channel to transmit (see Fig. 1). The main ideas in the framework are listed as follows

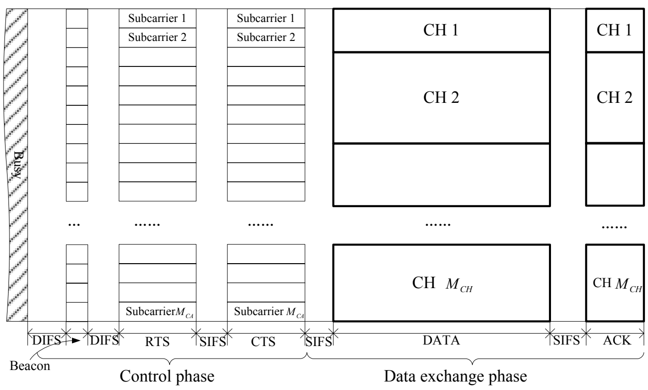

Fig. 1. Illustration of one data transmission procedure

(a) ***Packets sequence***. Any user with data to transmit will randomly select a sub-channel to send its requirement on the amount of sub-carriers to the AP in the RTS period (the number of selected sub-carriers can be increased for robust handshake). And then AP will allocate the sub-carriers to the users in the CTS. The IDs of the allocated sub-carriers will be enclosed in CTS and transmitted in the sub-channel that is selected by corresponding RTS. If a user successfully receives the sub-carrier allocation information, it will aggregate the allocated sub-carriers as one sub-channel to transmit DATA packets to the AP. If the DATA packets are received successfully, AP feedbacks ACKs to the transmitters. And the users that fail to receive the ACKs from AP will start a retransmission procedure in the next transmission procedure. On the other hand, if a user's requirement on sub-carriers is not acknowledged during CTS period, it will perform a backoff process as explained below.

(b) ***Control phase tradeoff***. During the control phase, each user competes for a sub-channel composing of several sub-carriers to transmit RTS frame, and then AP responds with CTS frame in the same sub-channel. Because of the limited bandwidth, higher bandwidth that each sub-channel utilizes means shorter duration of control phase, but it decreases the number of sub-channels and leads to fewer access opportunities, and vice versa. In our proposal, the number of sub-carriers contained in one sub-channel depends on the network density. In other words, if more users compete for the channel access, narrow-bandwidth sub-channel is suitable in order to increase the access probability. While in fewer users scenario, wide-bandwidth sub-channels is preferable to reduce the duration of control phase. By dynamically adjusting the bandwidth of sub-channels based on the network density during the control phase, the overhead introduced by the control phase reduces, guaranteeing enough access opportunities

(c) ***Frequency-time backoff***. There are two cases that a user fails to obtain the acknowledgment of its request on sub-carriers. First, the RTS is not received successfully by AP because of either collision or physical failure. Second, the RTS is received successfully; however, AP has no enough sub-carriers available for all requesting users because of the limited bandwidth. We introduce a combined frequency-time backoff process to tackle these two different conditions. In the first case, a user will randomly select a sub-carrier other than the one used last time to send RTS and thus can reduce the chance of collision or physical failure again. In the second case, we use time domain backoff such as the binary exponential backoff used in 802.11. Now the problem left is how to differentiate the collision or physical failure from bandwidth saturation. AP is naturedly aware of bandwidth saturation and it will notice the saturation situation to the suffering users. Otherwise, without receiving CTS or saturation notice from AP, a user can conclude that its RTS has not reached AP.

(d) ***Sub-carrier allocation and negotiation***. If the users have different priorities, sub-carrier allocation will satisfy the users in order of their priorities. For the users that have the same priority, if the total amount of the requested sub-carriers is no more than the available amount, all the requirements can be satisfied by AP. Otherwise, AP has to choose its allocation policy depending on the network scenario. Moreover, by utilizing physical layer parameters such as users' SNR on each sub-carrier, some complicated jointed bandwidth and power allocation algorithms based on cross-layer design are also compatible under our proposed framework.

(e) ***Uplink vs. downlink***. Downlink access follows the same process as uplink with roles reversed. AP will use the RTS to send the requested sub-carriers and respective receivers' IDs, and the receivers will feedback with the CTS. To avoid the collision between users and AP when both sides have packets to transmit, we can assign different DIFS times to the AP and users.

At last, we employ a simple scenario to validate the performance of our proposed framework by NS2 simulator. We consider a wireless network where contending users are randomly deployed in the area of 250m×250m and the AP is located in the center. The packet length subjects to uniformly distribution U[128,2048] bytes. It is assumed that all users have the same packets arrival rate. The two-ray ground reflection model is used to model radio propagation. In this simulation, proportion-fair principal for bandwidth adaptation is employed to maximize the aggregate throughput and fairness, in which the number of sub-carriers allocated to each user depends on the packet length. Other simulation parameters are listed in Table I.

TABLE I. SYSTEM PARAMETERS AND ADDITIONAL PARAMETERS USED IN THE SIMULATIONS

Parameters	Descriptions	Values
CW_0	Minimum contention window	4
RTS	Packet length of RTS	44bytes
CTS	Packet length of CTS	38bytes
ACK	Packet length of ACK	38bytes
SIFS	Time of SIFS	16μs
DIFS	Time of DIFS	34μs
B	Total data rate	80MHz
P	The number of sub-carriers	160
r	Data rate for each sub-carrier	0.5Mbps

Fig. 2 shows the saturated aggregate throughput vs. the number of contending users by dividing the total bandwidth into different number of sub-channels during the control phase. The figure indicates the tradeoff as explained above. Moreover, the aggregate throughput achieved by our proposed framework can reach up to 70% efficiency of the total data rate.

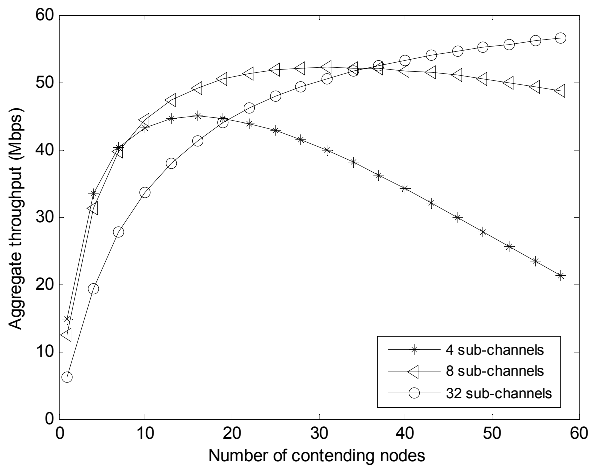

Fig. 2. The saturated aggregate throughput vs. the number of users