A Novel MAC Protocol for Full-Duplex WLANs

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Abstract

Recent progresses in signal processing have established in-band full-duplex competence at WiFi ranges. Moreover to concurrent two-way exchange between two nodes, full-duplex access points can possibly support simultaneous uplink and downlink flows. In this paper, we suggest a medium access control (MAC) protocol for refining throughput in full-duplex WLANs. The suggested MAC protocol familiarizes a dynamic contention window (CW) control at access point (AP) to increase the chance for full-duplex operations. In the suggested MAC protocol, an onset is set in the transmission queue length in APs. Small and large CWs are used adaptively. As soon as the transmission queue length of an AP surpasses the onset, the small CW is used for back off time calculation, which ranks the AP's transmission opportunity.

Keywords: Full-Duplex, Power Control, MAC Protocol, Wireless Network

I. INTRODUCTION

Recently, smartphones are widely used, and a large amount of data traffic from rich mobile applications on smartphones flows into mobile 3G networks, which makes wireless LANs (WLANs) more and more important for traffic offloading from mobile operators' 3G networks. WLAN technologies have been widely studied in recent years. Among them, a single channel full-duplex wireless (FDW) is reported [1][4]. In general, even if a node has two antennas: a transmission antenna and a receiving antenna, the node cannot use both antennas simultaneously due to the self-interference. In other words, the node cannot transmit during receiving, and vice versa. The FDW technology introduces analog and digital cancellations for reducing the self-interference. As the analog cancellation, a balanced/unbalanced (Balun) transformer is introduced for inverting the transmission signal in an analog domain. The inverted signal is through passive attenuation and delay lines, and is combined to the receive signal, which cancels the self-interference.

The FDW can reduce self-interference by up 73 dB for 10 MHz OFDM signal. A medium access control (MAC) protocol for eliminating hidden terminal problem in WLANs is also presented in [4]. Full-duplex radio implementation has motivated considerable research efforts in recent years [1]–[3]. Hypothetically, full duplex technologies can double the wireless link data rate. Nevertheless, it remains an open problem how full-duplex PHY layer can be integrated with a MAC protocol and in what way much performance gain it can accomplish in a wireless network with multiple contending links. The emphasis of this paper is to exploit the full-duplex potential over a MAC protocol that improves 802.11 multi-cell wireless LANs. We classify a unique design compromise in full duplex networks, i.e., full-duplex deals extra transmission chances, but at the cost of poorer spatial reuse: A full duplex transmission pair adds one more transmitter to a half-duplex link, which expands the interference range and tends to overwhelm other transmission attempts around it.

II. RELATED WORK

FDW is the technology that permits a node to send and receive data at the same time on a single channel. [1] comprehends full-duplex operation by using two transmitting (TX) antennas and one receiving (RX) antenna. It permits FDW by positioning a RX antenna on the site that transmission radio waves from two TX antennas cancel each other. Nonetheless, the FDW in [1] has a bandwidth constraint which stops supportive wideband signals such as WiFi. [4] comprehends FDW by using analog and digital cancellation.

The analog cancellation uses one RX antenna, one TX antenna and balanced/unbalanced (Balun) transformer. In the analog cancellation, transmission radio wave from the TX antenna and its inverted signal through Balun transformer cancel each other at the RX antenna. Sen et al. proposed carrier sense multiple accesses with collision notification (CSMA/CN) to directly inform a transmitter about a collision and halt the ongoing transmission [7]. Jain et al. offered a simple MAC protocol to alleviate hidden terminals using a busy tone [4]. Sahai et al. proposed a full-duplex MAC (FD-MAC) protocol to consistently offer transmission occasions and diminish collision probability [6]. Duarte et al. proposed a MAC protocol based on the IEEE 802.11 distributed coordinated function (DCF) with request to send (RTS) and clear to send (CTS) [6]. Tamaki et al. proposed a relay full-duplex MAC (RFD-MAC) protocol to select the next forwarding node using the 1-bit information slot in each frame [8]. Zhou et al. proposed a rapid concurrent transmission coordination (RCTC) protocol that enables exposed terminals to realize concurrent transmission [9]. Ramirez et al. proposed a joint algorithm to realize power allocation and routing in full-duplex wireless relay networks [10]. They presented a power allocation scheme bearing in mind both self-interference and interference among

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neighboring nodes. Singh et al. proposed a distributed MAC protocol with a selection scheme for a secondary receiver [11]. The selection scheme allocates weight values to candidates for the secondary receiver. If a candidate node practices more successful transmissions, it has a higher weight value and thus a better chance to be selected as the secondary receiver. Using this scheme, latent collisions at the secondary receiver owing to the primary transmission could be alleviated.

III. PROPOSED WORK

We propose the following two MAC protocols for improving throughput in full-duplex WLANs: AP-client initiated MAC (AC-MAC) and AC-MAC with dynamic CWs (ACMAC/DCW). In AC-MAC, AP, in addition to client nodes, can initiate data transmission, which is a modification to the conventional full-duplex MAC protocol for WLANs [2]. In AC-MAC/DCW, contention window size of AP is dynamically changed according to the queue length at AP to balance uplink and downlink traffic.

A. AP-Client initiated MAC Protocol (AC-MAC)

Basically, CSMA is adopted in the proposed AC-MAC as well as the conventional full-duplex MAC protocol for WLANs [2]. In AC-MAC, both AP and client nodes can initiate data transmissions. In AC-MAC, AP and client nodes randomly select a random backoff time in [0, CWmin] to get a wireless medium.

If a client node wins to get the medium (It selects the smallest backoff time.),

- The client node transmits a data frame to AP (Primary transmission).
- When the AP receives the data frame and decodes its header, the AP knows the sender of the data frame.
- If the AP has a data frame to the client node, AP transmits it to the client node (Secondary transmission). Full-duplex operation starts. Otherwise, AP does nothing (Half-duplex operation).

If an AP wins to get the medium,

- The AP transmits a data frame to a client node (Primary transmission).
- When the client node receives the data frame and decodes its header, the client node checks if the receiver of the data frame is the node itself.
- If the client node has a data frame to the AP, the client node transmits it to the AP (Secondary transmission). Full-duplex operation starts. Otherwise, the client node does nothing (Half-duplex operation).

B. AC-MAC with Dynamic Contention Window (ACMAC/DCW)

In AC-MAC, both AP and client nodes can initiate data transmission. AC-MAC can improve throughput performance when uplink and downlink traffic are symmetric thanks to the full-duplex wireless. However, when uplink and downlink are asymmetric, the opportunity for full-duplex operation decreases, which incurs throughput degradation. In ACMAC/DCW, contention window size of AP is dynamically changed according to the transmission queue length at AP to balance uplink and downlink traffic.

In AC-MAC/DCW, CSMA is adopted basically; AP and client nodes randomly select a contention window among $[0,CW_{min}]$. In AP, two values of contention window are defined:

CW_{small} and CW_{large}. In addition, a threshold Th is set at the transmission queue length at AP. The operation of AP is as follows:

1) When AP completes a data frame transmission, the AP checks the number of data frames in its transmission queue.
2) If the queue length is shorter than Th, CW_{large} is adopted for prioritizing client nodes' transmissions. AP randomly selects its backoff time in $[0, CW_{large}]$.
3) Otherwise, CW_{small} is adopted for prioritizing AP's transmission. AP randomly selects its backoff time is in $[0, CW_{small}]$.

IV. DISCUSSIONS

The situation where the queue length of AP is short implies that the downlink traffic is less than uplink one. In this case, CWlarge is adopted for preventing underflow of AP's transmission queue and increasing opportunity for client nodes to transmit. On the other hand, the situation where the queue length of AP is long means that the downlink traffic is more than uplink one. So, CWsmall is adopted for increasing transmission opportunity to AP. The proposed AC-MAC/DCW changes CW according to the queue length at AP to increase opportunity for full-duplex operations, which can bring out the potential of FDW in WLANs. We established an AP and four client nodes. AP and the four client nodes can do carrier sense each other. So, hidden terminal problem does not occur in this situation. Four uplink CBR flows at rate Rup are generated at each client node; four down link CBR flows at rate Rdn are generated at the AP. Simulation parameters are shown in Table I. The conventional full-duplex MAC protocol [2] is chosen as the comparative protocol.

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Table - 1
Simulation Parameter

PHY layer	*IEEE 802.11a*
Channel rate	*12 [Mb/s]*
CW_{min} *of client nodes*	*15*
Frame size	*1,024[Byte]*
Max.queue length	*400*

V. CONCLUSION

In this paper, we have suggested a MAC protocol for refining throughput in full-duplex WLANs. The suggested ACMAC/DCW familiarizes a threshold-based dynamic CW control at AP to increase the chance for full-duplex operations. In AC-MAC/DCW, small and large CWs are used adaptively. We observed that the suggested MAC protocol is operative to progress downlink throughput in full-duplex WLANs without degrading uplink throughput appreciations to the adaptive control of contention window at AP.

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