Power Control Algorithm for Throughput Enhancement in Full-Duplex Communications

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***Abstract*—Full-duplex (FD) communication transmits and receives packets simultaneously at the same channel. The FD communication is possible thanks to self-interference cancellation (SIC) technology that has developed. However, in the asymmetric FD pair, the interference should be carefully considered to fully utilize FD communication. In this paper, we propose a power control algorithm to improve throughput performance. The access point (AP) controls the transmission power of the AP and the uplink (UL) node. The simulation results show that the throughput performance of the proposed algorithm is higher than that of other algorithms.**

***Index Terms*—Full-duplex, medium access control (MAC) protocol, wireless lan (WLAN), power control**

I. Introduction

Full-duplex (FD) communication is one of the key technology to improve throughput. In literature, there have been many research results in order to realize FD network. The main challenge is to overcome self-interference. Many researchers have proposed self-interference cancellation (SIC) technologies [1]–[3]. Therefore, the FD communication is enabled to transmit and receive packets simultaneously at the same channel.

To utilize FD communication, the access point (AP) and nodes have to establish a pair. There are two types of pairs; (i) symmetric FD pair and (ii) asymmetric FD pair. In the symmetric FD pair, the AP and nodes have FD capability. Thus, uplink (UL) and downlink (DL) node are the same nodes. In the asymmetric FD pair, the AP only has FD capability. The UL and DL node are the different nodes. Unlike the symmetric FD pair, the inter node interference occur between UL and DL nodes. Thus, the inter-node interference must be considered in the asymmetric FD pair.

Many FD medium access control (MAC) protocols have been proposed [4]–[7]. In [4], the authors proposed polling based traffic-aware MAC protocol (pFD-MAC). The pFD-MAC is based on point coordination function (PCF). The AP collects interference information and packet length of each node. The AP transmits scheduling result to the DL node and the UL node transmit the packet to the AP simultaneously. In [5]–[7], the FD MAC protocols are based on distributed coordination function (DCF). The authors of [5] proposed A-duplex. The AP establish signal-to-interference ratio (SIR) map. The SIR map includes SIR information of each node. The AP selects DL node that exceeds SIR threshold based on SIR map. In [6], authors proposed power-controlled MAC protocol (PoCMAC). The AP controls transmission power of node to maximize SIR. The AP transmits power information to the UL node. The AP and UL node which is controlled transmission power transmit a packet simultaneously. In [7], the authors proposed power control and rate selection (PCRS) MAC protocol. The AP controls the transmission power of UL node and selects data rate to reduce asymmetric transmission time when the transmission time of UL and DL is asymmetric.

In this paper, we propose a power control algorithm to improve throughput . In the [4], [5], the authors assumed that each node transmit a packet with fixed transmission power. If the distance between the UL and DL nodes is not far enough, the FD communication is impossible. In the [6], [7], the authors proposed that the AP controls transmission power of UL node. However, the authors only consider the transmission power of node. Therefore, we focus on controlling transmission power of the AP and the UL node to improve throughput.

The remainder of this paper is organized as follows. In section II, we describe the system model. In section III, we explain the proposed algorithm. Then, the performance of the proposed algorithm is evaluated in section IV. Finally, we make conclusion in section V.

II. System Model

We consider a wireless local area network (WLAN) infrastructure system. We assume that only one AP is FD communication enabled and N nodes are half-duplex (HD) communication enabled. Thus, only asymmetric FD pair is possible. Each node calculates SIR and informs that to the AP during the request to send /clear to send (RTS/CTS) handshake. As the one of nodes transmits RTS packet to the AP, the other nodes can measure interference strength. As the AP replies CTS packet to the node, the other nodes can measure signal strength. Then, the nodes calculate SIR value, The SIR value of DL can be calculated as follows:

$$SIR_{DL} = P_{AP} + AG - PL(d_{AD}) - P_N - AG + PL(d_{UD}), \quad (1)$$

where P_{AP} and P_N stand for the transmission power of the AP and node, respectively, AG is the antenna gain, PL is the

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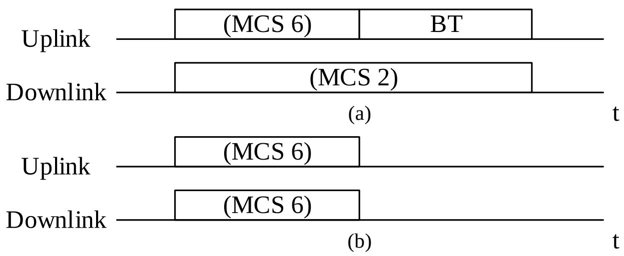

Fig. 1: (a) Example of transmission time in case of UL and DL is different (b) transmission time in case of UL and DL is same

path loss, d_{AD} is the distance between the AP and DL node, and d_{UD} is the distance between the UL and DL nodes. Also, the AP calculate the SIR value of UL. as follows:

$$SIR_{UL} = P_N + AG - PL(d_{UA}) - \gamma, \quad (2)$$

where d_{UA} is the distance between the UL node and the AP, γ is the residual self-interference. The condition of FD pair is as follows:

$$SIR_{UL}, SIR_{DL} \geq \delta[n], \quad (3)$$

where $\delta[n]$ is the SIR threshold according to the modulation coding scheme (MCS) level denoted as n.

III. Proposed Algorithm

The MCS level of the AP and UL node is determined when the transmitting a packet. It is determined based on SIR value. If the MCS level of UL and DL are different, the transmission time is wasted. Fig. 1 (a) shows the transmission time of the UL and DL are different. Thus, performance of throughput is degraded. However, if the transmission power of the AP and UL node is controlled to reduce interference, the transmission time of the DL becomes with that of the UL. Thus, the performance of throughput is improved. Fig. 1 (b) shows the transmission time of UL and DL is same.

The proposed power control algorithm is shown in Algorithm 1. The AP controls the transmission power of the AP and the UL node to improve throughput. The node that wins channel competition, it becomes the UL node. It transmits the RTS packet that includes SIR information to the AP. The AP calculates the SIR. If the SIR_{UL}, SIR_{DL} is higher than $\delta[n]$, the AP transmits CTS packet to the UL node. However, SIR_{UL}, SIR_{DL} is lower than $\delta[n]$, the AP controls transmission power of the UL node. To control transmission power of the UL node, the AP calculates the power control condition of the UL node using (1) and (2). It is given by:

$$P_{min1} \leq P_N \leq P_{max1}, \quad (4)$$

where P_{min1} and P_{max1} are the minimum and maximum transmission power of the UL node that SIR_{UL} and SIR_{DL} exceeds $\delta[n]$, respectively. It is given by:

$$P_{min1} = \delta[n] + AG + PL(d_{UA}) - \gamma, \quad (5)$$

$$P_{max1} = P_{AP} + AG - PL(d_{AD}) - PL(d_{UD}) - \delta[n]. \quad (6)$$

Algorithm 1: Proposed power control algorithm

Input: SIR_{UL}, SIR_{DL}
Output: P_N, P_{AP}
if $SIR_{UL}, SIR_{DL} \geq \delta[n]$ **then**
  Do not support power control
else
  while $n > 0$ **do**
    if $P_{min1} \leq P_N \leq P_{max1}$ **then**
      $P_N \leftarrow P_{min1}$;
      break
    else
      $P_N \leftarrow P_{max1}$;
      if $P_{min2} \leq P_{AP} \leq P_{max2}$ **then**
        $P_{AP} \leftarrow P_{min2}$;
        break
      end if
    end if
    $n \leftarrow n - 1$;
  end while
  HD communication is possible
end if

TABLE I: SIR threshold, MCS level and data rate

SIR threshold	MCS level	Data rate
11 dB	2	12 Mbps
13 dB	3	24 Mbps
18 dB	4	36 Mbps
22 dB	5	48 Mbps
24 dB	6	54 Mbps

If the P_N satisfies condition (5), the AP controls P_N to P_{min1}. However, if the P_N doesn't satisfy (4), the AP calculates the power control condition of the AP using (1) and (2). It is given by:

$$P_{min2} \leq P_{AP} \leq P_{max2}, \quad (7)$$

$$P_{min2} = \delta[n] + AG + PL(d_{AD}) + PL(d_{UD}) + P_N, \quad (8)$$

$$P_{max2} = P_N + AG - PL(d_{UA}) + SIC - \delta[n] \quad (9)$$

where P_{min2} and P_{max2} are the minimum and maximum transmission power of the AP that SIR_{UL} and SIR_{DL} exceeds $\delta[n]$, respectively. If the P_{AP} satisfies (8), the AP controls P_{AP} to P_{min2}. However, if the P_{AP} doesn't satisfy (8), the AP recalculates power control condition of the AP and the UL node.

IV. Performance evaluation

We implement a simulator by using MATLAB to evaluate the proposed algorithm. We assume that one AP is placed in the center and N nodes are randomly distributed within in 20 meters. We consider saturation condition. The detailed simulation parameters and path loss model are based on IEEE 802.11 and TGax path loss model [8], [9]. The SIR threshold, MCS level, and data rate are described Table 1 [10]. We compare the proposed algorithm, the conventional

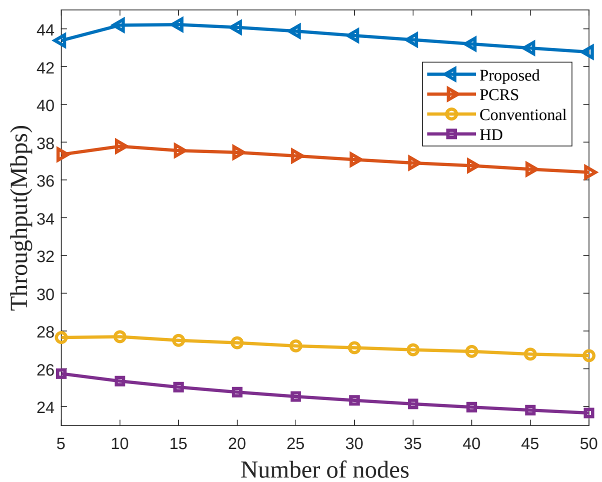

Fig. 2: Throughput vs. number of nodes (SIC=110 dB)

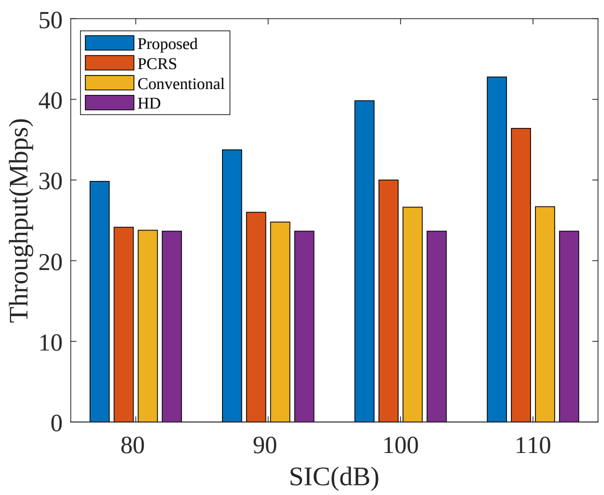

Fig. 3: Throughput vs. SIC ($N = 50$)

algorithm, HD and PCRS [7]. We evaluate the performance of the proposed algorithm in terms of the throughput according to the number of nodes and SIC value. The range of SIC value is from 80 to 110 dB.

Fig. 2 shows the throughput based on the number of nodes. The number of nodes is from 5 to 50. The simulation results show that the performance of throughput decreases as the number of node increases. This result is due to increase collision between the AP and nodes. The throughput performance of proposed algorithm is higher than that of other algorithms. Especially, the proposed algorithm improves throughput by 17 %, 60 % and 80 % over PCRS, conventional algorithm, and HD when the number of nodes is 50. The proposed algorithm can reduce interference by controlling the transmission power of the AP and UL node. Therefore, the AP transmits a packet with a high MCS level.

Fig. 3 presents the throughput based on the SIC value when the number of node is 50. In the corresponding setting, the minimum and maximum SIC value are 80 and 110 dB, respectively. As the SIC value reduces, the throughput decreases because of residual self-interference. The throughput of proposed algorithm is higher that that of other algorithms. The proposed algorithm controls transmission power of the AP. Even though SIC value is lower, the self-interference reduces. Thus, the FD pair increases and throughput increases. For the lower SIC values (i.e, 80 dB), the throughput of PCRS, conventional algorithm, and HD is almost same result. This result shows that FD pair is impossible when the SIC 80 dB because of residual self interference.

V. CONCLUSION

In this paper, we proposed the power control algorithm to improve throughput performance. The AP controls the transmission power of the AP and UL node to reduce interference. Thus, the AP and the UL node transmit a packet with a high MCS level. The simulation results show that the throughput performance of the proposed algorithm is higher than PCRS, conventional algorithm, and HD as the number of nodes increases. Also, when the SIC value is lower, the throughput of the proposed algorithm is higher than that of other algorithms.

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