Performance Evaluation of Full-duplex MAC Protocol Depending on Ratio of Full-duplex and Half-duplex node

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***Abstract*—Compared to half-duplex (HD) wireless communication system, full-duplex (FD) wireless communication system can double throughput in theory. To implement FD wireless communication system, medium access control (MAC) protocol must be changed, because the current MAC protocol is suitable for HD wireless communication system. Most of proposals assumed that all node have FD capability or only the access point (AP) has FD capability. However, in real world, since the nodes that only have HD capability (HD nodes) change the nodes that have FD capability (FD nodes) gradually, the coexistence of the FD nodes and the HD nodes should be occurred. In this paper, we propose a FD MAC protocol and evaluate its performance in a coexisted environment with HD nodes and FD nodes. In the FD MAC protocol, FD nodes operate symmetric FD pair or asymmetric FD pair and HD nodes operate asymmetric FD pair or HD mode. Simulation results show an increase of system throughput as the ratio of the FD nodes increase. It also shows that the system throughput increases according to the increase of the number of the nodes.**

***Index Terms*—Full-duplex, medium access control protocol, wireless LAN, coexistence between full-duplex node and half-duplex node**

I. Introduction

Full-duplex (FD) technique plays more important role in wireless communication system. Since device can transmit and receive at the same time and same frequency, the FD technique potentially is capable of doubling throughput in theory. In order to implement the FD wireless communication system in real world, it is essential to handle self-interference. In recent work, there are many technique to enhance self-interference cancellation [1]-[4]. However, since current medium access control (MAC) protocol is suitable for half-duplex (HD) wireless communication system, new MAC protocol for FD wireless communication system should be developed.

Recently, Several MAC protocols for FD wireless communication system have been proposed [5]-[12]. The authors of [5] proposed FD MAC protocol with busytone to solve hidden terminal problem. However, since busytone do not carry any useful data, it is a waste of resource. For the following reason, the authors of [6] reduce the ratio of transmitting busytone by maximizing similarity of the payload length sent in downlink and uplink. In [7], the authors proposed request to send (RTS)/full-duplex clear to send (FCTS) based on MAC protocol for FD wireless communication system. The FCTS has original CTS frame structure added the address of downlink receiver. The authors of [8] proposed a FD MAC protocol so-called asymmetrical duplex (A-duplex). The A-duplex was developed in the environment of single FD access point (AP) and a number of HD nodes. When a node accesses the channel and transmits RTS, the AP selects downlink receiver node using signal-to-interference ratio (SIR) map. However, the AP cannot select uplink transmitter node when it accesses the channel. In [9], the authors proposed power-controlled MAC (PoCMAC). It coordinated uplink and downlink transmission power, so that maximized signal-to-interference-plus-noise ratio (SINR) and throughput. In FD wireless communication system, it is important to select the FD pair, which is a pair of nodes transmitting and receiving simultaneously. In [10], the authors proposed optimal FD pair selection algorithm by applying many-to-many matching theory [13] with SINR, length of data, and waiting time information. The authors in [11] introduced so-called Janus. In Janus scheme, the AP collected traffic and interference information from the nodes. Through the collected information, the AP scheduled transmission. Then the AP and the nodes transmit data as the AP scheduled. In contrast to [5]-[11] proposals, the authors of [12] proposed time-frequency domain channel access scheme. In this scheme, the nodes access channel using orthogonal frequency division multiplex (OFDM) subcarriers. Since the proposed time-frequency domain channel access scheme use only three symbol time, it is

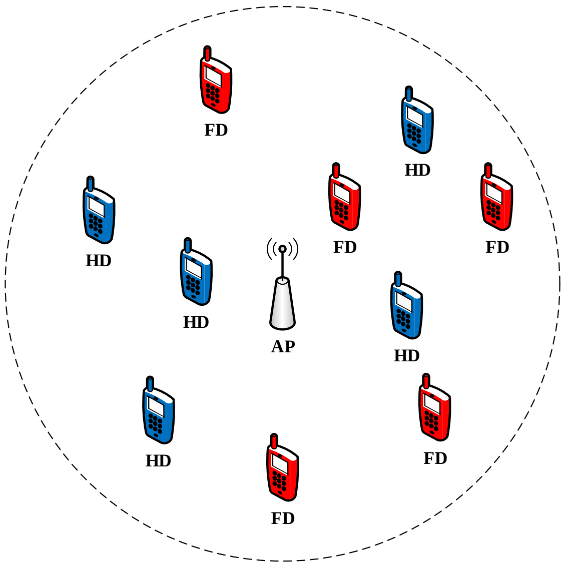

Fig. 1. System model

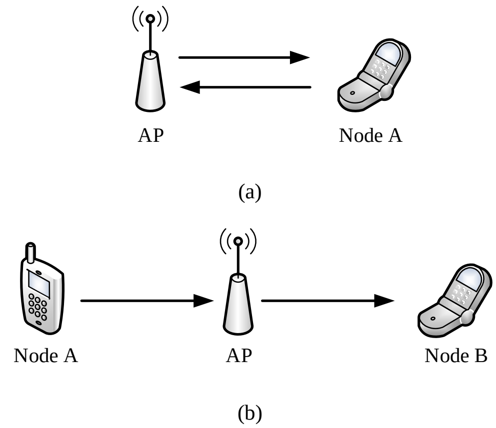

Fig. 2. Cases of FD pair: (a) Symmetric FD pair. (b) Asymmetric FD pair.

useful compared to time domain channel access using control frames (e.g., RTS/CTS). The proposals in [5], [6], [7], [11], and [12] assumed that the AP and all the nodes have FD capability (FD nodes). In contrast, the proposals in [8]-[10] assumed that the AP has FD capability and all the nodes only have HD capability (HD nodes). However, since FD nodes gradually come in real wireless communication system, it cannot help coexisting between FD nodes and HD nodes. So it is essential to analysis FD wireless communication system in environment where the FD nodes and the HD nodes are coexisted.

In this paper, we consider FD MAC protocol for an environment where coexisting the FD nodes and the HD nodes. Using proposed FD MAC protocol, we compare the throughput as ratio of FD nodes and HD nodes. Furthermore, we compare the throughput as the number of nodes increases while the ratio of FD nodes and HD nodes is fixed. Simulation results show the throughput of the system increases as the FD nodes increase. It also shows the throughput increases as the number of nodes increases.

The remainder of this paper is organized as follows. Section II presents the FD MAC protocol that can be used to environment of coexisting FD and HD nodes. In Section III, we present a simulation setup and simulation results. Finally, Section IV summarizes our paper.

II. FD MAC PROTOCOL

In section II, we present the proposed FD MAC protocol. Fig. 1 shows the example of system model. The proposed FD wireless system is composed of one AP and *N*-nodes. The nodes only communicate with the AP. We assume that the AP has FD capability. Each node has FD capability or HD capability. In addition, the self-interference cancellation is perfect and the AP has an SIR map of each node. The SIR map introduced in [8] has node interference information. When a node transmits data onto the AP, the node is called uplink transmitter. When the AP transmits data onto a node, the node is called downlink receiver.

Fig. 2 presents the cases of FD pair. When the AP and a node transmit data to each other, as we can see Fig. 2. (a), it is called symmetric FD pair. In this case, the node becomes both uplink transmitter and downlink receiver. Since the AP and the node transmit and receive simultaneously, they should have FD capability. In contrast, when a node transmits data onto the AP and the AP transmits other node, as we can see in Fig. 2. (b), it is called asymmetric FD pair. In this case, one node transmitting data to the AP becomes uplink transmitter and the other node receiving data from the AP becomes downlink receiver. Since only the AP transmit and receive simultaneously, the AP should have FD capability.

The FD MAC protocol proposed in this paper uses RTS/CTS mechanism. It is consists of 3 steps: *A. Establishment of FD table*; *B. Channel access and pair selection; C. Sending data and acknowledgement packet.* The procedure of the FD MAC protocol is as follows.

A. Establishment of FD table

First, the AP establishes a FD table. The FD table contains information about the FD pair of nodes. To establish the FD table, the AP needs an SIR map. If a node has a higher SIR value than the threshold, it can become the FD pair of the uplink transmitter. For example, in Fig. 2 (b), the AP have to know the SIR value of node B. It can be obtained through the SIR map. In this case, signal strength from the AP is signal value and that from the node A is interference value. If this SIR value is higher than threshold, the AP records this information to the FD table. Especially, in case of FD node, as we see in Fig. 2. (a), it can be FD pair of itself because we assume self-interference cancellation is

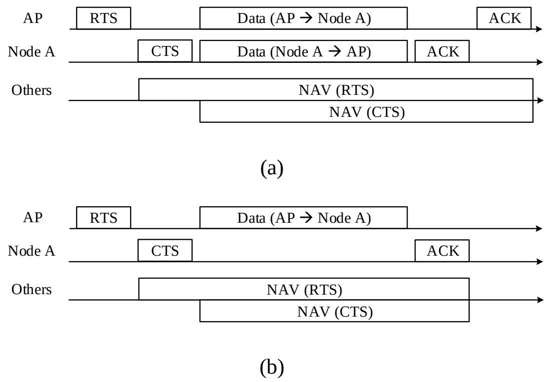

Fig. 3. Data transmission procedures when the AP accesses channel: (a) symmetric FD pair. (b) HD mode

perfect. It is so-called symmetric FD. In this way, the AP establishes the FD table through all the SIR map contents.

B. Channel access and pair selection

After establishment of the FD table, the AP and the nodes which have data for others contend channel by using backoff algorithm. Dedending on the backoff algorithm, the AP and the nodes access channel. We explain about two cases: *1) The AP accesses the channel; 2) One of the nodes accesses the channel.*

1) The AP accesses the channel

If the AP accesses the channel, it sends RTS packet to a node. The node then sends CTS packet to the AP. Then we consider two cases: *a) the node has FD capability; b) the node only has HD capability.* Fig. 3. describes the procedure of the FD MAC protocol. In first case, when the node has data for the AP, it becomes symmetric FD pair. In this case, the data transmission procedures is described in Fig. 3. (a). Even if the node has FD capability, the node operates with HD mode if the node does not have data for the AP. In this case, the data transmission procedures is described in Fig. 3. (b). In second case, only the AP transmits data onto the node regardless whether the node has data for the AP or not. In this case, the data transmission procedures is described in Fig. 3. (b).

2) One of the nodes accesses the channel

In case the one of the nodes accesses the channel, it sends RTS packet to the AP and becomes the uplink transmitter. When the AP received the RTS packet from the node, it finds other node that can receive the data from the AP. According to the FD table established in step *A*, the AP randomly selects a downlink receiver among the set of the nodes matched to the uplink transmitter. If the uplink transmitter and the downlink receiver are different, asymmetric FD pair is established and the procedure of the data transmission is described in Fig. 4. (a). If the uplink transmitter has FD capability, it has at least one matched downlink receiver. As we mentioned before, this is because the node can become FD pair itself. In this case, a symmetric FD pair is established and the procedure of the data transmission is described in Fig. 4. (b). However, If the uplink transmitter only has HD capability, when the node has no FD pair in the FD table, it happens that downlink transmission cannot operate. In this case, we describe the procedure of the data transmission as Fig. 4. (c). For all cases, after the AP finds the downlink receiver, it transmits CTS packet onto the uplink transmitter and the downlink receiver.

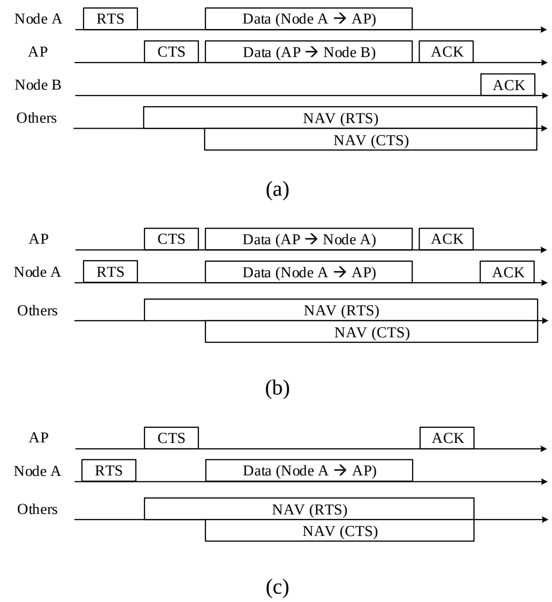

Fig. 4. Data transmission procedures when one of the nodes accesses channel: (a) Asymmetric FD pair. (b) Symmetric FD pair. (c) HD mode

C. Sending data and acknowledgement packet

After two steps, the AP and the node received the RTS packet or CTS packet transmit their data to the each intended node or AP. After finishing receiving data, the AP and the node send acknowledgement (ACK) packet, respectively.

III. Simulation Results and Evaluation

In this section, the simulation results will be presented to show the performance of the FD MAC protocol. The simulator is developed with Riverbed Modeler. We consider the throughput of system and the probability that a node cannot be FD pair the performance evaluation metric. The system model and other parameter will be introduced in section III-A and III-B. The simulation results are discribed in III-C.

A. System model

For the system model, one AP and *N*-nodes are considered. Each node is placed in the coverage area of the AP with circular uniform distribution. The number of nodes is changed from 10 to 100. The ratio of FD nodes are changed from 0% to 100%. In other words,

TABLE 1. System Parameters

Parameters	Values
RTS size	20 bytes
CTS size	14 bytes
ACK size	14 bytes
Payload size	1500 bytes
Data rate	18 Mbps
Slot time	9 µs
SIFS(Short Inter-frame Space)	16 µs
DIFS (Distributed Inter-frame Space)	34 µs
CW size	CWmin = 15, CWmax=1023
Path loss model	TGax pathloss model[15]
Antenna gain	0 dBi (AP), -2 dBi (node) [15]
Transmit power	20 dBm (AP), 15 dBm (STA) [15]

the ratio of HD nodes are changed from 100% to 0%. The AP always has FD capability.

B. System parameters

We apply general parameters of IEEE 802.11ac. Specially, IEEE 802.11ax simulation scenario parameter are applied in path loss model, antenna gain, and transmit power [15]. The radius of the AP's coverage circle is 20 meters. For the simulation, we should set up the threshold SIR value to find FD pair. In [14], the authors found that the threshold SIR that two node is to be FD pair was about 10dB. We apply this results to our simulation. The details of the parameter shown in Table 1.

C. Simulation results and evaluation

Fig. 5 presents the throughput depending on the ratio of FD nodes. As the ratio of FD nodes increases from 0% to 100%, the throughput of the system increases about 1Mbps. Regardless of the number of the node, it always show that the throughput of system increases as the ratio of FD nodes increases. Since the FD node can transmit and receive simultaneously, it always have a symmetric FD pair. Therefore, as the number of FD nodes are increased, the probability of the node cannot match FD pair decreases and the throughput increases.

Fig. 6 presents the throughput depending on the number of the nodes. We compare the FD MAC protocol to the CSMA/CA protocol where the AP and the nodes operate only HD communication. Simulation results show the throughput of the system increases as the number of the nodes increases. Compared to the CSMA/CA with HD protocol, the throughput of the FD MAC protocol increases 83% where the ratio of FD is 100% and the number of nodes is 100. As the number of nodes increases, the throughput of system increases, regardless of the ratio of FD nodes. When the number of nodes increases, the idle slot time decreases and the throughput of system increases. However, as the number

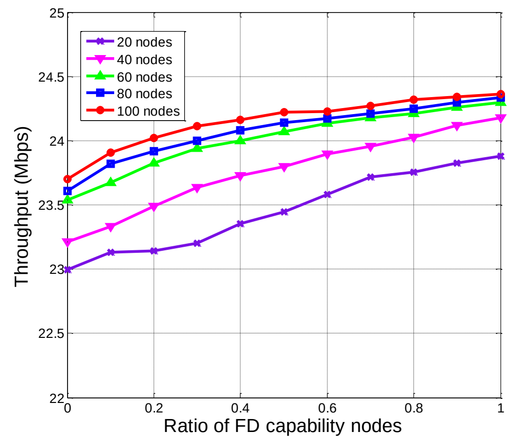

Fig. 5. Throughput depending on the ratio of FD capability nodes

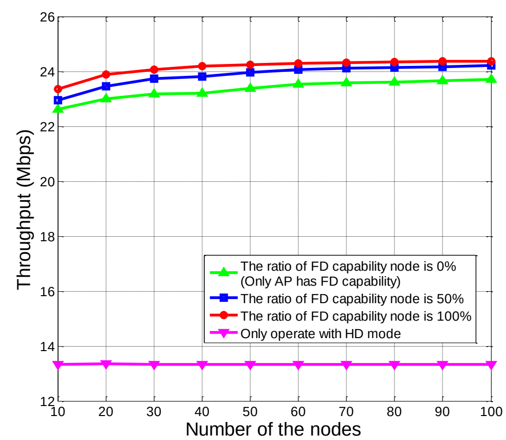

Fig. 6. Throughput depending on the number of nodes

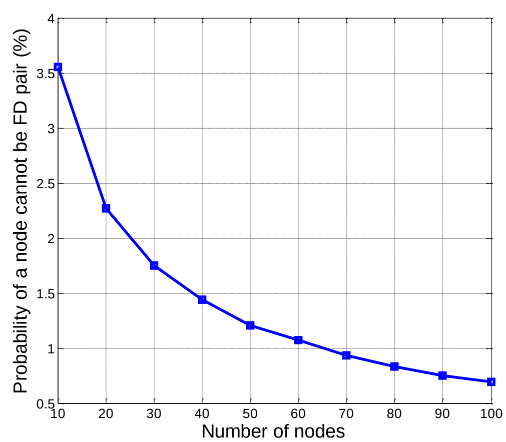

Fig. 7. Probability that a node has no FD pair depending on the number of nodes

of the nodes is large, the throughput of system is saturated. This is because the probability of collision in channel access increases as the number of nodes increases.

Fig. 7 presents the probability that node cannot match FD pair depending on the number of nodes. As the number of the nodes increases, the probability decrease. When the number of the nodes increases, the probabiltiy that a node has at least one FD pair increases. Therefore the probability that node cannot match FD pair decreases as the number of the node increases.

IV. Conclusion

In this paper, we evaluated the performance of the proposed FD MAC protocol. We considered granular migration from network deployment scernario with HD nodes to that with FD nodes. Simulation results show that the throughput of system increased, as the ratio of FD nodes increased. Simulation results also show that the throughput of system increased, as the number of the nodes in the system increased. However, there is no noticeable throughput difference as the ratio of FD nodes and the number of nodes. The simulation results is expected to be used in coexisting FD nodes and HD nodes.

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