Immediate Acknowledgement for Single-Channel Full-Duplex Wireless Networks

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***Abstract*—Driven by advances in the signal processing and antenna technology, it has become possible for wireless nodes to simultaneously transmit and receive a packet through self-interference cancellation using multiple antennas. This is known as a full-duplex communication. In this paper, we propose a MAC protocol with immediate acknowledgement (ACK) for single-channel full-duplex wireless networks. The proposed scheme in a full-duplex communication can solve the hidden terminal problem by using the immediate ACK. That is, the proposed scheme ensures that the transmission of a packet that is being correctly received is continued, and prevents the transmission of an already failed packet. To evaluate the performance of the proposed scheme, we carried out extensive simulations and subsequently showed that the proposed scheme significantly improves the network throughput.**

I. Introduction

In a traditional wireless network environment, all nodes can simultaneously either transmit or receive a packet. That is, a node cannot receive information transmitted from other nodes until its own packet transmission to another node is completed. If another packet is received at the node while it is transmitting a packet, a collision occurs. This one-way communication system is called a half-duplex communication, which is common in wireless networks.

With increasing advancement in the signal processing and antenna technology, it has become possible for nodes to transmit and receive a packet simultaneously through self-interference cancellation using multiple antennas. This is called full-duplex communication. In particular, the single-channel full-duplex system driven by recent technological developments uses only one channel, unlike existing methods that use more than two channels for transmission and reception. Therefore, the existing medium access control (MAC) protocols such as IEEE 802.11 are not efficient in single-channel full-duplex systems. Here, we design a new MAC protocol for single-channel full-duplex wireless networks.

Many studies have been conducted on MAC protocols for single-channel full-duplex systems. Choi *et al.* proposed antenna cancellation and digital interference cancellation for the self-interference cancellation required for a full-duplex communication [1]. Jain *et al.* presented a balun cancellation method to reduce the number of antennas and extend the bandwidth in full-duplex systems [2]. In [3], Sen *et al.* proposed a carrier sense multiple access with collision notification (CSMA/CN) using self-interference cancellation. When a packet received in a wireless network collides with another packet, the receiver immediately notifies the sender

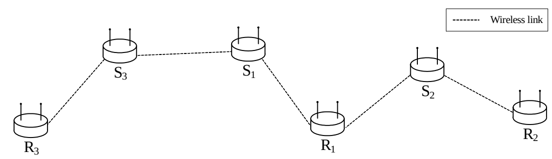

Fig. 1. An example of single-channel full-duplex wireless networks.

of this collision. During packet transmission, the sender can listen for the collision notification and can then stop the ongoing transmission. However, CSMA/CN suffers from the disadvantage that a packet that is being correctly received can be stopped because of the collision notification due to the interference caused by packet transmission to another receiver. To overcome this disadvantage and to maximize the efficiency of full-duplex communication, we propose a MAC protocol that uses immediate acknowledgement (ACK) and negative ACK (NACK); the former ensures the transmission of packet that is correctly being received is continued, while the latter aborts the transmission of the already failed packet.

II. Proposed MAC Protocol with Immediate ACK

In this paper, we consider a single-channel full-duplex wireless network that consists of a sender and receiver with two antennas each, and Fig. 1 shows an example of this network. Each node has two antennas for transmitting and receiving packets. The dashed lines in Fig. 1 denote the wireless links between the nodes that can communicate with each other. To transmit a packet, a node performs carrier sensing and a random backoff process, as is done in IEEE 802.11. In order to fully exploit the advantage of full-duplex communication, we design a new MAC protocol using self-interference cancellation.

A. Self-Interference Cancellation

For a full-duplex communication, we assume that all the nodes have more than two antennas and that they are capable of carrying out self-interference cancellation. The self-interference cancellation technique that uses two antennas (TX and RX) can receive another signal while transmitting another by subtracting the signal transmitted by TX antenna from the incoming signal on RX antenna. This becomes possible because the signal transmitted by TX antenna located at a very short distance is very strong, and such a strong signal can be removed almost completely from the signal received by RX antenna [1], [2].

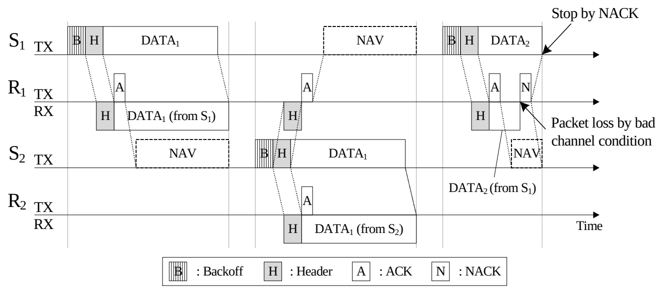

Fig. 2. Operation of the proposed scheme under the network topology as shown in Fig. 1. In case of receiver, both transmission and reception are presented.

B. Detailed Procedure of Proposed Scheme

The main feature of the proposed scheme is that the ACK or NACK is immediately transmitted to the sender as soon as the header of the transmitted packets is received or the transmission fails, respectively. An immediate ACK solves the hidden terminal problem, while an immediate NACK aborts the transmission of an already failed packet. The procedure of the proposed scheme is as follows.

1) Sender:

(S1) RX antenna is always in a listening state.

(S2) If ACK is received from RX by transmission of other nodes, the sender sets a network allocation vector (NAV) for the time indicated in the ACK.

(S3) If NAV is zero and the channel is idle, the transmission of DATA frame begins through TX antenna.

(S4) During packet transmission through RX antenna:

(S4-1) If ACK is received, the sender continues the ongoing transmission.

(S4-2) If NACK is received or ACK is not received for ACK timeout, the sender stops the ongoing transmission immediately and returns to the initial state for retransmitting failed packet.

2) Receiver:

(S1) RX antenna is always in a listening state.

(S2) When the header of a DATA to be transmitted is received from RX antenna:

(S2-1) If the desired recipient is the receiver itself, the receiver transmits its own ACK through TX antenna and continues to receive DATA frame.

(S2-2) Otherwise, the receiver transmits the same ACK as the intended receiver would transmit through TX antenna and stops receiving DATA frame.

(S3) If the reception of DATA frame fails owing to bad channel condition or multiple signals, etc., the receiver stops receiving DATA frame immediately, and transmits NACK periodically until transmission by the sender is terminated.

Fig. 2 shows the operation of the proposed scheme under the example network topology shown in Fig. 1.

III. Performance Evaluation

In order to evaluate the performance of the proposed scheme, we have carried out extensive simulation using MATLAB. For comparative verification, we compared the proposed MAC protocol with CSMA/CN and IEEE 802.11. All nodes were uniformly distributed, and the network parameters are set to the values defined in the IEEE 802.11 standard.

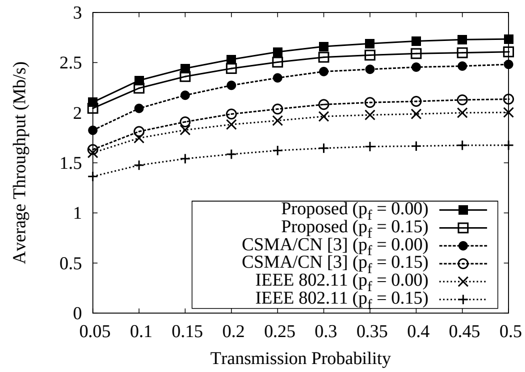

Fig. 3. Average throughput of proposed scheme, CSMA/CN [3], and IEEE 802.11 with respect to transmission probability and frame loss ratio.

Fig. 3 shows the average throughput of the proposed scheme with respect to the transmission probability, when the frame loss rate in wireless channel (p_f) is 0 and 0.15. As the transmission probability increases, the performance rapidly increases in the beginning and gradually converges. The proposed scheme exhibits a significant performance improvement as compared to the IEEE 802.11, and it also outperforms CSMA/CN that uses full-duplex, because the transmission of a packet that is correctly being received is continued, unlike what is done by CSMA/CN. In particular, as the frame loss ratio increases, the performance degradation of the proposed scheme becomes smaller than CSMA/CN and IEEE 802.11, because the proposed scheme can immediately cope with frame loss by using immediate NACK.

IV. Conclusion and Future Work

The main objective of the proposed scheme was to improve the network throughput by exploiting full-duplex wireless networks. To do so, we proposed a MAC protocol to solve the hidden terminal problem by using immediate ACK, and to abort the transmission of an already failed packet by using immediate NACK. We could obtain a significant performance improvement as compared to CSMA/CN and IEEE 802.11. For empirical verification, we intend to perform throughput analysis and various experiments using the USRP platform.

Acknowledgment

This work was supported by MKE, Korea, under the ITRC program supervised by NIPA (NIPA-2012-(H0301-12-2003)).

References

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