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A MAC Protocol for Full Duplex Cellular Networks

Sammy Chan*

Department of Electronic Engineering
City University of Hong Kong
Tat Chee Avenue, Kowloon Tong
Hong Kong

Abstract

Full duplex wireless communication is one of the enabling technologies of the fifth generation (5G) mobile telecommunication networks. It boosts up the bandwidth by enabling simultaneous data transmission and reception on a single channel. In this paper, we design a suitable medium access control (MAC) protocol for 5G networks to realize the benefit of full duplex communication. We also develop an analytical model to evaluate the performance of our proposed MAC protocol.

Keywords: full duplex; MAC; cellular networks

1. Introduction

With the tremendous success of smart phones, mobile telecommunications networks need to support higher user density, and more bandwidth intensive and time-sensitive multimedia applications. In addition, the bandwidth demand is further increased by newly emerging technologies such as Internet of Things (IoT). These factors drive the evolution of the fourth-generation (4G) mobile telecommunications networks to the fifth generation (5G). Currently, 5G networks are under intensive research.

Compared with the 4G networks, 5G networks are expected to provide higher bandwidth by several orders of magnitude. This requires a multitude of new technologies, such as spectrum efficiency optimization, cooperative communications and multiple-input multiple-output (MIMO), to significantly enhance spectrum efficiency. Besides these new technologies, the recently proposed full duplex (FD) transmission techniques [1,2] also offer great potential to significantly boosting spectrum efficiency.

Currently, frequency-division duplexing (FDD) and time-division duplexing (TDD) transmission techniques are commonly deployed. Both of them operate in half-duplex modes. In FDD, two frequency channels are needed to

* Corresponding author. Tel.: +852-3442-7781 ; fax: +852-3442-0562.
E-mail address: eeschan@cityu.edu.hk

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support bidirectional communications; one for uplink and one for downlink. In TDD mode, the uplink and downlink data are sent in orthogonal time-slots. On the other hand, FD transmission is the techniques which allow a node to simultaneously send and receive data on a single channel. According to the approach proposed by Choi *et al.*[1], two transmitting (TX) antennas and one receiving (RX) antenna are installed in each node. The RX antenna is positioned in a location such that the signals from the two TX antennas cancel each other. Thus, the transmitted signal does not interfere with the received signal and FD transmission is realized. However, this approach suffers from a bandwidth constraint and is not suitable for broadband wireless communications. In the approach proposed in[2], FD transmission is realized by the use of analog and digital cancellation. It requires one RX antenna, one TX antenna and a balanced/unbalunced (Balun) transformer. First, analog cancellation is used. The signal from the TX antenna is cancelled at the RX antenna by the inverted signal generated by the Balun transformer. It can cancel a minimum of 45 dB across a 40 MHz spectrum. Then, digital cancellation is employed to further reduce self-interference by up to 73 dB for 10 MHz OFDM signal.

When FD transmission is enabled, it can be deployed in two different modes. As shown in Fig. 1(a) , both nodes 1 and 2 are equipped with one TX antenna and one RX antenna. They can send and receive data simultaneously over the single channel. This mode is referred to as *FD-bidirectional transmission*. Alternatively, as shown in Fig. 1(b), node 1 is sending data to node 2. While node 2 is receiving the data, it can immediately forward it to node 3. In other words, node 2 is simultaneously receiving and transmitting. This mode is referred to as *FD-relay transmission*. For this mode, only node 2 needs to have two antennas installed; one TX antenna and one RX antenna. Since node 1 and node 3 do not transmit and receive simultaneously, each of them only need to have one antenna.

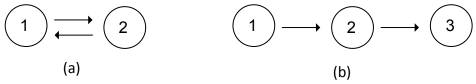

Fig. 1. FD transmission modes.

Having FD transmission enabled at the physical layer, there is a need for a suitable medium access control (MAC) protocol to realize its benefit. So far, MAC protocols for FD transmission are mainly designed for wireless local area networks (WLANs). In this paper, we propose a MAC protocol for cellular networks in which both base stations and user equipments can support FD transmission. We also develop an analytical model to evaluate the average packet delay and its standard deviation under the saturated condition. The remainder of this paper is organized as follows. In Section 2, we review some recently proposed full duplex MAC protocols. In Section 3, we present our proposed MAC protocol. Then, we develop an analytical model in Section 4. Explicit expressions for the average packet delay, its standard deviation, and frame utilization are given. In Section 5, we verify the accuracy of our model by comparing with simulation results. We also investigate the impact of system parameters on the MAC layer performance. Finally, Section 6 concludes the paper.

2. Related Work

Besides proposing an innovative radio design to support full duplex operation on a single channel,[2] also suggests a MAC protocol to exploit the benefit of full duplex radios. It is based on the CSMA/CA protocol, each node accesses the channel by following the standard procedures of CSMA/CA. The difference comes when a node is transmitting. Consider an example shown in Fig. 2, node 1 is sending a packet to node 2 after carrier sensing. Once node 2 has received the header information, it realizes that node 1 is sending a packet to itself. Since full duplex is allowed in a single channel, node 2 can also immediately start transmitting a packet to node 1. Note that this MAC protocol naturally mitigates the hidden terminal problem. Referring again to Fig. 2, node 3 is a hidden terminal to Node 1 and could cause collision at node 2. However, with this MAC protocol, transmission at node 1 also triggers simultaneous transmission at node 2. node 3 thus could sense that the channel is busy and will not initiate any transmission, which leads to collision. This works well if both nodes finish transmission at the same time. However, if node 2 has no packet for node 1, or transmits a smaller packet and hence finishes transmission before node 1, node 3 can still be a