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Contents

In-Band Full-Duplex Radios in 6G Networks: Implementation and Applications

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ABSTRACT

Sixth-generation (6G) wireless communication networks will transform connected things in 5G into connected intelligence. The networks can have human-like cognition capabilities by enabling many potential services, such as high-accuracy localization and tracking, augmented human sense, gesture and activity recognition, etc. For this purpose, many emerging applications in 6G have stringent requirements on transmission throughput and latency. With the explosion of devices in the connected intelligence world, spectrum utilization has to be enhanced to meet these stringent requirements. In-band full-duplex (IBFD) has been reported as a promising technique to enhance spectral efficiency and reduce end-to-end latency. However, simultaneous transmission and reception over the same frequency introduce additional interference compared to conventional half-duplex (HD) radios. The receiver is exposed to the transmitter of the same node operating in IBFD mode, causing self-interference (SI), which could be more than 100dB higher than the signal of interest from other nodes due to the proximity of the transceiver. Due to the significant power difference between SI and the signal of

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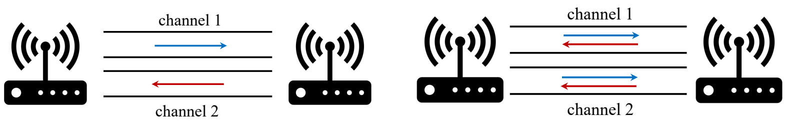
interest (SoI), SI must be effectively suppressed to benefit from IBFD operation. In addition to SI, uplink users will interfere with downlink users within the range, known as co-channel Interference (CCI). This interference could be significant in cellular networks, so it has to be appropriately processed to maximize the IBFD gain. The objective of this monograph is to present a timely overview of self-interference cancellation (SIC) techniques and discuss the challenges and possible solutions to implement effective SIC in 6G networks. Then, we investigate beamforming to manage the complex interference and maximize the IBFD gain in cellular networks. Furthermore, we give a deep insight into the benefits of IBFD operations on various emerging applications, e.g., integrated access and backhaul (IAB) networks, integrated sensing and communications (ISAC), and physical layer security (PLS).

1

Introduction

Since wireless communication became a topic of study in the 1960s, there has been a consensus that it is generally not possible for radios to transmit and receive simultaneously over the same frequency [67]. Thus, radios have been working in half-duplex (HD) mode (i.e., either transmit and receive in different time slots or over orthogonal channels, as Figure 1.1(a) shows) since the first generation (1G) analog radio communication systems. However, the wireless communication society never gives up pursuing in-band full-duplex (IBFD) radios (i.e., transmit and receive simultaneously over the same channel, as Figure 1.1(b) shows). The main driving force for researching IBFD radios is their potential to double the spectral efficiency compared to existing HD radios. Until the last decade, researchers from groups in both academia and industry have demonstrated the feasibility of IBFD radios [13], [30], which has tremendous implications for wireless communication networks, including but not limited to doubling the spectral efficiency and decreasing the latency. These studies invalidate the above assumption and allow radios to work in IBFD mode by successfully breaking the barrier, i.e., eliminating the significant self-interference (SI).



(a) Half-duplex (HD) (b) In-band full-duplex (IBFD)

Figure 1.1: Schematic figures of HD and IBFD radios.

IBFD has not been introduced into the fifth-generation (5G) new radio (NR) protocol yet, but it is regarded as a promising technique in beyond 5G (B5G) or sixth-generation (6G) networks, complementing and sustaining the evolution of 5G toward denser heterogeneous networks. Therefore, it is timely and meaningful to discuss the implementation and applications of IBFD radios in 6G. Existing studies have proposed various self-interference cancellation (SIC) schemes to implement effective IBFD radios. We review these techniques in detail and analyze their advantages and disadvantages. According to the requirements of 6G networks and emerging applications, we discuss the limitations of existing SIC methods and explore some feasible solutions. Effective SIC techniques can maximize the IBFD gain in a point-to-point system but are not enough for cellular networks due to the additional co-channel interference (CCI), which means the downlink users are interfered with by uplink users within the range. We present beamforming and power allocation schemes to manage the complex interference in cellular networks based on 3GPP-specified simulations, showing the achievable IBFD gain. In addition to the spectral efficiency improvement, we further illustrate the advantages of IBFD operations in some emerging applications, i.e., integrated access and backhaul (IAB) networks, integrated sensing and communications (ISAC), and physical layer security (PLS). This monograph introduces the reader to IBFD radios in a structured way.

- Section 2 first introduces the causes of SI, then reviews existing SIC techniques, followed by the analysis of their advantages, disadvantages, and limitations. The massive multi-input and multi-output (MIMO) and high-mobility scenarios, which are likely to appear in 6G, are further discussed with the associated challenges of SIC. Some worthwhile research directions are highlighted for feasible IBFD radios implementation in 6G networks.

- Section 3 discusses beamforming schemes for IBFD cellular networks. The performance of extending three common linear beamformers (i.e., zero-forcing, maximum ratio transmission and combining, and minimum mean-squared error) in IBFD cellular networks is compared via simulations, followed by a discussion of beamforming cancellation, i.e., utilize beamforming to suppress SI. Joint power allocation and beamforming designs are further presented in this section.

- Section 4 introduces an emerging application of IBFD radios: integrated access and backhaul. The architecture of the IAB network is given, followed by the mmWave channel model. Then, the beam management and user selection schemes, which can provide reliable access and backhaul mmWave links with the help of large-scale antenna arrays, are given in detail on the basis of 5G NR standards.

- Section 5 introduces a typical application of IBFD radios: integrated sensing and communications. The conventional orthogonal frequency division multiplexing (OFDM)-based ISAC is first introduced. Then, the sensing and data detection methods for orthogonal time frequency space (OTFS) systems are investigated to support high-mobility environments.

- Section 6 discusses the advantages of applying IBFD radios to physical layer security. We first introduce the benefits and various implementations of PLS, then focus on the physical layer-based secret key generation (PHY-SKG) schemes. The advantages and limitations of applying IBFD are analyzed by deriving the secret key capacity with practical imperfections.

- Section 7 closes this review and draws conclusions.

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