Power Allocation for Downlink and Uplink Full-Duplex Integrated Sensing and Communications

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***Abstract*—Integrated sensing and communication (ISAC) has emerged as a promising technology that shares spectrum and hardware. In particular, the combination with Full-Duplex (FD) can improve spectral efficiency by enabling simultaneous transmission and reception of radar and communication signals. In this paper, we propose a scheme that schedules downlink (DL) and uplink (UL) communication periods based on the radar pulse timing and expected echo arrival times by leveraging the FD capability. We then perform power allocation subject to sensing and communication constraints and evaluate the performance through simulation.**

***Index Terms*—ISAC, full-duplex, communication rate, SINR, power allocation**

I. Introduction

Integrated sensing and communication (ISAC) is a promising technology that efficiently utilizes limited spectral resources by sharing frequency bands and hardware [1]. In particular, full-duplex (FD) technology, which enables simultaneously transmission and reception, can provide improved spectral efficiency in ISAC systems [2]. To simultaneously transmit and receive sensing and communication signals in an FD-ISAC system, it is important to manage interference and ensure the required performance for both functions. To achieve this, resource allocation methods such as time division and power allocation have been studied. A new FD-ISAC system based on time-division duplexing design was proposed to perform downlink (DL) communication by utilizing the long idle time between the pulses of a traditional pulse radar [3]. In [4], the authors proposed a power allocation optimization scheme for both time-variant and time-invariant channels.

However, most FD-ISAC resource allocation studies have considered the interference between DL signals and the radar echoes, but not the interference between uplink (UL) and radar signals. In this paper, we propose a FD-ISAC system that considers both UL and DL communications. We then perform power allocation under specific sensing and communication constraints. We adopt the waveform design proposed in [3]. By exploiting the FD mode, we perform time division and allocate transmit power to satisfy the signal to interference-plus-noise ratio (SINR) for sensing and the required communication rates.

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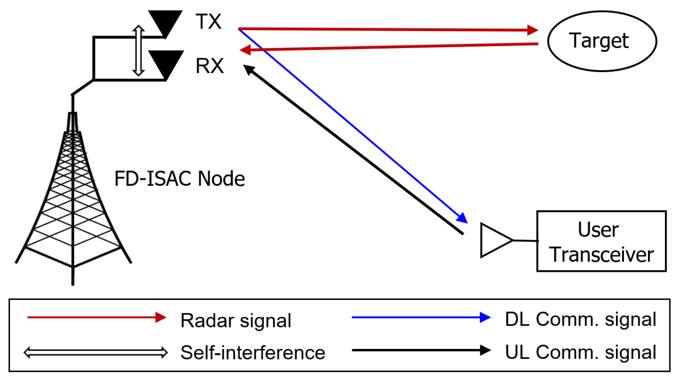

Fig. 1. System model of the FD-ISAC

The performance of the proposed power allocation scheme is evaluated through simulations.

II. System Model and Proposed Scheme

In this section, we first describe the FD-ISAC system model that incorporates both DL and UL communication. We then detail the proposed scheme for scheduling communication periods based on FD operation and for performing power allocation subject to system constraints.

A. System model

As illustrated in Fig. 1, we consider an FD-ISAC Node equipped with separate transmit and receive antennas. The FD-ISAC node communicates with a single user equipped with a single-antenna and senses a single target at a remote distance. Leveraging FD capabilities, the FD-ISAC node simultaneously transmits DL communication signals while receiving radar echoes, and transmits radar pulses while receiving UL communication signals. The user transmits UL signals and receives DL signals from the FD-ISAC node. We assume that the communication delay between the FD-ISAC node and the user is negligible. The target is assumed to be stationary, and its echo arrival times are assumed to be known from previously performed sensing operations. The signal transmitted by the FD-ISAC node within a single pulse repetition interval (PRI) can be expressed as

$$x_I(t) = \begin{cases} \sqrt{P_r}p(t), & 0 \le t \le \tau + T_g \\ \sqrt{P_{DL}}g(t), & \tau + T_g < t \le T_e + \tau + T_g, \end{cases} \quad (1)$$

where P_r and P_{DL} are the transmit powers for the radar pulse and DL communication, respectively. Here, τ is the radar pulse duration, and T_e is the echo arrival time. The DL and UL periods are allocated according to the pulse transmit time and the echo arrival time. The guard time T_g after the pulse allows for switching between radar and communication functions. The DL period is scheduled to encompass the echo arrival time. An additional guard time is included after the expected echo arrival to account for timing uncertainty.

The user transmits the UL signal during two distinct periods: concurrently with the FD-ISAC node's radar pulse transmission, and again after the DL communication period concludes. Thus, the user's transmitted signal is expressed as follows:

$$x_U(t) = \sqrt{P_{UL}}h(t), \quad \begin{cases} 0 \leq t \leq \tau + T_g \\ T_e + \tau + T_g < t \leq L \end{cases} \tag{2}$$

where P_{UL} is the UL transmit power, and L is the PRI duration.

B. Power allocation mechanism

Once the DL and UL periods are established, power allocation is performed to satisfy sensing and communication constraints. For sensing, the radar SINR must be greater than a given threshold (γ_r). The SINR constraint is given by:

$$SINR_r \geq \gamma_r \tag{3}$$

The constraints for communication are that the DL and UL rates must be greater than their respective thresholds (γ_{DL}, γ_{UL}). These constraints are given by:

$$C_{DL} \geq \gamma_{DL}, \quad C_{UL} \geq \gamma_{UL} \tag{4}$$

We consider two primary sources of interference: self-interference (SI) arising from the FD operation, and interference from the high-power radar pulse affecting the DL communication signal.

III. Simulation Results

The simulation is designed to evaluate the power allocation performance in the proposed FD-ISAC system. The duty-cycle $\frac{\tau}{L}$ is 10%. For radar sensing, the distance between the FD-ISAC node and the target is d, and the two-way channel gain is modeled. The maximum detection distance d_{max} is 50 km. For the communication function, a path-loss model is considered, and the user is located near the FD-ISAC node. The signal bandwidth is 1 MHz and the SI cancellation capability parameter is set to $\kappa = -90$dB.

The performance of the power allocation is illustrated in Fig. 2 using 10^3 Monte-Carlo simulations. We evaluate the power allocation for different communication rate constraints and target distances d when the radar constraint γ_r is 10 dB. In the DL, as the target distance increases, the echo arrives later, allowing more time for DL transmission, which could potentially reduce the required transmit power. However, more radar pulse power is needed for distant targets to maintain the sensing SINR, which increases interference with the DL signal. Consequently, the interference from the powerful radar pulse required for long-range target has a greater impact on the required DL power than the potential power savings from the longer transmission time. In the UL, as the target distance increases, less time is available for UL communication, and the SI caused by the radar pulse increases, so that more power is needed to meet the rate constraint. Additionally, as communication constraints become more stringent, the required transmission power for both links increases.

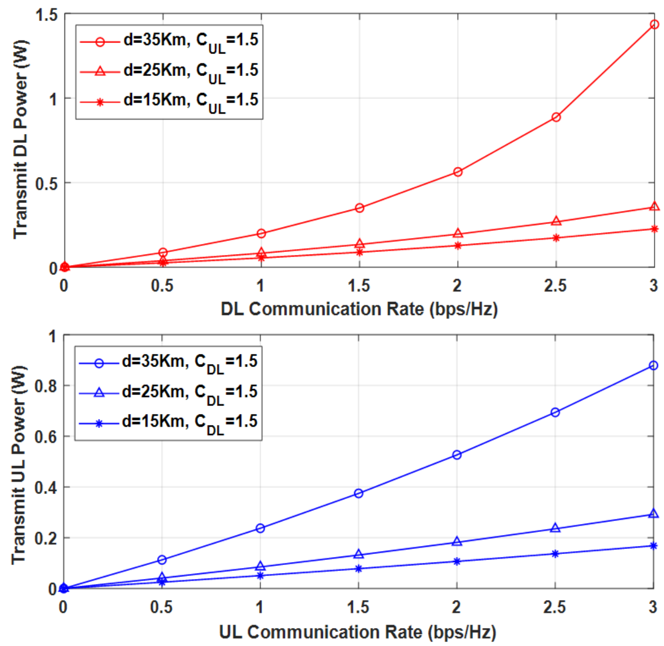

Fig. 2. Power allocation of DL and UL versus different communication rate constraints with different target distances.

IV. Conclusion

In this paper, we proposed a power allocation scheme for FD-ISAC system that considers both DL and UL communications. By utilizing the simultaneous transmission and reception capabilities of FD, DL and UL communication periods are scheduled based on radar pulse timings and echo arrival times. The power allocation was designed to meet radar SINR and communication rate constraints. We then evaluated the performance of the proposed allocation mechanism through simulation, considering the interference between the radar and allied communication signals.

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