Impact of Blockage on the Sum-Rate Performance of ISAC-NOMA Systems

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Concerted efforts have been made in academia towards integrating sensing and communication (ISAC) technology with non-orthogonal multiple access (NOMA) for 6G wireless networks. However, the performance of ISAC-NOMA users can be degraded by various factors, particularly blocker that may partially obstruct the communication path or causes shadowing effects. This paper investigates the performance loss induced by (human body) blocker in such systems and proposes a joint waveform strategy to mitigate this challenge.

***Index Terms*—Hybrid-beamforming, ISAC-NOMA, massive-MIMO, multicarrier system.**

I. Introduction

A key component of 6G research is ISAC, which unifies sensing and communication operations using shared hardware and spectrum resources. Cutting-edge wireless joint sensing and communication applications, namely autonomous vehicles, robotics, augmented reality, and simultaneous localization and mapping, to name but a few, can be efficiently supported by ISAC network, leveraging high resolution and ultra-wide band (UWB) capabilities in millimeter wave and THz spectra. However, these spectra are vulnerable to path loss fading and multipath effects. Massive multiple input multiple output (MIMO) and hybrid beamforming (HBF) technologies have been established by researchers as part of solutions to mitigate these fading effects, thereby ensuring a higher throughput for ISAC systems.

HBF in massive MIMO systems typically dedicates one beam and radio frequency (RF) chain per user, but NOMA overcomes this limitation by allowing multiple users to share the same beam and RF chain. Power-domain NOMA, which superimposes users' symbols at the base station (BS) and employs successive interference cancellation at receivers, is adopted here for ISAC systems. Effective NOMA communication requires users pairing, grouping users with correlated channels or similar angles of arrival (AoA) before superposition coding [1]. A key challenge is performance degradation caused by static or mobile blocker in the communication path. Addressing this issue requires adaptive beamforming and dynamic power allocation strategies to detect and mitigate such obstructions.

A. Related Studies

NOMA integration was explored in [2] and [3], focusing on radar-communication trade-offs, yet these studies and existing works assume narrowband channels, neglecting HBF and wideband interference. Recent advances in beamforming, such as [4], improved channel estimation but lack NOMA-ISAC adaptation. RIS-assisted designs [5] enable waveform optimization but ignore blockers detection scenario. Key gaps remain include real-time blocker detection and multicarrier (MC) HBF optimization. This work proposes a blocker-aware HBF-MIMO-NOMA-ISAC system to enhance 6G spectral efficiency and resilience.

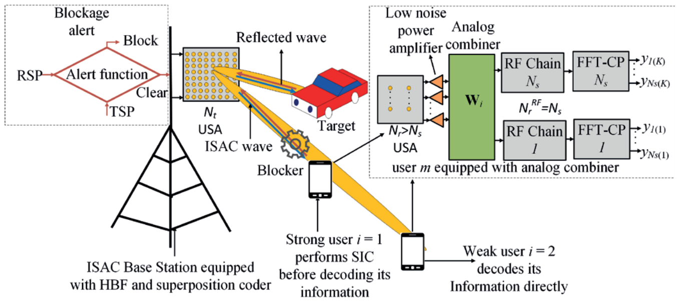

Fig. 1: Illustration of an ISAC-enabled Blocker aware mmWave NOMA Communication system.

II. System Model

We consider a downlink ISAC system where a base station (BS) equipped with a uniform square array (USA) of $N_t(=64)$ antennas simultaneously serves I NOMA user (equipped with $N_r(=4)$ USA antennas) pairs and performs monostatic sensing. The BS employs HBF across K subcarriers, with the joint precoding matrix expressed as $\mathbf{F}_{c,s}(k) = \mathbf{F}_{\text{RF}}\mathbf{F}_{\text{BB}}(k) \in \mathbb{C}^{N_t \times N N_s}$, where $\mathbf{F}_{\text{RF}}$, $\mathbf{F}_{\text{BB}}(k)$, N_s and $N(=2)$ denote the ISAC analog and digital precoders on subcarrier k, user's data symbols and number of clusters, respectively. First cluster contains a dedicated target and the other cluster contains $I(=2)$ NOMA strong and weak users in the same angle-of-arrival (AoA), with power allocation satisfying $p_2(k) > p_1(k)$.

A. Communication Model

The received signal at user i is $\mathbf{y}_i(k) = \mathbf{W}_i^H(k)\mathbf{H}_i(k)\mathbf{F}_c(k)\mathbf{s} + \mathbf{n}_i(k)$ where $\mathbf{W}_i(k)$ is the combining matrix. The achievable rate follows:

$$R_i(k) = \log_2\left(1 + \frac{p_i(k)\left|\mathbf{W}_i^H(k)\mathbf{H}_i(k)\mathbf{F}_c(k)\right|^2}{\sum_{j>i} p_j(k)\left|\mathbf{W}_i^H(k)\mathbf{H}_i(k)\mathbf{F}_c(k)\right|^2 + \hat{\sigma}_i^2}\right). \quad (1)$$

B. Sensing Model

The BS processes echoes from both users and a dedicated target: $\mathbf{y}_R(k) = \sum_{o\in\mathcal{O}} \rho_o \mathbf{H}_o^H \mathbf{F}_s(k) s_s(k) + \mathbf{n}_R(k)$ with sensing SINR:

$$\gamma_o(k) = \frac{p_o\left|\rho_o(k)\mathbf{W}_R^H(k)\mathbf{H}_o(k)\mathbf{F}_s(k)\right|^2}{\sum_{j\in\mathcal{O},\, j\neq o} p_j\left|\rho_j(k)\mathbf{W}_R^H(k)\mathbf{H}_j(k)\mathbf{F}_s(k)\right|^2 + \hat{\sigma}_R^2}. \quad (2)$$

C. Problem Formulation

We formulate the joint ISAC optimization problem as:

$$\begin{aligned} \max_{\mathbf{F}_{\text{RF}},\mathbf{F}_{\text{BB}},\mathbf{p}} \quad & \eta R_{\text{sum}}^c + (1-\eta) R_{\text{sum}}^s \\ \text{s.t.} \quad & R_i \geq R_i^{\min}, \forall i, \quad R_O \geq R_o^{\min} \\ & \gamma_o \geq \gamma_o^{\min}, \forall o \\ & \|\mathbf{F}_{\text{RF}}\mathbf{F}_{\text{BB}}\|_F^2 \leq P_{\max} \\ & p_2 > p_1, \sum_i p_i \leq P_{\max} \end{aligned} \quad (3)$$

where $\eta \in [0,1]$ balances communication sum rate R_{sum}^c and sensing sum rate R_{sum}^s tradeoffs.

D. Problem Solution

The proposed solution implements a joint waveform-based MC-HBF scheme for ISAC-NOMA systems that adapts to blockage conditions, benefiting from reduced (sensing) interference signal power and robust HBF with combining optimization. The algorithm first evaluates channel states using NYU millimeter-wave channel models, comparing transmit signal power (TSP) and received signal power (RSP) at the BS to detect blockages exploiting Frobenius norm analysis. When blockage is detected, the system automatically empowers the sensing sum rate gains owing to reduced interferences from sensing NOMA users. The analog beamformers and combiners are optimized, using phase alignment approach, while digital precoder is computed via pseudo-inversion of the aggregated analog channel matrix. Power allocation between NOMA users is dynamically adjusted through an iterative process that guarantees minimum rate requirements for weak users, with sensing and communication resources balanced via the η parameter.

III. Results

The simulation results illustrated in Fig.2 indicate that the proposed blocker-aware MC-HBF-ISAC-NOMA system efficiently improves sensing performance under human body blockage condition with reduced impact on communication. Notably, a 174   enhancement in sensing sum rate is attained at the expense of only a 22   reduction in communication sum rate at 10 dB SNR, highlighting the system's robustness and efficiency in maintaining dual-functionality under difficult propagation environments.

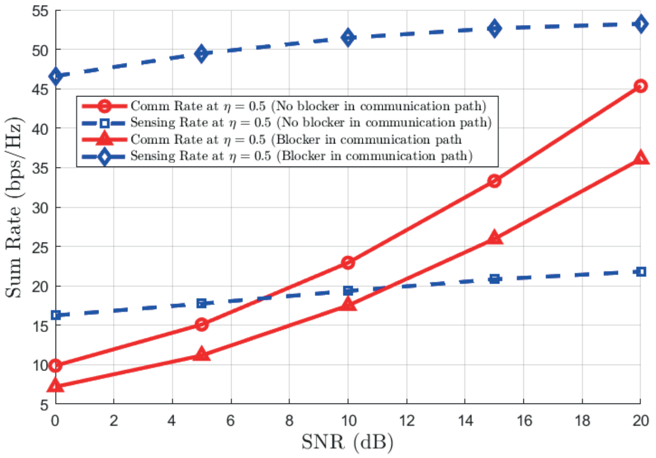

Fig. 2: Achievable sum rates for sensing and communication, deploying the proposed blocker aware MC-HBF-ISAC-NOMA system.

IV. Conclusion

This study examined blockage impacts on the sum rate performance of an ISAC-NOMA system enabled by MC-HBF technology, maximizing both joint communication and sensing capabilities. In order to ensure QoS, the solution has an adaptive NOMA power regulation, real time blockage detection and a low-complexity adaptive HBF via phase alignment and zero forcing scheme. The simulation results indicate that the proposed joint waveformed-based MC-HBF-ISAC-NOMA scheme significantly enhances sensing performance under blockage condition with minimal impact on communication, highlighting a favorable tradeoff under ISAC operation. AI-powered blocker prediction and RIS-assisted extensions are examples of future research. In dynamic contexts, our work offers a workable implementation of resilient 6G networks.

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