STAR-RIS Aided Integrated Sensing and Communication

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Abstract

This paper considers simultaneously transmitting and reflecting reconfigurable intelligent surface (STAR-RIS) assisted integrated sensing and communication (ISAC) system. Our objective is to maximize the sum rate of downlink multiuser communication while satisfying radar sensing requirements. An algorithm using successive convex approximation is proposed to optimize transmit beamforming and STAR-RIS phase shift coefficients. Simulation results demonstrate the effectiveness of the proposed scheme.

Ⅰ. Introduction

Integrated sensing and communication (ISAC) enables simultaneous data transmission and radar sensing using shared wireless resources [1]. Non-orthogonal multiple access (NOMA) further enhances spectral efficiency in ISAC systems by allowing multiple users to share the same time-frequency resources via superposition coding and successive interference cancellation (SIC) [2]. Simultaneously transmitting and reflecting reconfigurable intelligent surfaces (STAR-RISs) have emerged as a promising solution to support full-space coverage in ISAC systems [3,4]. Recent works have addressed beampattern design [3] and secrecy rate maximization [4] problems in STAR-RIS aided NOMA-ISAC systems, but efficient sum rate maximization problem under ISAC constraints remains open. In this work we address this gap by maximizing the sum rate of communication users while satisfying target sensing requirements.

Ⅱ. System Model and Problem Formulation

We consider a downlink ISAC system as shown in Fig. 1, where a base station (BS) equipped with M antennas communicates with K single-antenna users via STAR-RIS with N antennas. The STAR-RIS reflects signals toward users (communication space) and simultaneously transmits toward a radar target (sensing space). Let

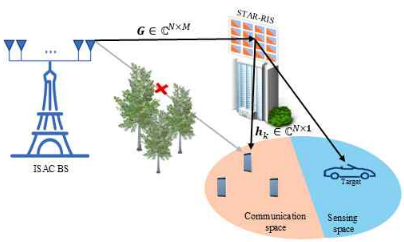

Fig. 1. System model of STAR-RIS assisted NOMA-ISAC system

$\boldsymbol{w}_k \in \mathbb{C}^{M\times 1}$ denote transmit beamforming vector and $\boldsymbol{\Theta}_t, \boldsymbol{\Theta}_r \in \mathbb{C}^{N\times N}$ be diagonal STAR-RIS reflection and transmission matrices, with entries $\sqrt{\beta_{r,n}} e^{j\phi_{r,n}}$, $\sqrt{\beta_{t,n}} e^{j\phi_{t,n}}$ respectively. The transmitted signal is:

$$\boldsymbol{x} = \sum_{k=1}^{K} \boldsymbol{w}_k s_k \quad (1)$$

The signal received at the communication user is given as

$$y_k = \boldsymbol{h}_k^H \boldsymbol{\Theta}_r \boldsymbol{G} \sum_{i=1}^{K} (\boldsymbol{w}_i s_i) + n_k \quad (2)$$

The signal-to-interference-plus-noise ratio (SINR) is:

$$SINR_{k\to k} = |\boldsymbol{h}_k^H \boldsymbol{\Theta}_r \boldsymbol{G} \boldsymbol{w}_k|^2 / \sum_{i>k} |\boldsymbol{h}_k^H \boldsymbol{\Theta}_r \boldsymbol{G} \boldsymbol{w}_i|^2 + \sigma^2) \quad (3)$$

The achievable rate of signal s_k at user j where $(j \geq k)$ under SIC decoding is $R_{k\to j} = \log_2(1 + SINR_{k\to j})$. The total communication sum rate is given as:

$$R_{sum} = \sum_{k=1}^{K} R_{k\to k} \quad (4)$$

The effective sensing power in the target direction is defined as:

$$P(\zeta) = \boldsymbol{a}^H(\zeta) \boldsymbol{\Theta}_t \boldsymbol{G} (\sum_{k=1}^{K} \boldsymbol{w}_k \boldsymbol{w}_k^H) \boldsymbol{G}^H \boldsymbol{\Theta}_t^H \boldsymbol{a}(\zeta) \quad (5)$$

where $\boldsymbol{a}(\zeta)$ is the steering vector. The optimization problem aiming to maximize the total sum rate while ensuring the radar sensing requirements is:

$$\max_{\boldsymbol{w}_k, \boldsymbol{\Theta}_t, \boldsymbol{\Theta}_r} \quad R_{sum} = \sum_{k=1}^{K} R_{k\to k} \quad (6a)$$

$$\text{s.t.} \quad R_{k\to k} \geq R_{\min,k}, \ \forall k \in \mathcal{K} \quad (6b)$$

$$R_{k\to j} \geq R_{k\to k}, \ \forall k \in \mathcal{K}, \ \forall j > k \quad (6c)$$

$$\sum_{k=1}^{K} \|\boldsymbol{w}_k\|^2 \leq P_{\max} \quad (6d)$$

$$P(\zeta) \geq \eta_{\min} \quad (6e)$$

$$\beta_{t,n} + \beta_{r,n} \leq 1, \forall n \in \mathcal{N} \quad (6f)$$

$$\phi_{t,n}, \phi_{r,n} \in [0, 2\pi], \forall n \in \mathcal{N} \quad (6g)$$

The optimization problem is non-convex due to the coupled nature of the beamforming vectors and the STAR-RIS coefficients. To tackle it, we propose a two-stage iterative algorithm that alternates between optimizing the beamforming vectors and the STAR-RIS phase shifts using successive convex approximation (SCA).

III. Results and Discussion

For our simulations, we adopt a setup similar to [4], including the BS and STAR-RIS deployment, user distribution, and propagation model.

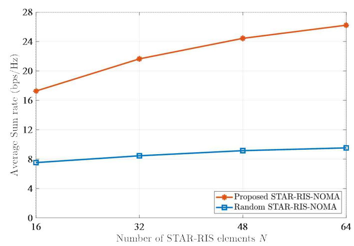

Fig. 2. Achievable sum rate vs number of STAR-RIS elements

The results show that the proposed STAR-RIS-NOMA scheme, which optimizes transmit beamforming and STAR-RIS phase shifts, outperforms the baseline random STAR-RIS-NOMA with random configurations, with the performance gap increasing more as the number of STAR-RIS elements increases.

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