STAR-RIS Assisted ISAC with Energy Splitting: Effect of Residual SI

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Abstract

This paper investigates the performance trade-off between an uplink communication user and a sensing target in a monostatic integrated sensing and communication (ISAC) system assisted by a simultaneously transmitting and reflecting reconfigurable intelligent surface (STAR-RIS) operating in the energy splitting (ES) mode. We analyze the impact of self-interference (SI) and the trade-off between the communication and sensing performance.

Ⅰ. Introduction

A new and emerging technology for beyond 5G systems is integrated sensing and communication (ISAC), which improves system efficiency by sharing resources for sensing and communication [1]. Simultaneously transmitting and reflecting RIS (STAR-RIS) is another such technology that extends coverage at a low cost [2]. Integrating STAR-RIS with ISAC further enhances network efficiency and coverage [3]. However, in monostatic sensing, the base station inherently experiences self-interference (SI) [4]. In this paper, we explore the trade-off between the performance of an uplink communication user (CU) and a sensing target (ST), both being serviced via a STAR-RIS operating in the energy splitting (ES) mode in the presence of SI.

Ⅱ. System Model and Problem Formulation

The system consists of an M-antenna BS communicating with an uplink CU while simultaneously sensing an ST through an N-element STAR-RIS. Direct paths are assumed to be blocked so all communication or sensing occurs through the STAR-RIS. The BS to STAR-RIS channel is denoted as $\mathrm{G}\in\mathbb{C}^{M\times N}$, STAR-RIS to CU channel is denoted by $\boldsymbol{f}_c\in\mathbb{C}^{N\times 1}$ and STAR-RIS to ST channel is denoted by $\boldsymbol{f}_s\in\mathbb{C}^{N\times 1}$. The STAR-RIS coefficients are denoted by $\boldsymbol{\theta}_q=[\theta_1,\theta_2,\cdots,\theta_N]^T\in\mathbb{C}^{N\times 1}$, $q=\{t,r\}$ for transmitting and reflecting regions respectively with ST in the transmitting region and CU in the reflecting region. The STAR-RIS is considered to be operating in the ES mode so the BS receives both the uplink communication signal and the reflected sensing target response. As we are considering monostatic sensing, the received signal also includes the effect of residual SI due to the transmitted sensing signal. The received signal at the BS can then be modeled as

$$\begin{aligned}\mathrm{Y}=\sqrt{\mathrm{p_c}}\,\mathrm{h}_c(\boldsymbol{\theta}_r)\mathrm{s}_c^T+\sqrt{p_s}\,\beta\,\mathrm{h}_s(\boldsymbol{\theta}_t)\mathrm{h}_s^T(\boldsymbol{\theta}_t)\mathrm{w}_s\mathrm{s}_s^T\\+\sqrt{p_s}\,\mathrm{H}_{\mathrm{SI}}\mathrm{w}_s\mathrm{s}_s^T+\mathrm{Z}\in\mathbb{C}^{\mathrm{M}\times\mathrm{L}}\end{aligned}\tag{1}$$

where p_c and p_s are the transmit power for CU and ST respectively, $\mathrm{h}_s(\boldsymbol{\theta}_t)=\mathrm{G}\,\mathrm{diag}(\boldsymbol{\theta}_\mathrm{t})\boldsymbol{f}_s$ and $\mathrm{h}_c(\boldsymbol{\theta}_r)=\mathrm{G}\,\mathrm{diag}(\boldsymbol{\theta}_\mathrm{r})\boldsymbol{f}_c$ are the cascaded channels between the BS and ST and CU respectively, $\mathrm{w}_s\in\mathbb{C}^{M\times 1}$ is the transmit beamforming for sensing, s_s and s_c are the sensing waveform and information symbols transmitted by the CU respectively, $\beta\sim CN(0,\alpha_s)$ is the amplitude of the target response, and $\mathrm{vec}(\mathrm{Z})\sim CN(0,\sigma^2\mathrm{I}_{ML})$ is the noise received at the BS. $\mathrm{H}_{\mathrm{SI}}\in\mathbb{C}^{M\times M}$ is the self interference at the BS and is modeled as [4]

$$[\mathrm{H}_{\mathrm{SI}}]_{m,n}=\sqrt{\alpha^{\mathrm{SI}}}\,e^{-j2\pi\frac{d_{m,n}}{\lambda}},m,n=1,2,\cdots,M\tag{2}$$

for the (m,n)th component where α^{SI} is the residual SI channel power and $d_{m,n}$ is the distance between the mth transmit antenna and nth receive antenna. For evaluating the sensing performance, we utilize the sensing rate (R_s) as the performance metric. The sensing and communication SNR with the effect of SI in a sensing-centric design where communication is decoded first are given as

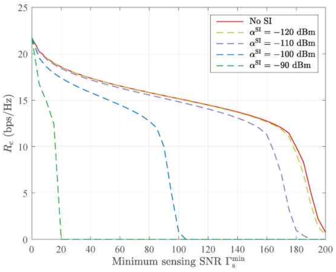

Fig. 1. Effect of SI level on performance of STAR-RIS assisted ISAC system

$$\gamma_s=p_s\alpha_s\|\mathrm{H}_s\boldsymbol{\theta}_t\|^2\mathrm{s}_s^H\mathrm{H}_s^H(\boldsymbol{\theta}_t)\mathrm{R}_{\mathrm{Z}^{\mathrm{SI}}}^{-1}\mathrm{H}_s(\boldsymbol{\theta}_t)\mathrm{s}_s,\tag{3}$$

and

$$\gamma_c=p_c\boldsymbol{\theta}_r\mathrm{H}_c^H\,\mathrm{R}_{\mathrm{Z}_s^{\mathrm{SI}}}^{-1}\mathrm{H}_c\boldsymbol{\theta}_r,\tag{4}$$

where

$$\mathrm{R}_{\mathrm{Z}^{\mathrm{SI}}}=p_s\mathrm{H}_{\mathrm{SI}}(\mathrm{w}_s)\mathrm{H}_{\mathrm{SI}}(\mathrm{w}_s)^H+\sigma^2\mathrm{I}_M,\tag{5}$$

$$\mathrm{R}_{\mathrm{Z}_s^{\mathrm{SI}}}=p_s\alpha_s\|\mathrm{H}_s\boldsymbol{\theta}_t\|^2\mathrm{H}_s\boldsymbol{\theta}_t\boldsymbol{\theta}_t^H\mathrm{H}_s+p_s\mathrm{H}_{\mathrm{SI}}\mathrm{w}_s\mathrm{w}_s^H\mathrm{H}_{\mathrm{SI}}^H+\sigma^2\mathrm{I}_M,\tag{6}$$

and, $\mathrm{H}_{\mathrm{SI}}(\mathrm{w}_s)=\mathrm{I}_L\otimes(\mathrm{H}_{\mathrm{SI}}\mathrm{w}_s)$ and $\mathrm{H}_s(\boldsymbol{\theta}_t)=\mathrm{I}_L\otimes(\mathrm{H}_s\boldsymbol{\theta}_t)$. To solve the problem, we opt for a low complexity method while using a common ES factor β_t for all STAR-RIS elements to get $\boldsymbol{\theta}_q=\sqrt{\beta_q}\tilde{\boldsymbol{\theta}}_q$. The solution for the phase shifts is found based on the eignevector $\mathrm{u}_{q,1}$ corresponding to the largest eigenvalue of $\mathrm{H}_q^H\mathrm{H}_q$ as

$$\tilde{\boldsymbol{\theta}}_t=e^{j\angle\mathrm{u}_{t,1}},\quad\tilde{\boldsymbol{\theta}}_r=e^{j\angle\mathrm{u}_{r,1}},\tag{7}$$

Ⅲ. Results and Discussion

The simulations are set up with $M=16$, $N=64$, $p_s=30\,\mathrm{dBm}$, $p_c=23\,\mathrm{dBm}$, $\sigma^2=-100\,\mathrm{dBm}$ and a carrier frequency of 2.5GHz. The locations of BS and RIS are (3, -3, 8) and (0, 0, 5), respectively while the CU and ST are located at (4, 40, 0) and (-3, 0, 5), respectively. The results clearly demonstrate a critical tradeoff between communication and sensing performance, showing that a careful balance must be maintained to achieve optimal system operation. The effect of SI is minimal when its power is suppressed below the noise level; however, exceeding the noise level leads to severe degradation in the achievable SNR.

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