STAR-RIS Assisted Integrated Sensing and Communication with Time Switching

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Abstract

This paper studies a simultaneously transmitting and reflecting reconfigurable intelligent surface (STAR-RIS)-assisted integrated sensing and communication (ISAC) system using time-switching protocol at the STAR-RIS. A communication user and sensing target are served on opposite sides, with self-interference at the base station during sensing. We analyze the trade-off between communication and sensing performance under varying time and interference.

Ⅰ. Introduction

Integrated sensing and communication (ISAC) is a promising technology for beyond 5G systems, enabling joint sensing and communication at the receiver side [1]. Reconfigurable intelligent surface (RIS) can further enhance system performance by improving coverage with minimal power consumption [2]. Simultaneously transmitting and reflecting RIS (STAR-RIS) further enhance the network by servicing users on both the transmitting and reflecting side of the STAR-RIS [3]. In monostatic sensing, however, the base station (BS) may experience self-interference (SI) during sensing [4]. In this paper, we explore the trade-off in the performance of a communication user (CU) and sensing target (ST) being serviced by a STAR-RIS in time-switching (TS) mode in the presence of SI.

Ⅱ. System Model and Problem Formulation

The system includes an M-antenna BS, a STAR-RIS with N elements, an uplink CU and an ST. All communication between the BS and the CU or ST is through the STAR-RIS as direct links are assumed to be blocked. The channel from BS to STAR-RIS is denoted as $\mathrm{G}\in\mathbb{C}^{M\times N}$ while the channel between the STAR-RIS and CU (ST) is denoted as $\boldsymbol{f}_c\in\mathbb{C}^{N\times 1}$ ($\boldsymbol{f}_s\in\mathbb{C}^{N\times 1}$). The STAR-RIS coefficients are denoted as $\boldsymbol{\theta}_q=[\theta_1,\theta_2,\cdots,\theta_N]^T\in\mathbb{C}^{N\times 1}$, $q=\{t,r\}$ for transmitting and reflecting regions respectively. For simplicity of notation, we consider the ST to be in the transmitting region and the CU to be in the reflecting region of the STAR-RIS. We consider the STAR-RIS to be operating in the TS mode so at a given time the BS receives either the communication or the sensing signal. The received signals in the communication and sensing slots are modeled as

$$\mathrm{Y}_c=\sqrt{p_c}\mathrm{h}_c(\boldsymbol{\theta}_r)\mathrm{s}_c^T+\mathrm{Z}_c\in\mathbb{C}^{M\times L_c} \quad (1)$$

and

$$\mathrm{Y}_s=\sqrt{p_s}\beta\mathrm{h}_s(\boldsymbol{\theta}_t)\mathrm{h}_s^T(\boldsymbol{\theta}_t)\mathrm{w}_s\mathrm{s}_s^T+\sqrt{p_s}\mathrm{H}_{\mathrm{SI}}\mathrm{w}_s\mathrm{s}_s^T+\mathrm{Z}_s\in\mathbb{C}^{M\times L_s} \quad (2)$$

where p_c and p_s are the transmit power for CU and ST respectively, $\mathrm{h}_s(\boldsymbol{\theta}_t)=\mathrm{G}\,\mathrm{diag}(\boldsymbol{\theta}_t)\boldsymbol{f}_s$ and $\mathrm{h}_c(\boldsymbol{\theta}_r)=\mathrm{G}\,\mathrm{diag}(\boldsymbol{\theta}_r)\boldsymbol{f}_c$ 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 $\mathrm{vec}(\mathrm{Z}_u)\sim CN(0,\sigma^2\mathrm{I}_{ML_u})$ 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]

$$[\mathrm{H}_{\mathrm{SI}}]_{m,n}=\sqrt{\alpha^{\mathrm{SI}}}e^{-j2\pi\frac{d_{m,n}}{\lambda}}, m,n=1,2,\cdots,M \quad (3)$$

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 rate with the effect of SI is given as

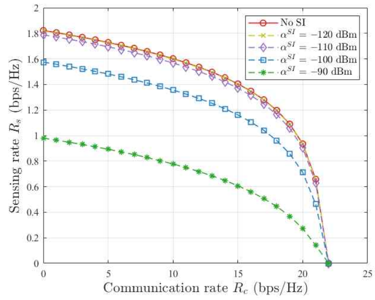

Fig. 1. Effect of SI level on performance of STAR-RIS assisted ISAC system

$$R_s=\frac{1}{L}\log_2(1+\tau\,\gamma_s), \quad (4)$$

where

$$\gamma_s=p_s\alpha_s\|\mathrm{H}_s\boldsymbol{\theta}_t\|^2\mathrm{x}_s^H\mathrm{H}_s^H(\boldsymbol{\theta}_t)\mathrm{R}_{z_{\mathrm{SI}}}^{-1}\mathrm{H}_s(\boldsymbol{\theta}_t)\mathrm{x}_s, \quad (5)$$

and

$$\mathrm{R}_{z_{\mathrm{SI}}}^{-1}=\mathrm{I}_{L_s}(p_s\mathrm{H}_{\mathrm{SI}}\mathrm{w}_s\mathrm{w}_s^H\mathrm{H}_{\mathrm{SI}}^H+\sigma^2\mathrm{I}_M). \quad (6)$$

The communication rate is also given by

$$R_c=(1-\tau)\log_2\left(1+\frac{p_c}{\sigma^2}\|\mathrm{h}_c(\boldsymbol{\theta}_r)\|_2^2\right). \quad (7)$$

The problem can be solved by maximizing R_s and R_c individually for given time allocation τ.

Ⅲ. Results and Discussion

For the simulations, we chose $M=16$, $N=64$, $p_s=30\,\mathrm{dBm}$, $p_c=23\,\mathrm{dBm}$, $\sigma^2=-100\,\mathrm{dBm}$. The carrier frequency is set to 2.5 GHz. The BS and RIS are located at (3, -3, 8) and (0, 0, 5), respectively. The CU and ST are located at (4, 40, 0) and (-3, 0, 5), respectively. The trade-off between R_s and R_c can be seen as τ varies from 0 to 1. At $\tau=1$, all time is allocated to ST so $R_c=0$ and for $\tau=0$, all time is allocated to CU so $R_s=0$. The results also show that as the SI level increase, the achievable rate decreases. If the SI power level exceeds the noise power, performance degrades significantly, therefore the SI power level must be suppressed below the noise level through interference cancellation to ensure smooth system operation.

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