Study on STAR-IRS Assisted Uplink NOMA with Two Users

Luiggi Cantos°, Noureen Khan°, Jihyun Choi*, and Yun Hee Kim°*

°Dept. of Electronics and Information Convergence Engineering, *Dept. of Electronic Engineering, Kyung Hee University

Abstract

We consider simultaneously transmitting and reflecting intelligent surface (STAR-IRS) supporting non-orthogonal multiple access (NOMA) in the uplink. The maximum achievable sum rate is investigated for the two user case by optimizing transmitting and receiving reflection coefficients.

Ⅰ. Introduction

Simultaneously transmitting and reflecting intelligent surface (STAR-IRS) has gained significant attention for its capability of providing 360° coverage while improving the network performance by configuring the channel environment smartly [1]. In addition non-orthogonal multiple access (NOMA) is attractive in improving the spectral efficiency and providing massive connectivity [2]. Thus the uplink NOMA assisted by STAR-IRS was proposed to minimize the power consumption of two users in [3]. This paper considers STAR-IRS assisted uplink NOMA with two users and optimizes transmitting and receiving reflection coefficients of STAR-IRS to maximize the sum rate.

Ⅱ. System Model and Problem Formulation

Consider the STAR-IRS assisted uplink NOMA, where a single-antenna base station (BS) supports two single-antenna users through an STAR-IRS as shown in Fig. 1. The STAR-IRS operates in energy splitting (ES) mode with N transmiting and receiving reflection elements. It is assumed that no direct link exists between the BS and users. We denote the user in transmission space by user t and the user in reflecting space by user r. The channel between STAR-IRS and BS and that between user and STAR-IRS are denoted by $\boldsymbol{g} \in \mathbb{C}^{N\times 1}$ and $\boldsymbol{f}_q \in \mathbb{C}^{N\times 1}$, respectively. The transmission and reflection coefficients of STAR-IRS are denoted by $\boldsymbol{\theta}_t = \left(\sqrt{\beta_{t,1}}e^{j\phi_{t,1}}, \cdots, \sqrt{\beta_{t,N}}e^{j\phi_{t,N}}\right)^T$ and $\boldsymbol{\theta}_r = \left(\sqrt{\beta_{r,1}}e^{j\phi_{r,1}}, \cdots, \sqrt{\beta_{r,N}}e^{j\phi_{r,N}}\right)^T$, respectively, where $\beta_{t,n} + \beta_{r,n} = 1$ for $n = 1,2,\cdots,N$.

For the uplink NOMA, the received signal at the BS is expressed as

$$\begin{aligned} r &= \sqrt{p_t}\boldsymbol{g}^T diag(\boldsymbol{\theta}_t)\boldsymbol{f}_t s_t + \sqrt{p_r}\boldsymbol{g}^T diag(\boldsymbol{\theta}_r)\boldsymbol{f}_r s_r + n \\ &= \sqrt{p_t}\boldsymbol{h}_t^T\boldsymbol{\theta}_t s_t + \sqrt{p_r}\boldsymbol{h}_r^T\boldsymbol{\theta}_r s_r + n \end{aligned} \quad (1)$$

where p_q and s_q are the transmit power and symbol of user q with $E[|s_q|^2] = 1$ for $q \in \{t, r\}$ and $n \sim \mathbb{CN}(0, \sigma^2)$ is the additive white Gaussian noise at the BS. After applying successive interference cancellation (SIC), the sum rate expression is given by

$$R_{sum} = \log_2\left(1 + \frac{p_t}{\sigma^2}\left|\boldsymbol{h}_t^T\boldsymbol{\theta}_t\right|^2 + \frac{p_r}{\sigma^2}\left|\boldsymbol{h}_r^T\boldsymbol{\theta}_r\right|^2\right). \quad (2)$$

The sum rate maximization problem under the ES mode is given by

$$\begin{aligned} &\max_{\boldsymbol{\theta}_t \boldsymbol{\theta}_r} \quad R_{sum} \\ &s.t \quad |\theta_{t,n}|^2 + |\theta_{r,n}|^2 = 1 \quad, n = 1,2,\cdots,N \end{aligned} \quad (3)$$

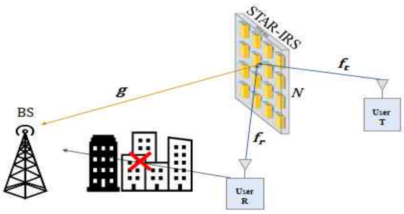

Fig 1. STAR-IRS assisted uplink NOMA with two users.

Ⅲ. Optimization Algorithm and Results

Maximizing the sum rate is equivalent to maximizing the sum SNR given by

$$\gamma_{sum} = \frac{p_t}{\sigma^2}\left|\boldsymbol{h}_t^T\boldsymbol{\theta}_t\right|^2 + \frac{p_r}{\sigma^2}\left|\boldsymbol{h}_r^T\boldsymbol{\theta}_r\right|^2 = \rho_t\boldsymbol{h}_t^T\boldsymbol{X}_t\boldsymbol{h}_t^* + \rho_r\boldsymbol{h}_r^T\boldsymbol{X}_r\boldsymbol{h}_r^*, \quad (4)$$

where $\rho_q = p_q/\sigma^2$ and $\boldsymbol{X}_q = \boldsymbol{\theta}_q\boldsymbol{\theta}_q^H$ for $q \in \{t, r\}$, since the monotonic increasing property of the log function. Problem (3) is then transformed to

$$\begin{aligned} &\max_{\boldsymbol{X}_t \boldsymbol{X}_r > 0} \quad Tr(\rho_t\boldsymbol{X}_t\boldsymbol{h}_t^*\boldsymbol{h}_t^T + \rho_r\boldsymbol{X}_r\boldsymbol{h}_r^*\boldsymbol{h}_r^T) \\ &s.t \quad [\boldsymbol{X}_t]_{nn} + [\boldsymbol{X}_r]_{nn} = 1, \; n = 1,2,\cdots,N, \\ &\qquad rank(\boldsymbol{X}_t) = 1, \; rank(\boldsymbol{X}_r) = 1 \end{aligned} \quad (5)$$

which can be solved by using semi-definite relaxation (SDR) approach [2]. First, we solve problem (5) by removing the rank conditions and find the solution $\boldsymbol{X}_t^+, \boldsymbol{X}_r^+$. We then apply Gaussian randomization to find a feasible rank-one solution $\boldsymbol{\theta}_t^+, \boldsymbol{\theta}_r^+$ to obtain the near-optimal performance. To reduce the complexity, we propose a suboptimal approach employing the same amplitudes as $\beta_{q,n} = \beta_q$ for which the optimal phase shift is given by $\phi_{q,n} = -\angle h_{q,n}$.

We compare the performance of the near-optimal SDR method and the suboptimal phase matching with the identical amplitudes to show the merits of the suboptimal approach under different conditions.

ACKNOWLEDGMENT

This work was supported by the Ministry of Science and ICT, South Korea, in part through the National Research Foundation of Korea (NRF) under Grant NRF-2021R1A2C1005869 and in part through the Institute for Information & Communications Technology Planning & Evaluation (IITP) under the Information Technology Research Center Support Program under Grant IITP-2021-0-02046.

References

[1] Liu, Y., Mu, X., Xu, J., Schober, R., Hao, Y., Poor, H.V. and Hanzo, L. "STAR: Simultaneous transmission and reflection for 360° coverage by intelligent surfaces". *IEEE Wireless Commun,* vol. 28, no. 6, pp.102-109, June 2021.

[2] G. Yang, et al., "Reconfigurable intelligent surface-assisted non-orthogonal multiple access," *IEEE Trans. Wirel. Commun.,* vol. 20, no. 5, pp. 3137-3151, May. 2021.

[3] Zuo, J., Liu, Y., Ding, Z. and Wang, X.,. "Uplink NOMA For STAR-RIS Networks". arXivpreprint arXiv:2110.05686. 2021.