STAR-RIS-IM Assisted Constellation Rotation NOMA System

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***Abstract*—In this study, the index modulation (IM) is applied to the simultaneously transmitting and reflecting reconfigurable intelligent surface (STAR-RIS) aided non orthogonal multiple access (NOMA) to give additional bits for the higher spectral efficiency. Assuming the imperfect signal interference cancellation (SIC) can be happened to the system, constellation rotation of NOMA is utilized to reduce the necessity of SIC to the receiver. Simulation result demonstrates that the capacity of the proposed STAR-RIS-IM-ConNOMA performs better than the conventional STAR-RIS-NOMA-IM and STAR-RIS-NOMA under perfect and imperfect SIC.**

***Index Terms*—Constellation domain non-orthogonal multiple access, imperfect signal interference cancellation, index modulation, simultaneously transmitting and reflecting reconfigurable intelligent surface, sum capacity.**

I. Introduction

Reconfigurable intelligent surface (RIS) is a device that is available to modify the channel realization and electromagnetic waves that can lead to improving the signal quality [1]. However, the conventional RIS can only cover 180° coverage because it is only available to reflect the signal. Recently, the more advance RIS can solve the previous limited coverage because it is equipped with magnetic circuit in each RIS element that can re-transmit the signal and has 360° coverage [2].

Several previous studies has combined the STAR-RIS with non-orthogonal multiple access (NOMA), that enables the signal of multiple users to be allocated in the same time/frequency/space by differentiating the power allocation of each user [3]. By using signal interference cancellation (SIC), the interference from the far user can be cancelled at the near user. However, not all of the interference can be perfectly cancelled at the near user. In [4], the perfect and imperfect SIC in NOMA was studied.

Another promising technique is index modulation (IM), that can manage the activation of resources for additional bits. That activation is used for the additional bits as spatial symbols along with the the conventional I/Q constellation symbols [5] as the benefit of IM. Furthermore, there are some previous studies about IM in an RIS-aided communication. In [6], IM was utilized for RIS-assisted communication with spatial modulation (SM) at the receive antennas. Recently, Index modulation applied STAR-RIS assisted power domain (PD) NOMA system is studied in [7]. It enables bits to be transmitted by using RIS subsurfaces to a different users. However, previous works only focus on the two-user PD-NOMA system. The constellation rotated two-user downlink NOMA was proposed in [8] to improve sum capacity, namely ConNOMA. The main principle of this approach is to get distinct constellation points to apply a rotated symbol constellation. As a result, this method may reduce the necessity for successive interference cancellation (SIC) processes in the NOMA receiver. Motivated by this, this paper proposed a novel STAR-RIS-IM assisted NOMA system by using constellation rotation for three-users downlink NOMA to improve spectral efficiency and reduce the number of SIC processes.

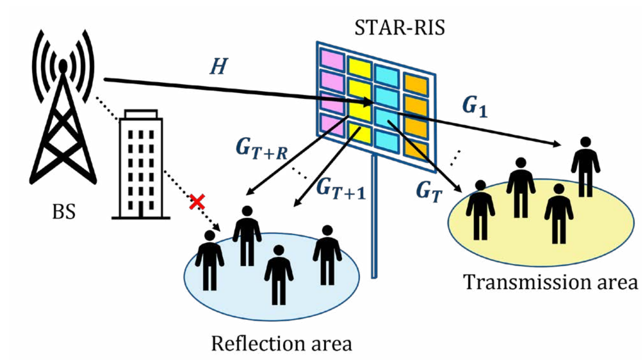

Fig. 1. System model of MRB-IM where R-number of RISs are exploited as additional information bits.

Throughout this paper, $\mathbb{E}[\cdot]$, $\Re(\cdot)$, $\Im(\cdot)$ represent the expectation operator, real and imaginary parts of a complex number, respectively.

II. Channel and System Model

Fig. 1 illustrates the proposed system model of IM applied STAR-RIS assisted multi-user downlink NOMA system, where K users, a single base station (BS), and a STAR-RIS consisting of S multi-subsurfaces. The K users are split into two groups, the K_r and K_t $(K_t + K_r = K)$ users, which are located in the reflection (r) and transmission (t) zones, respectively. For simplicity, $\chi \in \{t, r\}$ is used for the changeable variables of t or r mode. The N reflecting elements of each subsurfaces is denoted with $N_s = \lfloor \frac{N}{K} \rfloor$. The channel between BS to STAR-RIS, and the STAR-RIS to k-th of K users from the s-th of S subsurfaces is written as $\mathbf{H}_k^s = \left[h_k^{s,1}, \ldots, h_k^{s,n}, \ldots, h_k^{s,N_s}\right]^T \in \mathbb{C}^{N_s \times 1}$ and $\mathbf{G}_{k\chi}^s = \left[g_{k\chi}^{s,1}, \ldots, g_{k\chi}^{s,n}, \ldots, g_{k\chi}^{s,N_s}\right]^T \in \mathbb{C}^{N_s \times 1}$, respectively. Each subsurface of STAR-RIS has transmission/reflection coefficient diagonal matrix that is denoted with $\mathbf{\Theta_k}\chi^{\mathbf{s}} \in \mathbb{C}^{N \times N}$ with each n diagonal element denoted with $\Theta_k\chi^{s,n} = \beta_k\chi^{s,n}e^{j\theta_k\chi^{s,n}}$, $\theta_k\chi^{s,n} \in (0, 2\pi]$, and $\beta_k\chi^{s,n} = 1$. Assuming gamma distribution $\Gamma(l, \theta)$ is applied to the composite channel power gain, the shape and scale parameter can be expressed with

$$\begin{aligned} l &= \frac{\Gamma\left(m+\frac{1}{2}\right)^2}{4\left(m\Gamma(m)^2 - \Gamma\left(m+\frac{1}{2}\right)^2\right)} N \\ \theta &= 4\Omega N - \frac{4\Omega}{m}\left(\frac{\Gamma\left(m+\frac{1}{2}\right)}{\Gamma(m)}\right)^2 N, \end{aligned} \tag{1}$$

where m is the shape parameter and Ω is the spread parameter from the Nakagami distribution.

Considering the spatial correlation of the RIS elements that affects the channel capacity in [9]. The following correlation model is considered in this study

$$(\mathbf{R}_k)_{nj} = \sigma_{h_k}^2 \operatorname{sinc}\left(\frac{2\left\|\mathbf{v}_n - \mathbf{v}_j\right\|}{\lambda}\right), n, j = 1, 2, \ldots, N, \tag{2}$$

where n and j denote a different RIS elements.

A. Constellation NOMA

In this paper, reflection users are assigned to the ConNOMA pair, and reflection users and transmission users are assigned to the NOMA pair. In general, the complex symbols of the constellation x_i is used for M-ary PSK/QPSM symbols with $\mathbb{E}[|x_i|^2] = 1$. However, ConNOMA has utilized the concept of signal-space diversity (SSD) by rotating constellation [10]. Therefore, the symbols are represented as $x_2 = \sqrt{2}\Re(s_2 \exp(j\theta))$ and $x_3 = \sqrt{2}j\Im(s_3 \exp(j\theta))$, where $s_i \exp(j\theta)$ represents the rotated modulation with rotation angle θ. In this paper, the optimal rotation angle for rotation QPSK is used as $26.565°$ [11]. $\sqrt{2}$ means symbol energy equal to 1 since $\mathbb{E}[|\Re(s_2 \exp(j\theta))|^2] = \mathbb{E}[|\Im(s_3 \exp(j\theta))|^2] = 1/2$. The superposed signal x can be defined as

$$\begin{aligned} x &= \sqrt{p_1}x_1 + \sqrt{p_2}x_2 + \sqrt{p_3}x_3 \\ &= \sqrt{p_1}x_1 + \sqrt{2p_2}\Re\left(s_2 \exp(j\theta)\right) + j\sqrt{2p_3}\Im\left(s_3 \exp(j\theta)\right) \end{aligned} \tag{3}$$

where p_k is the power allocation coefficients of user k, where $\sum_{k=1}^{K} p_k = 1$. Based on the NOMA principle, power allocation coefficients are allocated as $p_1 \geq p_2 \geq p_3$.

The received signal for k-th user is expressed as

$$y_k = A_k\sqrt{p_k}x_k + \sum_{l=1, l\neq k} A_l\sqrt{p_l}x_l + n_k, \tag{4}$$

where l denotes a different user with k and A denotes the amplitude of the signal.

B. Sum capacity Analysis

The near users at the reflection zone do not require SIC to decode their own desired signal as ConNOMA is applied for these users. The achievable capacity of each user located in the reflection zone for the proposed scheme can be given as

$$Rk_r = \log_2\left(1 + \frac{p_k\left(d_{\mathbf{G}_{k_r}^s}^2\right)^{-\alpha}\left(d_{\mathbf{H}_k^s}^2\right)^{-\alpha}\left|\mathbf{G}_{\mathbf{k_r}}^{\mathbf{s}}{}^T \mathbf{\Theta}_{\mathbf{k_r}}^{\mathbf{s}} \mathbf{H}_k^s\right|^2}{\sigma^2}\sigma^2\right), \tag{5}$$

where $k \in \{K_t + 1, \ldots, K\}$.

However, the users situated in the transmission zone decode their messages while treating the signal from the reflection zone as interference. As a result, the achievable capacity for users in the transmission zone can be determined as follows:

$$Rk_t = \log_2\left(1 + \frac{p_k\left(d_{\mathbf{G}_{k_t}^s}^2\right)^{-\alpha}\left(d_{\mathbf{H}_k^i}^2\right)^{-\alpha}\left|\mathbf{G}_{k_t}^s{}^T \mathbf{\Theta}\mathbf{H}\right|^2}{\sum\left(d_{\mathbf{G}_{k_t}^s}^2\right)^{-\alpha}\left(d_{\mathbf{H}_k^i}^2\right)^{-\alpha}\left|\mathbf{G}_{k_t}^s{}^T \mathbf{\Theta}\mathbf{H}\right|^2 p_l + \sigma^2}\right), \tag{6}$$

where $k \in \{1, \ldots, K_t\}, l \in \{K_t + 1, \ldots, K\}$.

Therefore, the achievable capacity for the proposed STAR-RIS with IM assisted ConNOMA (STAR-RIS-IM-NOMA) can be expressed with

$$\mathrm{Rk}_r^{con} = Rk_r + \left\lfloor \log_2\binom{S}{bS} \right\rfloor \tag{7}$$

$$\mathrm{Rk}_t^{con} = Rk_t + \left\lfloor \log_2\binom{S}{bS} \right\rfloor \tag{8}$$

III. Numerical results

In this study, the simulation is done using MATLAB software with the following parameters ; Consider a NOMA pair with three users with denoting transmission and reflection users, respectively.

- Number of user $K = 3$ which is divided into $K_t = 1, K_r = 2$
- Gamma distribution parameters $\Gamma(l, \theta) = \Gamma(3, 14)$
- RIS total elements $N = 16$, elements in each subsurface $N_g = 4$
- For the IM, the number of activated subsurface is 1 from 4 surfaces,
- Pathloss exponent $\alpha = 2.6$
- Power allocation $p_r = 0.6, p_t = 0.4$
- The location in X dan Y axis ($[X, Y]$) of BS [0,10], RIS [150,8], Users K_t [260,0] K_r [80,0], [110,0], in meter(m) unit. It can be seen in 2
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The simulation result for the comparison of the proposed system and other previous works are depicted in Fig. 3. After removing the effect of the SIC, The STAR-RIS-IM-ConNOMA performs the highest sum capacity based on the Eq. (7,8). Other than that, the result for the STAR-RIS with IM assisted NOMA (STAR-RIS-IM-NOMA) has the similar result with the STAR-RIS assisted NOMA (STAR-RIS-IM).

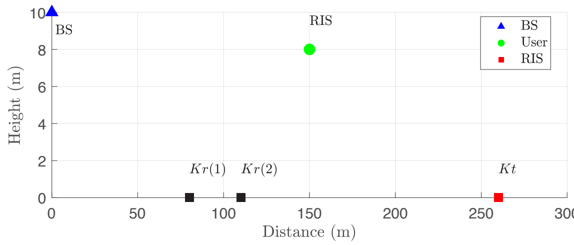

Fig. 2. Location settings of BS, RIS, and the users

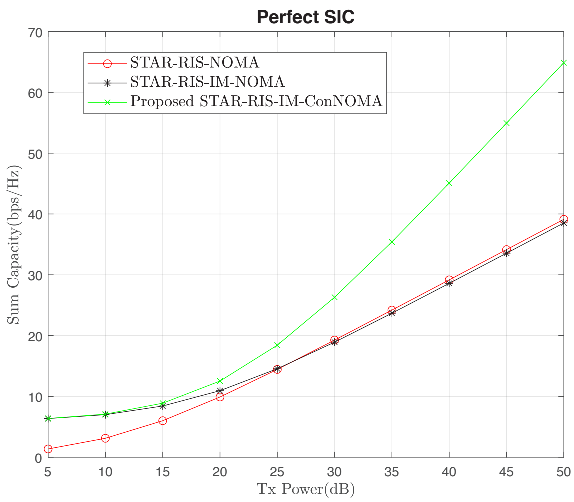

Fig. 3. Comparison of proposed STAR-RIS-IM-ConNOMA, STAR-RIS-IM-NOMA, and STAR-RIS-NOMA in terms of sum capacity under perfect SIC.

STAR-RIS-IM-NOMA and STAR-RIS-IM-ConNOMA has the benefits of the activation bits of the active subsurface. Therefore, it has enhancement capacity although it activates less RIS elements. The lowest capacity is from the conventional STAR-RIS-NOMA.

In 4, the comparison is performed under imperfect SIC. In this result, the proposed STAR-RIS-IM-ConNOMA still performs the highest capacity from all the mentioned system, but the gap is higher because the other system the got less capacity due to the effect of the imperfect SIC. However, the STAR-RIS-IM-NOMA performs higher capacity than the STAR-RIS-NOMA. This phenomena is caused by the less number of active RIS elements in the STAR-RIS-IM-NOMA than in the STAR-RIS-NOMA.

IV. Conclusion

In this paper, the proposed STAR-RIS-IM-ConNOMA performs the highest sum capacity between the other scheme, STAR-RIS-IM-NOMA, and STAR-RIS-NOMA, both in perfect and imperfect SIC. This phenomena can happened because ConNOMA can reduce the necessity for the SIC processess at the receiver.

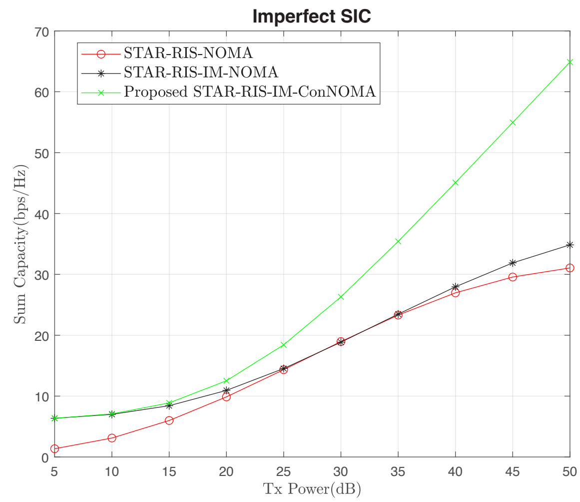

Fig. 4. Comparison of proposed STAR-RIS-IM-ConNOMA, STAR-RIS-IM-NOMA, and STAR-RIS-NOMA in terms of sum capacity under imperfect SIC.

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