Reconfigurable Intelligent Surface based Index Modulation with Non-Orthogonal Multiple Access

Krisma Asmoro, *Soo Young Shin
Dept. of IT Convergence Engineering, Kumoh National Institute of Technology
krisma@kumoh.ac.kr, *wdragon@kumoh.ac.kr

Abstract
In this study, a non-orthogonal multiple access is integrated into reconfigurable intelligent surface (RIS) based index modulation (IM) transmission to support multiple user capabilities. This scheme includes a bits splitter to divide incoming bits to activate RIS elements and amplitude-phase modulation (APM). Finally, to differentiate the information for different users, NOMA is utilized to assign a different power level. This study observes the RIS-IM-NOMA capacity and mutual information performance for two users.

Ⅰ. Introduction

In recent advanced development of 5G communication, non-orthogonal multiple access (NOMA) served as a promising candidate towards high capacity compared to orthogonal multiple access (OMA)[1-2]. On the other hand, reconfigurable intelligent surfaces (RIS) have been developed recently to seize the error rates by the principle of signal diversity and increase coverage by modifying signal phase [3-5]. RIS comprises of a finite length number of elements that can work and be tuned independently [6]. However, in practical scenario, RIS phase shift cannot be determined precisely, due to limitation of channel state information (CSI) at the receiver. Combining RIS-NOMA still causes a high complexity due the SIC process of near user at downlink scenario.

Spatial modulation (SM) is a well-known technique to provide better spectral efficiency (SE) and implementation cost of MIMO systems [7]. The spatial modulation technique employs a bit splitter to divide incoming bits into spatial bits and amplitude phase modulation (APM). Further, the spatial bits act as an activator to activate a single or one group of antennas. Then, the transmitted symbol contains an index of an active antenna and APM symbols. As a result, users can jointly decode an incoming symbol to detect spatial bits and modulate APM bits. Therefore, with a spatial signal constellation, the system can increase bits per channel usage (BPCU) and reduce symbol error rates (SER). Motivated by these benefits, the SM technique is integrated with RIS to provide better SE and SER [8].

This study proposed an integration of NOMA to RIS based IM with the main objective to serve multiple users. Without NOMA technique, RIS-IM is only capable of serving a single user because symbol activator can be overlapped.

Ⅱ. System Model

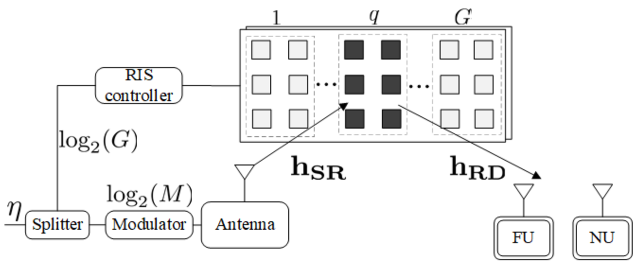

Fig.1. System Model of RIS-IM-NOMA transmission.

Consider a downlink RIS-NOMA assisted system model in Fig.1. In this scenario, incoming bits are split into two parts. The first part will go to RIS controller as an activator for a group sets of elements. The second part will go to amplitude-phase modulator (APM) to be further modulated as a regular symbol transmission. Refer to the Fig.1, after the signals transmitted by an BS, all the incident signal are reflected through an RIS with N elements to overcome the obstacles, where N∈[1,2,⋯,N]. It is assumed that in order to enhance SNR, RIS is capable of independently configured to the appropriate angle to maximize each signal phase. Therefore, the received signal on the receiver side could be written as:

$$r = \sqrt{\varepsilon}\left[\sum_{i=1}^{N} h_i e^{j\phi_i} g_i\right]x + n, \quad (1)$$

where $\varepsilon$is the transmitted signal power and i∈[1,2,⋯,N] is an index of the RIS elements. Then n are referring to noise power with the distribution of gaussian as known as additive white gaussian noise (AWGN) and $e^{j\phi i}$ is the adjusted phase from RIS elements with i^{th} index

Assuming two users NOMA in the cell, hence the modulated symbol for NU and FU were S_{nu} and S_{fu} respectively. Afterwards, successive interference cancellation (SIC) is performed to obtain $x_{nu} =$

$\sqrt{\alpha P}S_{nu,I} + j\sqrt{(1-\alpha)P}S_{fu,I}$ and $x_{fu} = \sqrt{\alpha P}S_{nu,Q} + j\sqrt{(1-\alpha)P}S_{fu,Q}$, where P is the total transmitted power at the BS, α is a power allocation for NU and FU with the value lies in between 0 and 1 (0< α <1). The baseband transmitted signal from the BS were denoted by $x = x_{nu} + x_{fu}$.

Therefore, transmitted signal for each user can be written as:

$$x_t^{RF}(t) = \underbrace{[0 \ \cdots \ \mathcal{S}_m \ \cdots 0]}_{N}{}^{T}. \tag{2}$$

Therefore, the received signa for of RIS-IM-NOMA can be written as:

$$\boldsymbol{Y} = \boldsymbol{h_{SR}} \boldsymbol{\Phi} \boldsymbol{h_{RD}} x + \boldsymbol{n}, \tag{3}$$

where $[\boldsymbol{h_{SR}} \in \mathbb{C}^{N \times 1}, \boldsymbol{h_{RD}} \in \mathbb{C}^{N_r \times N}]$ all channel follows a rayleigh fading channel with zero mean and variance. To detect an overall symbol, a maximum likelihood detector is proposed and written as follows:

$$[\tilde{\ell}, \tilde{m}] = \arg\min_{\ell, x} \left\| \mathbf{Y} - \underbrace{\boldsymbol{h_{SR}} \boldsymbol{\Phi} \boldsymbol{h_{RD}}}_{\mathbf{H}_\ell} x \right\|_F^2, \tag{4}$$

where $\mathbf{H}$ is the selected index of the RIS elements that is activated. Here, m is a detected symbol of NOMA users. The ML detector works by comparing all incoming bits to the reference signal constellation. To analyze pairwise error probability (PEP), the formula can be written as follows:

$$\mathrm{P_e} = \Pr\left((\ell, x) \to (\tilde{\ell}, \tilde{x}) \mid \mathbf{h_{SR}}, \mathbf{h_{RD}}\right)$$

$$\mathrm{P_e} \leq Q\left(\sqrt{\frac{\left\|\mathbf{H}_\ell x - \mathbf{H}_{\tilde{\ell}} \tilde{x}\right\|_{\mathrm{F}}^2}{2\sigma_n^2}}\right) = Q\left(\sqrt{\frac{v_{\ell,\tilde{\ell}}^{m,\tilde{m}}}{2\sigma_n^2}}\right) \tag{5}$$

where $Q(.)$ denotes a q-function to predict an error probability of the detected symbol from APM and activated RIS elements. Here, the analysis is not an exact probability, but it is expressing an upperbound. The behavior of the analytical is upperbound for low transmit SNR, and proceed to be an exact analytical for higher transmit SNR.

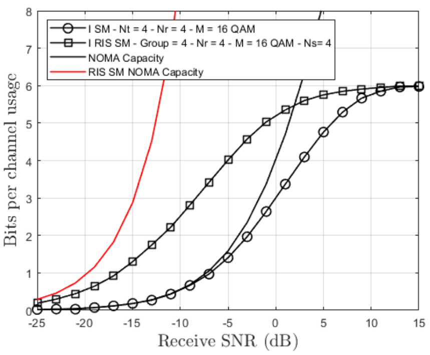

Figure 1 Mutual information and capacity of the proposed system.

III. Conclusion

The proposed RIS-IM-NOMA could support multiple users at the same time with a different power level. In comparison with regular NOMA, RIS-IM-NOMA preserves a lower complexity since IM holds a role to activate a desired RIS elements, hence it can achieve a similar BPCU with two users at cells coverage.

ACKNOWLEDGMENT

This research was supported by Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Education(2018R1A6A1A03024003) This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government. (MSIT) (No. 2022R1A2B5B01001994)

References

[1] Z. Ding, X. Lei, G. K. Karagiannidis, R. Schober, J. Yuan, and V. K. Bhargava. A survey on non-orthogonal multiple access for 5G networks: Research challenges and future trends. IEEE Journal on Selected Areas in Communications, 35(10):2181–2195, Oct 2017

[2] S. M. R. Islam, N. Avazov, O. A. Dobre, and K. Kwak. Power-domain non-orthogonal multiple access (NOMA) in 5G systems: Potentials and challenges. IEEE Communications Surveys Tutorials, 19(2):721–742, Secondquarter 2017.

[3] Q. Wu and R. Zhang. Towards smart and reconfigurable environment: Intelligent reflecting surface aided wireless network. IEEE Communication Magazine, 58(1):106–112, 2020

[4] Marco Di Renzo, et. Al. Reconfigurable intelligent surfaces vs. relaying: Differences, similarities, and performance comparison. IEEE Open Journal of the Communications Society, 1:798–807, 2020.

[5] E. Basar, M. Di Renzo, J. De Rosny, M. Debbah, M. Alouini, and R. Zhang. Wireless communications through reconfigurable intelligent surfaces. IEEE Access, 7:116753–116773, 2019.

[6] E. Basar, Transmission through large intelligent surfaces: Anew frontier in wireless communications, in: 2019 European Conference on Networks and Communications (EuCNC), 2019.

[7] R. Y. Mesleh, H. Haas, S. Sinanovic, C. W. Ahn, and S. Yun, "Spatial modulation," IEEE Transactions on Vehicular Technology, vol. 57, no. 4, pp. 2228–2241, 2008.

[8] E. Basar, "Reconfigurable intelligent surface-based index modulation: A new beyond MIMO paradigm for 6g," IEEE Transactions on Communications, vol. 68, no. 5, pp. 3187–3196, 2020.