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Performance Analysis on Strongest Channel Gain User for Intelligent Reflecting Surface NOMA

Kyuhyuk Chung

Professor, Department of Software Science, Dankook University, Korea
khchung@dankook.ac.kr

Abstract

Recently, fifth generation (5G) networks are being deployed in phases all over the world, the paradigm has shifted to developing the next generation wireless technologies, which have grown exponentially in last few decades, wireless networks are promising for the demand to enormous connections. Non-orthogonal multiple access (NOMA) and intelligent reflecting surface (IRS) are considered as the key technoloies for next-generation beyond 5G (B5G) and sixth generation (6G) networks, in which IRS can play an important advance in the wireless propagation environment, and NOMA can effectively increase massive connectivity to improve user fairness. In this paper, we analyze a performance on the strongest channel user in terms of achievable data rates numerically. Then, with the achievable data rates, the signal-to-noise ratio (SNR) gain is calculated for the IRS-NOMA network over the conventional NOMA network. As a consequence, IRS-NOMA schemes have been considered as some key technologies.

Keywords: *Intelligent Reflecting Surface, 6G, NOMA, 5G, Achievable Data Rate.*

1. Introduction

Owing to the demand of mass connectivity and spectrum efficiency, promising technologies have been required the fifth-generation (5G) communications [1]. one of the technologies in 5G is considered as non-orthogonal multiple access (NOMA) [2-4]. However, the sixth-generation (6G) communications have request higher data rates than 5G network [5]. For this end, intelligent reflecting surface (IRS) have been conceded as an efficient technology [6-8]. In NOMA, the bit-error rate (BER) of a weaker channel user has been calculated [9]. For the capacity of IRS transmissions, a tight upper bound was investigated [10].

In this paper, we analyze a performance on the strongest channel user in terms of achievable data rates numerically. First, we compare the achievable data rates of NOMA system to that of IRS-NOMA system, to analyze numerically the gain of the IRS-NOMA system with respect to the NOMA system in terms of achievable data rates as the number of reflecting devices increases. Then, with the achievable data rates, the SNR gain is calculated for the IRS-NOMA network over the conventional NOMA network.

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Corresponding Author: khchung@dankook.ac.kr
Tel: +82-32-8005-3237, Fax: +82-504-203-2043
Professor, Department of Software Science, Dankook University, Korea

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State-of-the-art advances in IRS-NOMA include studies of hybrid automatic repeat request (HARQ) technique for IRS-NOMA [11], simultaneously transmitting assisted IRS-NOMA [12], and ergodic rate analysis and phase design of IRS-NOMA [13]. In addition, covert communication is investigated in IRS-NOMA [14] and a rate-splitting (RS) scheme is proposed for IRS-NOMA [15].

This paper is organized as follows. The system and channel model are described, in Section 2. Achievable data rates of NOMA system and IRS-NOMA system are introduced in Section 3. In Section 4, the numerical results are presented. In Section 5, finally, the conclusions are given.

The main contributions are summarized as follows:

- We analyze a performance on the strongest channel user in terms of achievable data rates numerically.
- Then, we compare the achievable data rates of NOMA system to that of IRS-NOMA system, to analyze numerically the gain of the IRS-NOMA system with respect to the NOMA system in terms of achievable data rates as the number of reflecting devices increases.
- Moreover, with the achievable data rates, the SNR gain is calculated for the IRS-NOMA network over the conventional NOMA network.

2. System and Channel Model

We investigate an IRS-NOMA system from a base station to two users, who are a stronger channel user and a cell-edge user. A direct link between the base station and the near user, which is the flat-fading channel, denoted by $h_{1,d}$. The base station transmits the superimposed signal:

$$x = \sqrt{P\alpha} s_1 + \sqrt{P(1-\alpha)} s_2, \tag{1}$$

where the total transmitted power is P, s_m is the signal with the unit power for the mth user, $m = 1, 2$, and α denotes the power allocation coefficient. r_1 received by the near user is expressed by

$$r_1 = |h_1| x + n_1, \tag{2}$$

where $h_1 = h_{1,d} + \mathrm{h}_{br}^T \Theta \mathrm{h}_{ru}$ and $n_1 \sim N(0, N_0/2)$ is additive white Gaussian noise (AWGN). h_{br} is the $N \times 1$ flat-fading channel from the base station to the IRS and h_{ru} is the $N \times 1$ flat-fading channel from the IRS to the near user, where a given number N of reflecting devices. The IRS is expressed by the diagonal matrix

$$\Theta = \omega \, \mathrm{diag}\left(e^{j\theta_1}, \cdots, e^{j\theta_N}\right), \tag{3}$$

where the fixed amplitude reflection coefficient is $\omega \in (0,1]$ and the phase-shift variables are $\theta_1, \cdots, \theta_N$ optimized by the IRS.

3. Achievable Data Rates of NOMA system and IRS-NOMA system

In this section, we summarize achievable data rates of NOMA system and IRS-NOMA system for the strongest channel gain user.

First, the achievable data rates of NOMA system for the strongest channel gain user, which is used for simulations, is defined as follows:

$$R_1^{(\mathrm{NOMA})} = \log_2\left(1+\frac{\left|h_{1,d}\right|^2 P\alpha}{\sigma^2}\right), \tag{4}$$

where $R_1^{(\mathrm{NOMA})}$ is obtained after successive interference cancellation (SIC) is performed and the user-2 signal is removed.

second, the achievable data rates of IRS-NOMA system for the strongest channel gain user, which is also used for simulations, is given as follows:

$$R_1^{(\mathrm{IRS-NOMA})} = \log_2\left(1+\frac{\left(\left|h_{1,d}\right| + \omega\sum_{n=1}^{N}\left|\left(\mathrm{h}_{br}\right)_n\left(\mathrm{h}_{ru}\right)_n\right|\right)^2 P\alpha}{\sigma^2}\right), \tag{5}$$

where $R_1^{(\mathrm{IRS-NOMA})}$ is given by adding the channel gain of a direct link between the base station and the near user to the channel gain of IRS.

The maximum channel gain $\left|h_1\right|_{\max} = \left|h_{1,d}\right| + \omega\sum_{n=1}^{N}\left|\left(\mathrm{h}_{br}\right)_n\left(\mathrm{h}_{ru}\right)_n\right|$ can be expressed when the IRS selects the phase-shifts to maximize the channel gain, as follows:

$$\begin{aligned}\left|h_1\right|_{\max} &= \left(\left|h_{1,d}\right| + \omega\sum_{n=1}^{N}\left|\left(\mathrm{h}_{br}\right)_n\left(\mathrm{h}_{ru}\right)_n\right|\right) \\ &= \left|h_{1,d}\right|\underbrace{\left(1+\frac{\omega\sum_{n=1}^{N}\left|\left(\mathrm{h}_{br}\right)_n\left(\mathrm{h}_{ru}\right)_n\right|}{\left|h_{2,d}\right|}\right)}_{=\left|h_1\right|_{\mathrm{eff}}}.\end{aligned} \tag{6}$$

where the effective channel gain $\left|h_1\right|_{eff}$ is given by

$$\left|h_1\right|_{\mathrm{eff}} = \left(1+\frac{\omega\sum_{n=1}^{N}\left|\left(\mathrm{h}_{br}\right)_n\left(\mathrm{h}_{ru}\right)_n\right|}{\left|h_{2,d}\right|}\right). \tag{7}$$

Notably, the effective channel gain $\left|h_1\right|_{eff}$ represents the channel gain by IRS, which increases as the number of reflecting devices increases.

4. Numerical Results and Discussions

In this section, we compare the achievable data rate of NOMA system with IRS-NOMA system numerically. For this, it is assumed that $\omega = 1$, $|h_{1,d}| = 0.2$, $(\mathrm{h}_{br})_n = 0.3$ and $(\mathrm{h}_{ru})_n = 0.5$. Also we assume $0 \le N \le 100$.

First, we depict the achievable data rates of NOMA system and IRS-NOMA system, in Figure 1, to analyze numerically the gain of the IRS-NOMA system with respect to the NOMA system in terms of achievable data rates as the number of reflecting devices increases.

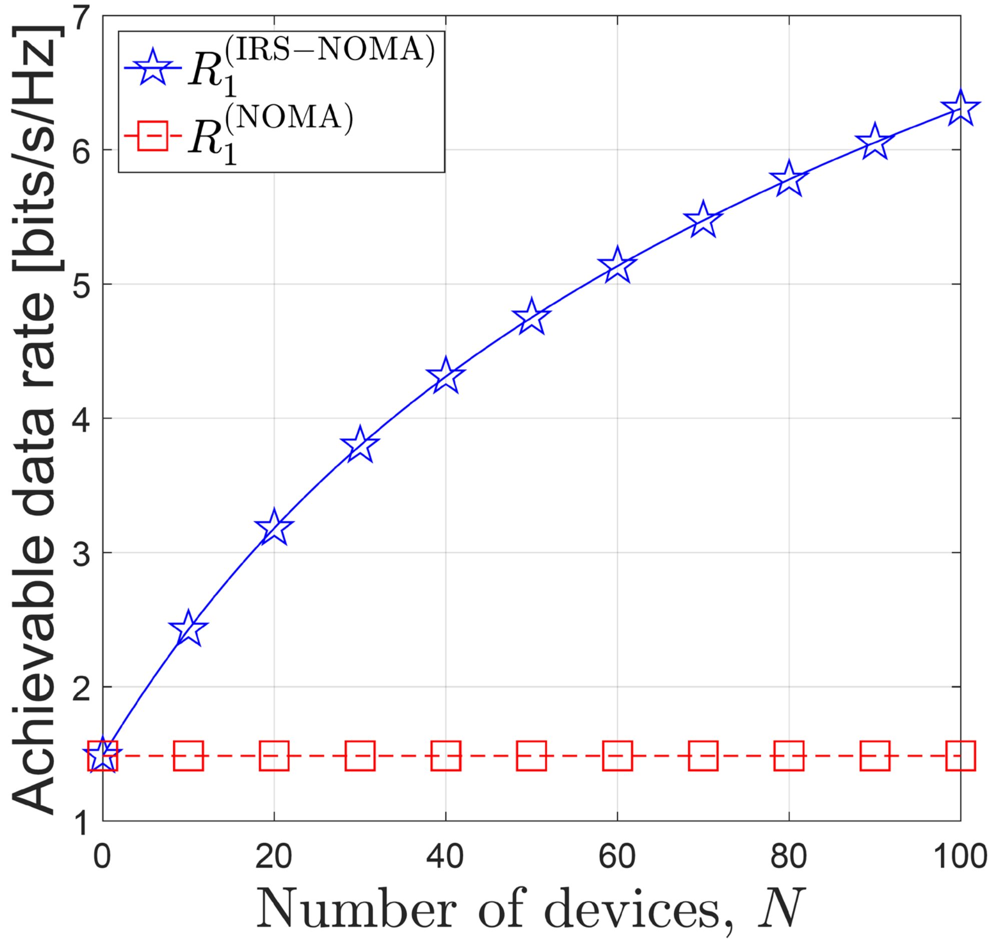

Figure 1. Comparison of achievable data rates of NOMA system and IRS-NOMA system versus the number of reflecting devices for the strongest channel user

As shown in Figure 1, the achievable data rate of the IRS-NOMA system increases, as the number of devices increases. However, the achievable data rate of the NOMA system remains constant because there is no channel link from the IRS. In addition, it is observed that the slope of the achievable data rate of the IRS-NOMA system decreases after the number of devices is $N \simeq 60$.

Second, in Figure 2, with $\alpha = 0.2$, to analyze the signal to noise ratio (SNR) power gain, we show the achievable data rates of the NOMA system and the IRS-NOMA system versus the SNR, $0 \le P/\sigma^2 \le 20$ (dB).

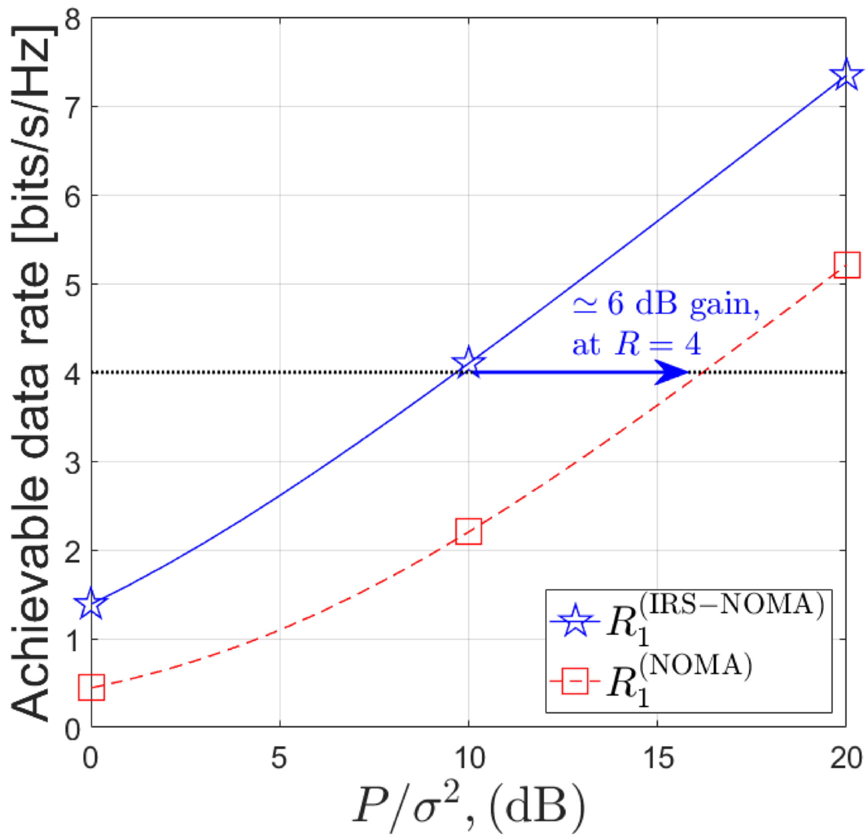

Figure 2. Comparison of achievable data rates of NOMA system and IRS-NOMA system for the strongest channel user

At the achievable data rate of $R=4$, the achievable data rate for the IRS-NOMA system becomes larger by about 6 dB than that of the NOMA system, as shown in Figure 2. Notably, the SNR gains of the achievable data rate for the IRS-NOMA system over the NOMA system increase about up to SNR power $P/\sigma^2 \simeq 20$ (dB).

5. Conclusion

In this paper, we analyzed a performance on the strongest channel user in terms of achievable data rates numerically. First, we compared the achievable data rates of NOMA system to that of IRS-NOMA system, to analyze numerically the gain of the IRS-NOMA system with respect to the NOMA system in terms of achievable data rates as the number of reflecting devices increases. Then, with the achievable data rates, the SNR gain was calculated for the IRS-NOMA network over the conventional NOMA network. Moreover, to analyze the SNR gain, we showed the achievable data rates of the NOMA system and the IRS-NOMA system versus the SNR, $0 \leq P/\sigma^2 \leq 20$ (dB). At the achievable data rate of $R=4$, the achievable data rate for the IRS-NOMA system became larger by about 6 dB than that of the NOMA system. As a consequence, IRS-NOMA schemes have been considered as some key technologies, for next-generation B5G and sixth 6G networks, in which especially, IRS can play an important advance in the wireless propagation environment.

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