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Performance Analysis on Intelligent Reflecting Surface Transmission for NOMA Towards 6G Systems

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Abstract

The efficiencies of rates and energy in the fifth generation (5G) wireless channels can be improved via intelligent reflecting surface (IRS) transmissions, towards the sixth generation (6G) mobile communications. While previous works have considered mainly optimizations of IRS transmissions, we propose a performance analysis on the total power in terms of the number of reflecting devices for IRS transmissions in non-orthogonal multiple access (NOMA) networks. First, we derive an analytical expression of the total power gain factor in terms of the number of reflecting devices for the cell-edge user in IRS-NOMA systems. Then we evaluate how many reflecting devices we need to obtain a total power gain in dB. Moreover, we also demonstrate numerically the signal-to-noise ratio (SNR) gain of the IRS-NOMA system over the conventional NOMA system based on the achievable data rate.

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

1. INTRODUCTION

The fifth-generation (5G) communications have been implemented over the most of countries [1]. One of the key technologies in 5G is non-orthogonal multiple access (NOMA) [2-4]. However, the sixth-generation (6G) communications have required faster networks [5]. For this, researchers have considered intelligent reflecting surface (IRS) transmissions towards the 6G mobile communications [6-8]. The cross-correlated quadrature amplitude modulation scheme was studied for NOMA [9]. The negatively asymmetric binary pulse amplitude modulation was proposed in NOMA [10].

In this paper, we analyze a performance of IRS-NOMA with the total power in terms of the number of devices. First, we derive a closed-form expression for the total power gain factor based on the number of reflecting devices for the cell-edge user in IRS-NOMA systems. Then we calculate how many reflecting devices we need to obtain a total power gain in dB. Moreover, we also show numerically the signal-to-noise ratio (SNR) gain of the IRS-NOMA system over the conventional NOMA system.

The remainder of this paper is organized as follows. In Section 2, the system and channel model are described. The total power gain factor is derived in Section 3. The numerical results are presented in Section 4. Finally, the conclusions are addressed in Section 5.

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The main contributions of this paper are summarized as follows:

- We propose a performance analysis on the total power in terms of the number of devices for IRS-NOMA systems.
- Then, we evaluate how many reflecting devices we need to obtain a total power gain in dB.
- Moreover, we also demonstrate numerically the SNR gain of the IRS-NOMA system over the conventional NOMA system.

2. SYSTEM AND CHANNEL MODEL

We consider an IRS-NOMA transmission system from a single-antenna base station to two single-antenna users, namely a near user and a cell-edge user. Assume that there is a direct link between the base station and the cell-edge user, which is the deterministic flat-fading channel, denoted by $h_{2,d}$. We assume that there is no direct link between the IRS and the near user. The base station broadcasts the superimposed signal:

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

where the average total transmitted power is P, s_m is the signal with the average unit power for the *m*th user, $m = 1,2$, and α is the power allocation coefficient. The signal r_2 received by the cell-edge user is expressed by

$$r_2 = |h_2| x + n_2, \tag{2}$$

where $h_2 = h_{2,d} + h_{br}^T \Theta \, h_{ru}$ and $n_2 \sim N(0, N_0/2)$ is additive white Gaussian noise (AWGN). For a given number N of reflecting devices, h_{br} denotes the $N \times 1$ deterministic flat-fading channel from the base station to the IRS and h_{ru} denotes the $N \times 1$ deterministic flat-fading channel from the IRS to the cell-edge user. The IRS is represented by the diagonal matrix

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

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

3. DERIVATION OF TOTAL POWER GAIN FACTOR

In this section, we interpret analytically the total power gain in terms of the number of reflecting devices. First, the IRS selects the phase-shifts to obtain the maximum channel gain, as follows:

$$|h_2| \left|h_{2,d}\right| \textstyle\sum_{n=1}^{N} |(h_{br} \quad)_n (h_{ru} \quad)_n|_{max} \tag{4}$$

Then, we derive the total power gain factor of the IRS system over the conventional NOMA system, as follows:

$$|h_2| \left(\left|h_{2,d}\right| + \omega \textstyle\sum_{n=1}^{N} |(h_{br} \quad)_n (h_{ru} \quad)_n|\right) \left(\sqrt{P\alpha} s_1 + \sqrt{P(1-\alpha)} s_2\right)_{max}$$

$$= \left(\left|h_{2,d}\right| + \omega \sum_{n=1}^{N} \left|(h_{br}\quad)_n (h_{ru}\quad)_n\right| \right) \sqrt{P} \left(\sqrt{\alpha} s_1 + \sqrt{(1-\alpha)} s_2 \right)$$

$$= \left|h_{2,d}\right| \underbrace{\left(1 + \frac{\omega \sum_{n=1}^{N} \left|(h_{br}\quad)_n (h_{ru}\quad)_n\right|}{\left|h_{2,d}\right|} \right) \sqrt{P}}_{=\sqrt{P_{eff}}} \left(\sqrt{\alpha} s_1 + \sqrt{(1-\alpha)} s_2 \right), \tag{5}$$

where the total effective power P_{eff} is given by

$$\sqrt{P_{eff}} = \left(1 + \frac{\omega \sum_{n=1}^{N} \left|(h_{br}\quad)_n (h_{ru}\quad)_n\right|}{\left|h_{2,d}\right|} \right) \sqrt{P},$$

$$P_{eff} = \underbrace{\left(1 + \frac{\omega \sum_{n=1}^{N} \left|(h_{br}\quad)_n (h_{ru}\quad)_n\right|}{\left|h_{2,d}\right|} \right)^2}_{\text{total power gain factor, } G_P} P. \tag{6}$$

Thus the total power gain factor G_P is given by

$$G_P \triangleq \frac{P_{eff}}{P} = \left(1 + \frac{\omega \sum_{n=1}^{N} \left|(h_{br}\quad)_n (h_{ru}\quad)_n\right|}{\left|h_{2,d}\right|} \right)^2. \tag{7}$$

Hence, the total power gain factor in dB $[G_P]$ dB is given by

$$[G_P]\ \text{dB} \triangleq 10\, log_{10}\, G_P$$

$$= 10\, log_{10} \left(1 + \frac{\omega \sum_{n=1}^{N} \left|(h_{br}\quad)_n (h_{ru}\quad)_n\right|}{\left|h_{2,d}\right|} \right)^2$$

$$= 20\, log_{10} \left(1 + \frac{\omega \sum_{n=1}^{N} \left|(h_{br}\quad)_n (h_{ru}\quad)_n\right|}{\left|h_{2,d}\right|} \right). \tag{8}$$

4. NUMERICAL RESULTS AND DISCUSSIONS

In this section, we will consider the total power gain factor G_P numerically. To this end, it is assumed that $\omega = 1$, $\left|h_{2,d}\right| = 0.2$, $(h_{br}\quad)_n = 0.3$ and $(h_{ru}\quad)_n = 0.5$. Also it is assumed that $0 \le N \le 100$.

First, we depict the total power gain factor versus the number of devices, in Figure 1, to analyze the impact of the number of devices numerically on the total power gain factor.

As shown in Figure 1, the total power gain factor in dB increase, as the number of devices. However, the total power gain factor in dB saturates almost when the number of devices is about 30; hence, when we calculate the SNR gain, we choose the number of devices $N = 20$.

Second, to investigate the SNR gain, we depict the achievable data rates versus the SNR, $0 \le P/\sigma^2 \le 20$ (dB), with $\alpha = 0.2$, in Figure 2, based on the achievable data rates of the IRS-NOMA system and the conventional NOMA system, which are given as

$$R_2^{(\text{NOMA})} = log_2 \left(1 + \frac{\left|h_{2,d}\right|^2 P(1-\alpha)}{\left|h_{2,d}\right|^2 P\alpha + \sigma^2} \right),$$

$$R_2^{(\text{IR}S-\text{NOMA})} = log_2 \left(1 + \frac{\left(\left|h_{2,d}\right| + \omega \sum_{n=1}^{N} \left|(h_{br}\quad)_n (h_{ru}\quad)_n\right|\right)^2 P(1-\alpha)}{\left(\left|h_{2,d}\right| + \omega \sum_{n=1}^{N} \left|(h_{br}\quad)_n (h_{ru}\quad)_n\right|\right)^2 P\alpha + \sigma^2} \right). \tag{9}$$

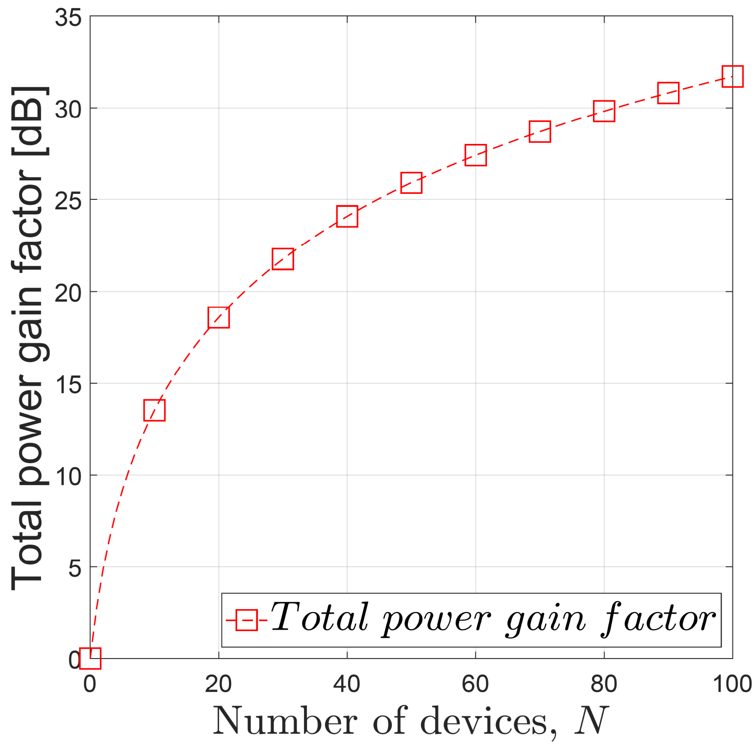

Figure 1. Total power gain factor versus the number of reflecting devices

As shown in Figure 2, the achievable data rate of the IRS-NOMA system improves largely by about 9 dB, compared to that of the NOMA system, at the achievable data rate of $R = 1.5$.

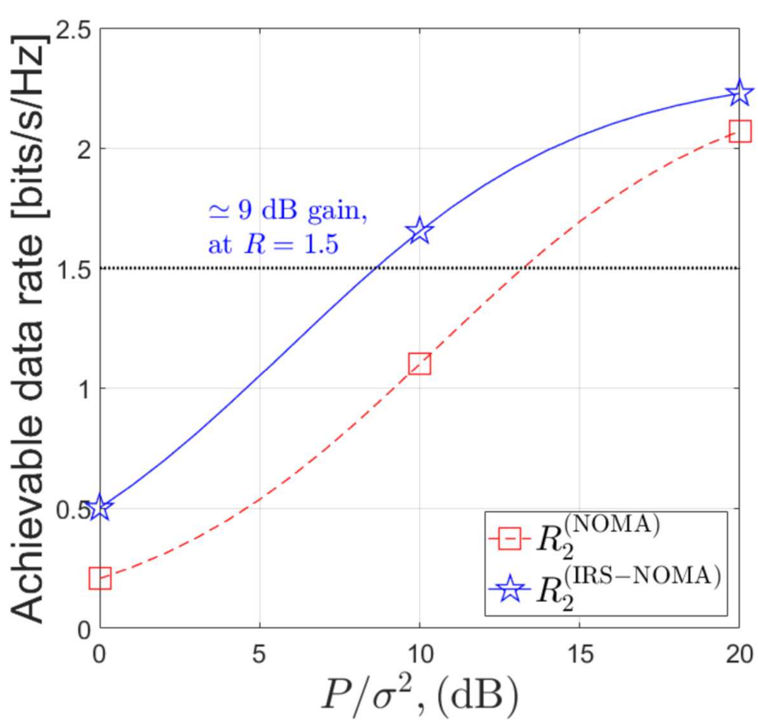

Figure 2. Comparison of achievable data rates of NOMA system and IRS-NOMA system

5. CONCLUSION

In this paper, we proposed a performance analysis on the total power in terms of the number of reflecting devices for IRS-NOMA networks. First, we derived an analytical expression for the total power gain factor in terms of the number of reflecting devices for the cell-edge user in IRS-NOMA systems. Then we evaluated how many reflecting devices we need to obtain a total power gain in dB. Moreover, based on the achievable data rate, we also demonstrated numerically the SNR gain of the IRS-NOMA system over the conventional NOMA system. In result, the IRS-NOMA network could be considered as a promising scheme with the total power gain factor.

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