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BER Performance Analysis of Strongest Channel Gain User for IRS NOMA with Rician Fading

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Abstract

Increasing demand for increasing higher data rate in order to solve computationally tasks timely and connecting many user equipment simultaneously have requested researchers to develop novel technology in the area of mobile communications. Intelligent reflecting surface (IRS) have been enabling technologies for commercialization of the fifth generation (5G) networks and the sixth generation (6G) systems. In this paper, we investigate a bit-error rate (BER) analysis on IRS technologies for non-orthogonal multiple access (NOMA) systems. First, we derive a BER expression for IRS-NOMA systems with Rician fading channels. Then, we validate the BER expression by Monte Carlo simulations, and show numerically that BER expressions are in good agreement with simulations. Moreover, we investigate the BER of IRS-NOMA systems with Rician fading channels for various numbers of IRS elements, and show that the BERs improve as the number of IRS elements increases.

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

1. Introduction

The fifth-generation (5G) networks have been required promising technologies, due to the demand of spectrum efficiency and mass connectivity [1]. Non-orthogonal multiple access (NOMA) is considered as a key technology in 5G [2-4]. However, the sixth-generation (6G) networks have demanded higher data rates compared to 5G network [5]. For this purpose, intelligent reflecting surface (IRS) is conceded as an important technology [6-8]. In NOMA, for a weaker channel user, the bit-error rate (BER) was calculated [9]. For the capacity of IRS networks, a tight upper bound has been investigated [10]. A performance analysis of the IRS communication systems with the direct link between the transmitter and receiver has been presented [11].

In this paper, we investigate a bit-error rate (BER) analysis on IRS technologies for non-orthogonal multiple access (NOMA) systems. First, we derive a BER expression for IRS-NOMA systems with Rician fading channels. Then, we validate the BER expression by Monte Carlo simulations, and show numerically that BER expressions are in good agreement with simulations. Moreover, we investigate the BER of IRS-NOMA systems with Rician fading channels for various numbers of IRS elements, and show that the BERs improve as the number of IRS elements increases.

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The main contributions are given as follows:

- We investigate a BER analysis on IRS technologies for NOMA systems.
- First, we derive a BER expression for IRS-NOMA systems with Rician fading channels.
- Then, we validate the BER expression by Monte Carlo simulations, and show numerically that BER expressions are in good agreement with simulations.
- Moreover, we investigate the BER of IRS-NOMA systems with Rician fading channels for various numbers of IRS elements, and show that the BERs improve as the number of IRS elements increases.

2. System and Channel Model

For an IRS-NOMA transmission system, there is a direct link between the basestation and the strongest channel gain user. The direct channel is Rayleigh distributed, with the strongest user's channel gain h_d of the second moment $\Sigma_d = \mathbb{E}\left[|h_d|^2\right]$. The basestation transmits the superimposed signal $x = \sqrt{Pa}s_1 + \sqrt{P(1-a)}s_2$, where the average transmitted power is P, s_m is the unit power signal for the mth user, $m = 1,2$. a is the power allocation factor. The strongest channel gain user's signal r_1 is given by

$$r_1 = |h|\sqrt{P\alpha}s_1 + n_1, \tag{1}$$

where $h = h_d + \mathrm{h}_{br}^T \Theta \mathrm{h}_{ru}$ and additive white Gaussian noise (AWGN) is denoted by $n_1 \sim N(0, N_0/2)$. For a given number N of IRS devices, h_{br} is the $N\times 1$ Rician fading channel from the basestation to the IRS and h_{ru} is the $N\times 1$ Rician fading channel from the IRS device to the strongest channel gain user. Thus, the channel gains is given as

$$\begin{aligned} \mathrm{h}_{br} &= \frac{1}{\sqrt{d_{br}^{\alpha_{br}}}}\left(\sqrt{\frac{K_{br}}{K_{br}+1}}\bar{\mathrm{h}}_{br} + \sqrt{\frac{1}{K_{br}+1}}\tilde{\mathrm{h}}_{br}\right), \\ \mathrm{h}_{ru} &= \frac{1}{\sqrt{d_{ru}^{\alpha_{ru}}}}\left(\sqrt{\frac{K_{ru}}{K_{ru}+1}}\bar{\mathrm{h}}_{ru} + \sqrt{\frac{1}{K_{ru}+1}}\tilde{\mathrm{h}}_{ru}\right), \\ h_d &= \frac{1}{\sqrt{d_d^{\alpha_d}}}\tilde{h}_d, \end{aligned} \tag{2}$$

where $\{d_{br}^{\alpha_{br}}, d_{ru}^{\alpha_{ru}}, d_d^{\alpha_d}\}$ and $\{\alpha_{br}, \alpha_{ru}, \alpha_d\}$ are the distances and path-loss exponents, and $\{K_{br}, K_{ru}\}$ is the Rician factors. $\{\bar{\mathrm{h}}_{br}, \bar{\mathrm{h}}_{ru}\}$ is the normalized LoS. $\{\tilde{\mathrm{h}}_{br}, \tilde{\mathrm{h}}_{ru}, \tilde{h}_d\}$ is the normalized non-LOS. The IRS is given by the diagonal matrix $\Theta = \omega \mathrm{diag}(e^{j\theta_1}, \cdots, e^{j\theta_N})$, with $\omega \in (0,1]$, i.e., fixed amplitude reflection coefficients. $\theta_1, \cdots, \theta_N$ denote the phase-shift variables.

3. Average BER expression for IRS-NOMA

We derive analytical expressions for the BER of IRS-NOMA with Rician fading channels. It is assumed that to obtain the maximum gain, the IRS chooses the phase-shifts:

$$|h|_{\max} = |h_d| + \underbrace{\omega \sum_{n=1}^{N} \left| (\mathrm{h}_{br})_n (\mathrm{h}_{ru})_n \right|}_{\xi} = |h_d| + \xi, \tag{3}$$

where $\xi = \omega \sum_{n=1}^{N} \left| (\mathrm{h}_{br})_n (\mathrm{h}_{ru})_n \right|$. The conditional average BER is expressed as:

$$P_{1||h_1|}^{(\text{IRS-NOMA})} = Q\left(\sqrt{2\gamma_b \xi_{\text{norm}}^2}\right) - Q\left(\sqrt{2(1+\gamma_b)\xi_{\text{norm}}^2}\left(\frac{\gamma_b}{1+\gamma_b}\right)\right) e^{-\left(\frac{\gamma_b}{(1+\gamma_b)}\right)\xi_{\text{norm}}^2} \sqrt{\frac{\gamma_b}{1+\gamma_b}}. \tag{4}$$

where

$$\gamma_{b,\text{norm}} = \frac{\alpha P}{N_0}, \qquad \gamma_b = \Sigma_d \gamma_{b,\text{norm}} \tag{5}$$

and

$$\xi_{\text{norm}}^2 = \frac{\xi^2}{\Sigma_d}. \tag{6}$$

By using Jensen inequality,

$$P_1^{(\text{IRS-NOMA})} = \mathbb{E}_{\xi_{\text{norm}}^2}\left[P_{1|\xi_{\text{norm}}^2}^{(\text{IRS-NOMA})}\right] \simeq P_{1|\xi_{\text{norm}}^2}^{(\text{IRS-NOMA})}(\mathbb{E}[\xi_{\text{norm}}^2]), \tag{7}$$

where, based on [11], we obtain

$$\mathbb{E}[\xi_{\text{norm}}^2] = \omega \frac{N}{\Sigma_d} \frac{1}{d_{br}^{\alpha_{br}}} \frac{1}{d_{ru}^{\alpha_{ru}}} + \omega \frac{N(N-1)}{\Sigma_d} \frac{\pi}{4 d_{br}^{\alpha_{br}}(K_{br}+1)} \left(L_{\frac{1}{2}}(-K_{br})\right)^2 \cdot \frac{\pi}{4 d_{ru}^{\alpha_{ru}}(K_{ru}+1)} \left(L_{\frac{1}{2}}(-K_{ru})\right)^2, \tag{8}$$

with $L_{\frac{1}{2}}(\cdot)$ being the Laguerre polynomial of degree $\frac{1}{2}$.

4. Numerical Results and Discussions

We present numerical results. The simulations uses the following parameters: $P/\sigma^2 = 70$ dB, $\omega = 1$, $\Sigma_d = 1$, $d_{br}^{\alpha_{br}} = 150$ m, $d_{ru}^{\alpha_{ru}} = 150$ m and $d_d^{\alpha_d} = 200$ m, $\alpha_{br} = 2.0$, $\alpha_{ru} = 2.0$, $\alpha_d = 2.5$, $N = 10$, and $K_{br} = K_{ru} = 1$.

First, the BER expression of IRS-NOMA is validated by Monte Carlo simulations over Rician fading channels, in Figure 1.

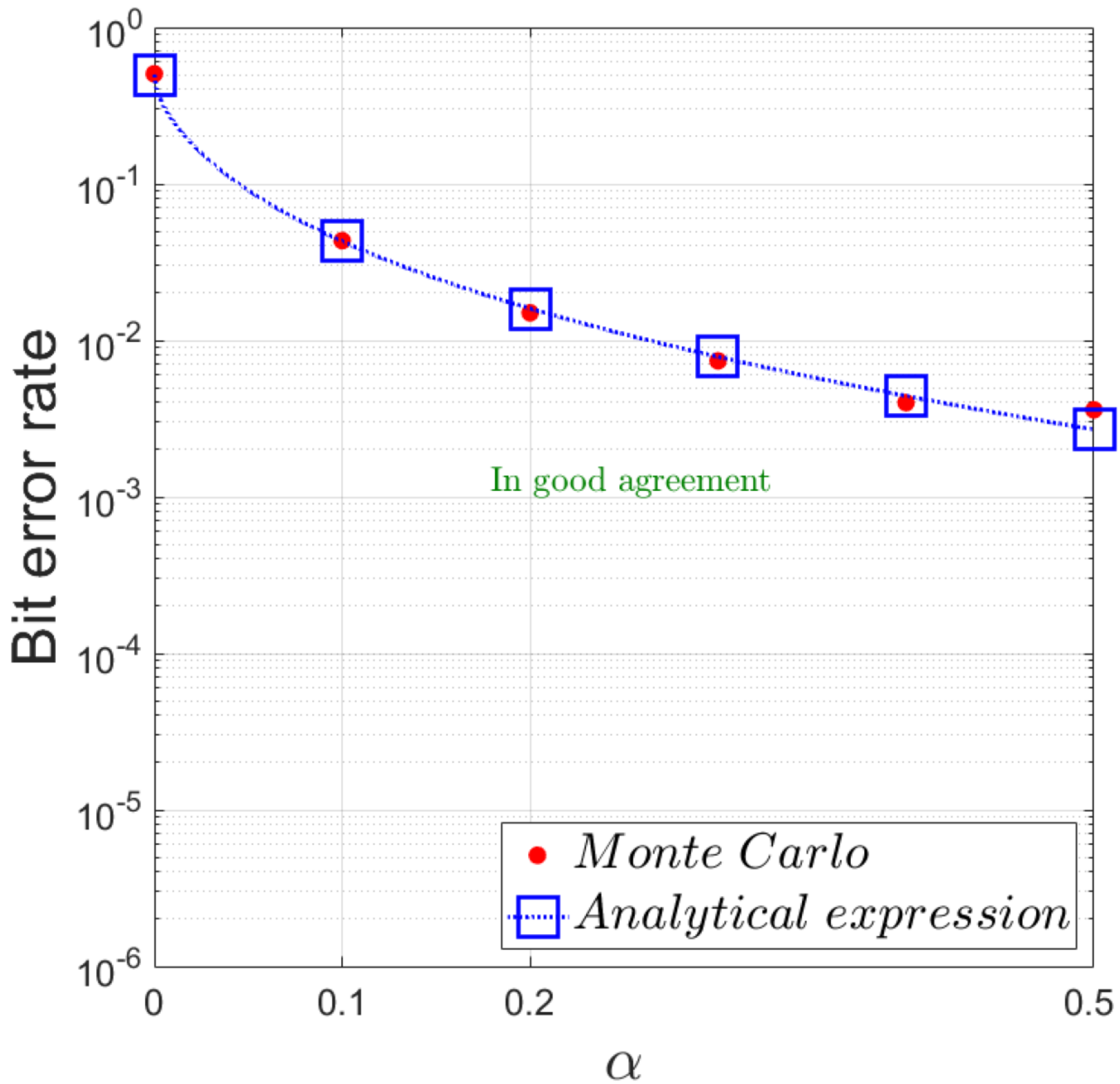

Figure 1. Monte Carlo simulations and BER expression for IRS-NOMA networks for strongest channel gain user

Monte Carlo simulations validate the BER expression of IRS-NOMA, in Figure 1; thus, we investigate the BERs of IRS-NOMA with the BER expression in the next simulations.

Second, to analyze effects of the number of IRS devices on the BER of IRS-NOMA, the BERs of IRS-NOMA with $N = 0$, $N = 10$, and $N = 20$ of IRS devices.

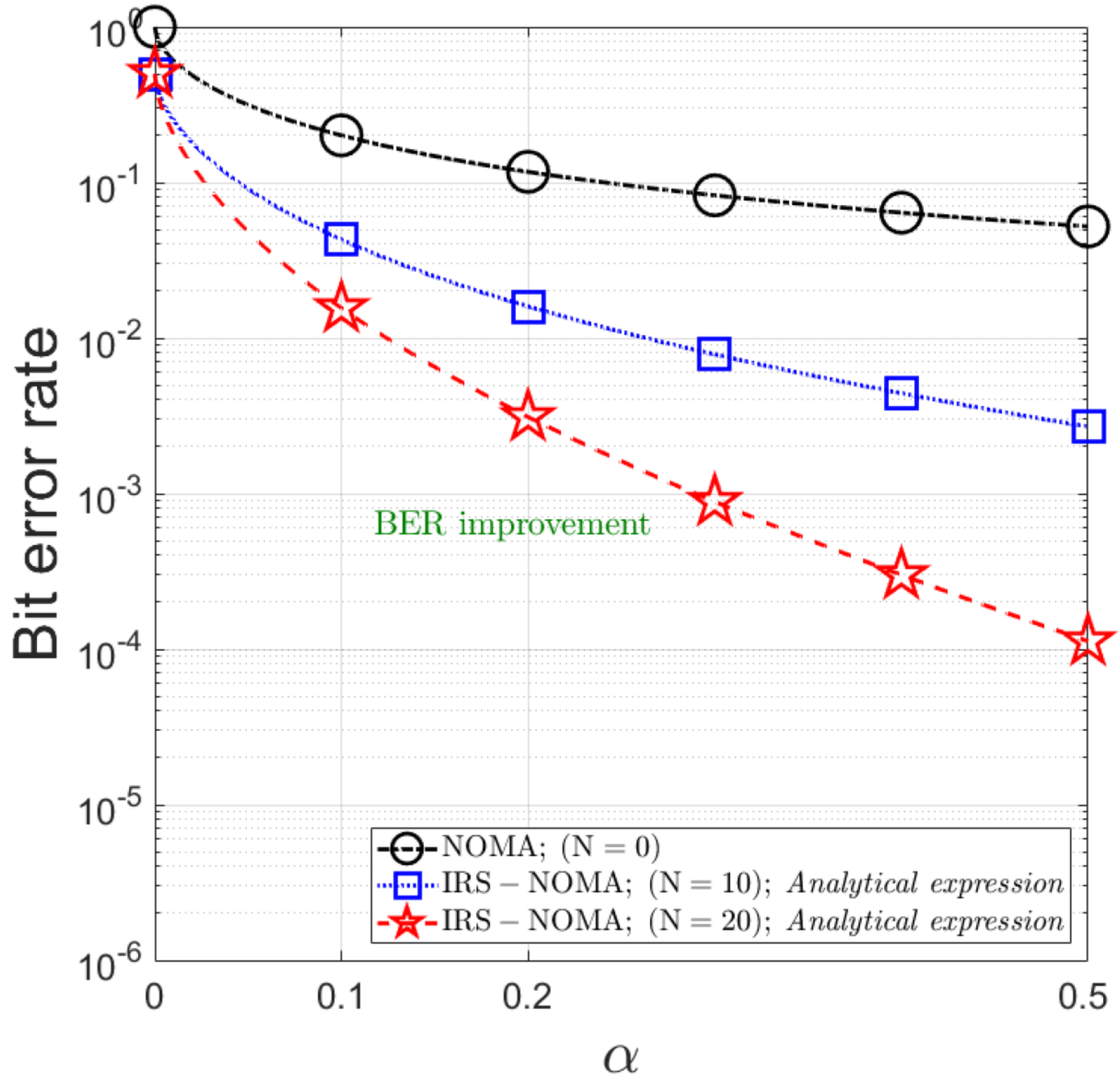

Figure 2. Comparison of BERs of IRS-NOMA networks with different numbers of IRS devices for strongest channel gain user

In Figure 2, it is observed that BER performances improves as the number N of IRS devices increases. Such results are intuitively reasonable.

5. Conclusion

In this paper, we studied a BER analysis on IRS technologies for NOMA systems. First, we derive a BER expression for IRS-NOMA systems with Rician fading channels. Then, we validate the BER expression by Monte Carlo simulations, and show numerically that BER expressions are in good agreement with simulations. Moreover, we investigate the BER of IRS-NOMA systems with Rician fading channels for various numbers of IRS elements, and show that the BERs improve as the number of IRS elements increases. In results, IRS-NOMA systems could be considered as important technologies with the good BERs towards 6G mobile systems. IRS-NOMA systems could play a promising role in the next generation mobile networks owing to lower latency, higher spectral efficiency, greater connectivity features, and user fairness, compared with the 5G technology. According to the simulation results, IRS-NOMA systems reduced the total energy consumption and improved the BER performance.

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