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Impact of Rician Fading on BER Performance on Intelligent Reflecting Surface NOMA Towards 6G Systems

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Abstract

The commercialization of the fifth generation (5G) mobile systems has quested enabling technologies, such as intelligent reflecting surface (IRS) transmissions, towards the sixth generation (6G) networks. In this paper, we present a bit-error rate (BER) performance analysis on IRS transmissions in 5G non-orthogonal multiple access (NOMA) networks. First, we derive a closed-form expression for the BER of IRS-NOMA transmissions under Rician fading channels. Then, by Monte Carlo simulations, we validate the proposed approximate BER expression, and show numerically that the derived BER expression is in good agreement with Monte Carlo simulations. Furthermore, we also analyze the BER performance of IRS-NOMA networks under Rician fading channels with different numbers of reflecting elements, and demonstrate that the performances improve monotonically as the number of reflecting devices increases.

Keywords: *Intelligent Reflecting Surface, 6G, NOMA, 5G, Bit-Error Rate*

1. INTRODUCTION

The fifth-generation (5G) networks have been commercialized almost all the countries [1]. Currently in 5G mobile systems, non-orthogonal multiple access (NOMA) has been one of promising technologies [2-4]. However, the demand for faster networks is now underway for the sixth-generation (6G) communications [5]. To this end, intelligent reflecting surface (IRS) has recently emerged as a 6G candidate [6-8]. The cross-correlated QAM was proposed for NOMA [9]. The negatively asymmetric 2PAM was investigated in NOMA [10].

In this paper, we present the investigation on a bit-error rate (BER) performance for the IRS assisted NOMA system in 5G networks. First, we derive an analytical expression for the BER performance of IRS-NOMA, especially under Rician fading channels. Then, we validate the proposed approximate BER expression with Monte Carlo simulations, and demonstrate numerically that the approximate BER expression is in good agreement with Monte Carlo simulations. Moreover, we also analyze the BER performance of IRS-NOMA networks under Rician fading channels with different numbers of reflecting elements, and demonstrate that the performances improve monotonically as the number of reflecting devices increases.

The remainder of this paper is organized as follows. In Section 2, the system and channel model are described. The closed form expression for the average BER 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 present the investigation on a BER performance for IRS assisted NOMA in in 5G networks.
- First, we derive a closed-form expression for the BER of IRS-NOMA transmissions under Rician fading channels.
- Then, by Monte Carlo simulations, we validate the proposed approximate BER expression, and show numerically that the derived BER expression is in good agreement with Monte Carlo simulations.
- Furthermore, we also analyze the BER performance of IRS-NOMA networks under Rician fading channels with different numbers of reflecting elements, and demonstrate that the performances improve monotonically as the number of reflecting devices increases.

2. SYSTEM AND CHANNEL MODEL

We consider an IRS-NOMA transmission network from a single-antenna base station to two single-antenna users. Assume that there is a direct link between the base station and the cell-edge user, which is Rayleigh distributed, denoted by h_2 with the second moment $\Sigma_2 = \mathbb{E}[|h_2|^2]$. We assume that there is no direct link between the IRS and the near user. The base station broadcasts the superimposed signal $x = \sqrt{P\alpha}s_1 + \sqrt{P(1-\alpha)}s_2$, 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

$$r_2 = |h|x + n_2, \tag{1}$$

where $h = h_2 + h_{br}^T\,\Theta\,h_{ru}$ 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 $N \times 1$ Rician fading channel from the base station to the IRS and h_{ru} denotes the $N \times 1$ Rician fading channel from the IRS to the cell-edge user. Thus, the channel gains can be expressed as

$$h_{br} = \frac{1}{\sqrt{d_{br}^{\alpha_{br}}}}\left(\sqrt{\frac{K_{br}}{K_{br}+1}}\bar{h}_{br} + \sqrt{\frac{1}{K_{br}+1}}\tilde{h}_{br}\right),$$

$$h_{ru} = \frac{1}{\sqrt{d_{ru}^{\alpha_{ru}}}}\left(\sqrt{\frac{K_{ru}}{K_{ru}+1}}\bar{h}_{ru} + \sqrt{\frac{1}{K_{ru}+1}}\tilde{h}_{ru}\right),$$

$$h_d = \frac{1}{\sqrt{d_d^{\alpha_d}}}\tilde{h}_d, \tag{2}$$

where $\{d_{br}^{\alpha_{br}}, d_{ru}^{\alpha_{ru}}, d_d^{\alpha_d}\}$ and $\{\alpha_{br}, \alpha_{ru}, \alpha_d\}$ denote the distances and path loss exponents, and $\{K_{br}, K_{ru}\}$ denotes the Rician factors. $\{\bar{h}_{br}, \bar{h}_{ru}\}$ denotes the normalized LoS component, and $\{\tilde{h}_{br}, \tilde{h}_{ru}, \tilde{h}_d\}$ denote the normalized non-LOS component. The IRS is represented by the diagonal matrix $\Theta = \omega\mathrm{diag}(e^{j\theta_1}, \cdots, e^{j\theta_N})$, 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 AVERAGE BER EXPRESSION FOR IRS-NOMA

In this section, we derive an approximate analytical expression for the average BER of IRS-NOMA over Rician fading channels. It is assumed that the IRS selects the phase-shifts to obtain the maximum channel gain, as follows:

$$|h||h_2|\underbrace{\omega\sum_{n=1}^{N}|(h_{br}\quad)_n(h_{ru}\quad)_n|}_{\xi}|h_2|_{max} \tag{3}$$

where $\xi=\omega\sum_{n=1}^{N}|(h_{br}\quad)_n(h_{ru}\quad)_n|$. We start the following conditional average BER in [11]:

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

$$+\frac{1}{2}Q\left(\sqrt{2\gamma_c\xi_{\text{norm}}^2}\right)-\frac{1}{2}Q\left(\sqrt{2(1+\gamma_c)\xi_{\text{norm}}^2}\left(\frac{\gamma_c}{1+\gamma_c}\right)\right)e^{-\left(\frac{\gamma_c}{1+\gamma_c}\right)\xi_{\text{norm}}^2}\sqrt{\frac{\gamma_c}{1+\gamma_c}}, \tag{4}$$

where

$$\gamma_b=\frac{\Sigma_2P\left(\sqrt{(1-\alpha)}-\sqrt{\alpha}\right)^2}{N_0},$$

$$\gamma_c=\frac{\Sigma_2P\left(\sqrt{(1-\alpha)}+\sqrt{\alpha}\right)^2}{N_0}, \tag{5}$$

and

$$\xi_{\text{norm}}^2=\frac{\xi^2}{\Sigma_2}. \tag{6}$$

Now we reference the technique in Jensen inequality and we approximate $P_2^{(\text{IRS-NOMA})}$ as follows:

$$P_2^{(\text{IRS-NOMA})}=\mathbb{E}_{\xi_{\text{norm}}^2}\left[P_{2|\xi_{\text{norm}}^2}^{(\text{IRS-NOMA})}\right]\simeq P_{2|\xi_{\text{norm}}^2}^{(\text{IRS-NOMA})}\left(\mathbb{E}[\xi_{\text{norm}}^2]\right), \tag{7}$$

where

$$\mathbb{E}[\xi_{\text{norm}}^2]=\omega\frac{N}{\Sigma_2}\frac{1}{d_{br}^{\alpha_{br}}}\frac{1}{d_{ru}^{\alpha_{ru}}}+\omega\frac{N(N-1)}{\Sigma_2}\frac{\pi}{4d_{br}^{\alpha_{br}}(K_{br}+1)}\left(L_{\frac{1}{2}}(-K_{br})\right)^2\cdot\frac{\pi}{4d_{ru}^{\alpha_{ru}}(K_{ru}+1)}\left(L_{\frac{1}{2}}(-K_{ru})\right)^2. \tag{8}$$

4. NUMERICAL RESULTS AND DISCUSSIONS

In this section, to validate the theoretical analysis, we present numerical results. Parameters are used in the simulations as follows: $P/\sigma^2 = 70$ dB, $d_{br}^{\alpha_{br}}$= 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, we validate numerically the proposed analytical expression for the average BER of IRS-NOMA over Rician fading channels with Monte Carlo simulations, in Figure 1.

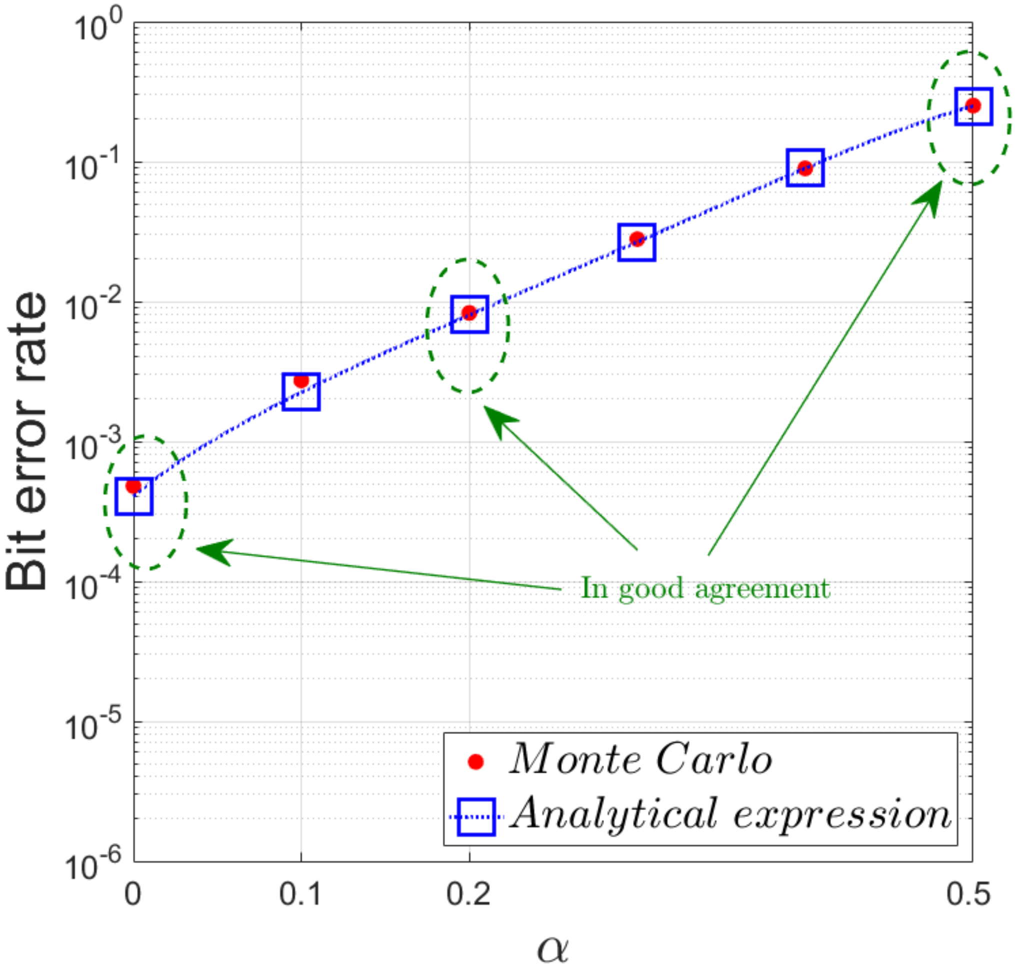

Figure 1. Monte Carlo simulations and analytical expression for IRS-NOMA system

As shown in Figure 1, the proposed analytical expression for the average BER of IRS-NOMA is in good agreement with Monte Carlo simulations; hence, we analyze the average BER performances of IRS-NOMA with the aforementioned analytical expression in the rest of this paper.

Second, to investigate impacts of the number of reflecting devices on the average BER of IRS-NOMA, we depict the average BERs of IRS-NOMA with the different numbers of reflecting devices, i.e., $N = 10$and $N = 20$.

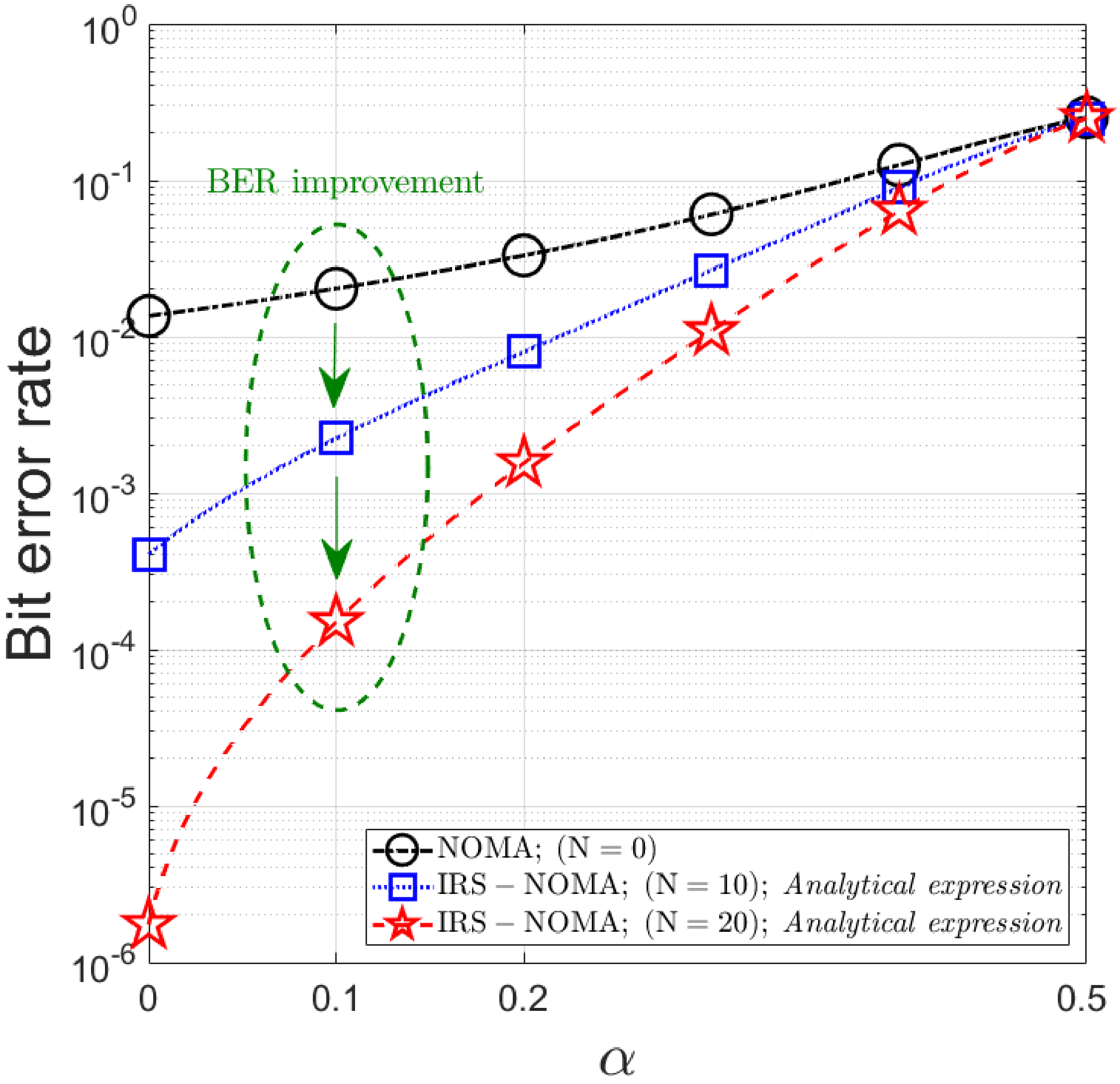

Figure 2. Comparison of BERs of IRS-NOMA systems with different numbers of reflecting devices

As shown in Figure 2, we observe the intuitive BER performances, i.e., BER performances improves monotonically with the number of reflecting devices N.

5. CONCLUSION

In this paper, we presented a BER performance analysis on IRS assisted 5G NOMA networks. First, we derived a closed-form expression for the BER of IRS-NOMA transmissions under Rician fading channels. Then, we validated the proposed approximate BER expression by Monte Carlo simulations, and showed numerically that the derived BER expression is in good agreement with Monte Carlo simulations. Furthermore, we also analyzed the BER performance of IRS-NOMA networks under Rician fading channels with different numbers of reflecting elements, and demonstrated that the performances improve monotonically as the number of reflecting devices increases. In result, the IRS-NOMA network could be considered as a promising technology with the outstanding BER performance towards 6G mobile networks.

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