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BER Performance Comparison for Intelligent Reflecting Surface in NOMA: Phase Shifts Perspective

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Abstract

As the sixth generation (6G) promising technique, intelligent reflecting surface (IRS) has recently attracted much attention. The IRS based wireless communication is expected to deploy the upcoming 6G mobile networks, to increase energy and spectrum efficiency in the fifth generation (5G) wireless networks. In this paper, we compare the bit-error rate (BER) performances for phase-shift schemes of IRS non-orthogonal multiple access (NOMA). First, we derive a BER expression for the equalizing phase-shift scheme in IRS-NOMA networks. Then we compare the BER of the equalizing phase-shift scheme to that of the identical phase-shift scheme in IRS-NOMA networks, and show the BER improvement of the equalizing phase-shift scheme IRS NOMA over the identical phase-shift scheme IRS NOMA. Furthermore, we also validate the proposed analytical BER for the equalizing phase-shift scheme in IRS-NOMA by Monte Carlo simulations, and demonstrate that they well match each other.

Keywords: *6G, Intelligent reflecting surface, NOMA, 5G, Power allocation.*

1. Introduction

Due to the demand of spectrum efficiency and mass connectivity, the fifth-generation (5G) communications have required highly competitive technologies [1]. Non-orthogonal multiple access (NOMA) has become been one of such technologies in 5G [2-4]. Nevertheless, the security risk become weakness of NOMA networks in the sixth-generation (6G) communications [5]. Fortunately, intelligent reflecting surface (IRS) emerges as an efficient technology to break through the weakness of NOMA [6-8]. The bit-error rate (BER) of weaker channel user in NOMA with novel BTS has been investigated [9]. A tight upper bound on capacity of IRS transmissions was proposed [10].

In this paper, we compare the BER performances for phase-shift schemes of IRS NOMA. First, we derive a BER expression for the equalizing phase-shift scheme in IRS-NOMA networks. Then we compare the BER of the equalizing phase-shift scheme to that of the identical phase-shift scheme in IRS-NOMA networks, and show that the BER improvement of the equalizing phase-shift scheme IRS NOMA over the identical phase-shift scheme IRS NOMA. Furthermore, we also validate the proposed analytical BER for the equalizing phase-shift scheme in IRS-NOMA by Monte Carlo simulations, and demonstrate that they well match each other.

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The remainder of this paper is organized as follows. In Section 2, the system model is described. A tighter upper bound on capacity of IRS transmissions is derived in Section 3. The numerical results are discussed in Section 4. Finally, Section 5 concludes the paper.

Our contributions can be summarized as follows:

- We compare the BER performances for phase-shift schemes of IRS NOMA mobile systems under Rayleigh fading channels.
- First, based on a mean value approximation, we derive a BER expression for the equalizing phase-shift scheme in IRS-NOMA networks.
- Then we compare the BER of the equalizing phase-shift scheme to that of the identical phase-shift scheme in IRS-NOMA networks, and show that the BER improvement of the equalizing phase-shift scheme IRS NOMA over the identical phase-shift scheme IRS NOMA.
- Furthermore, we also validate the proposed analytical BER for the equalizing phase-shift scheme in IRS-NOMA by Monte Carlo simulations, and demonstrate that they well match each other

2. System and Channel Model

We consider an IRS-NOMA system with two single-antenna users and one single-antenna base station. It is assumed that a direct link between the cell-edge user and the base station is Rayleigh distributed, which is h_2 with the second moment $\Sigma_2 = \mathbb{E}\left[|h_2|^2\right]$. The base station can broadcast the superimposed signal $x = \sqrt{P\alpha}s_1 + \sqrt{P(1-\alpha)}s_2$, where the transmitted power is P, s_m is the signal with the unit power for the *m*th user, $m = 1, 2$, and α is the power allocation coefficient. The cell-edge user signal r_2 is expressed by

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

where $n_2 \sim N(0, N_0/2)$ is additive white Gaussian noise (AWGN) and $h = h_2 + \mathrm{h}_{br}^H \Theta \mathrm{h}_{ru}$. N is the number of reflecting devices, $\mathrm{h}_{br} \sim CN(\mathbf{0}, \mathbf{K}_{br})$ denotes the $N \times 1$ Rayleigh fading from the base station to the IRS and $\mathrm{h}_{ru} \sim CN(\mathbf{0}, \mathbf{K}_{ru})$ denotes the $N \times 1$ Rayleigh fading from the IRS to the cell-edge user. The IRS is with the diagonal matrix $\Theta = \omega \,\mathrm{diag}\left(e^{j\theta_1}, \cdots, e^{j\theta_N}\right)$, where $\omega \in (0,1]$ is $\theta_1, \cdots, \theta_N$ are the phase-shift variables and the fixed amplitude reflection coefficient.

3. Derivation of BER Expression for Equalizing Phase-Shifts Scheme IRS-NOMA

In this section, we derive an analytical BER of equalizing phase-shifts scheme IRS NOMA. First, for the identical phase-shifts scheme, the power of the channel gain is given by [10]

$$\begin{aligned} E\left[|h|^2\right] &= \Sigma_2 + \mathrm{tr}\left(\mathbf{K}_{ru}\mathbf{K}_{br}\right) \\ &\triangleq \Sigma_h \end{aligned} \tag{2}$$

Then we use the central limit theorem, and we assume the distribution of h is the normal distribution, i.e.,

$h \sim CN\left(0, \Sigma_h\right)$. Hence the average BER of the identical phase-shifts IRS NOMA system is given by [10]

$$P_2^{\text{(IRS-NOMA)}} = \frac{1}{2} F\left(\frac{\Sigma_h P\left(\sqrt{(1-\alpha)} - \sqrt{\alpha}\right)^2}{N_0} \right) + \frac{1}{2} F\left(\frac{\Sigma_h P\left(\sqrt{(1-\alpha)} + \sqrt{\alpha}\right)^2}{N_0} \right) \tag{3}$$

where

$$F\left(\gamma_b\right) = \frac{1}{2}\left(1 - \sqrt{\frac{\gamma_b}{1+\gamma_b}}\right). \tag{4}$$

Second, for the equalizing phase-shifts scheme, the channel gain is expressed as

$$|h| = |h_2| + \underbrace{\omega \sum_{n=1}^{N} \left|\left(\mathrm{h}_{br}\right)_n\right| \left|\left(\mathrm{h}_{ru}\right)_n\right|}_{\xi_v} \tag{5}$$

where

$$\xi_v = \omega \sum_{n=1}^{N} \left|\left(\mathrm{h}_{br}\right)_n\right| \left|\left(\mathrm{h}_{ru}\right)_n\right| \tag{6}$$

In this case, we cannot resort to the central limit theorem. Instead, we approximate ξ_v by $E[\xi_v]$. Then we observe that h becomes a Rician random variable (RV). Thus, h can be expressed as

$$h = \left(\sqrt{E[\xi_v] + \Sigma_2}\right)\left(\sqrt{\frac{K}{K+1}}\,\bar{\mathrm{h}} + \sqrt{\frac{1}{K+1}}\,\tilde{\mathrm{h}}\right),$$

$$K = \frac{E[\xi_v]}{\Sigma_2}, \tag{7}$$

$$\mathrm{h}_{ru} = \frac{1}{\sqrt{d_{ru}^{\alpha_{ru}}}}\left(\sqrt{\frac{K_{ru}}{K_{ru}+1}}\,\bar{\mathrm{h}}_{ru} + \sqrt{\frac{1}{K_{ru}+1}}\,\tilde{\mathrm{h}}_{ru}\right), \; h_d = \frac{1}{\sqrt{d_d^{\alpha_d}}}\tilde{h}_d,$$

where $d_{br}^{\alpha_{br}}, d_{ru}^{\alpha_{ru}}, d_d^{\alpha_d}$ and $\alpha_{br}, \alpha_{ru}, \alpha_d$ denote the distance and path loss exponent, and K denotes the Rician factor. $\bar{\mathrm{h}}$ denotes the normalized LoS component, and $\tilde{\mathrm{h}}$ denotes the normalized non-LOS component.

Then we average $P_{2||h_2|}^{\text{(IRS-NOMA)}}$ over the Rayleigh fading distribution,

$$P_2^{(\text{IRS-NOMA})} = \int_0^{\infty} \left(\frac{1}{2} Q\left(\frac{\left(|h_2| + \xi\right)\sqrt{P}\left(\sqrt{(1-\alpha)} - \sqrt{\alpha}\right)}{\sqrt{N_0 / 2}} \right) + \frac{1}{2} Q\left(\frac{\left(|h_2| + \xi\right)\sqrt{P}\left(\sqrt{(1-\alpha)} + \sqrt{\alpha}\right)}{\sqrt{N_0 / 2}} \right) \right) \times e^{-K - \frac{(K+1)\left(|h_2|\right)^2}{\Omega}} 2\frac{(K+1)\left(|h_2|\right)}{\Omega} I_0\left(2\sqrt{\frac{K(K+1)}{\Omega}}\right) d|h_2|. \tag{8}$$

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: $P/\sigma^2 = 70\,\text{dB}$, $d_{br}^{\alpha_{br}}$ = 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 identical phase-shifts IRS-NOMA over Rician fading channels with Monte Carlo simulations, in Figure 1.

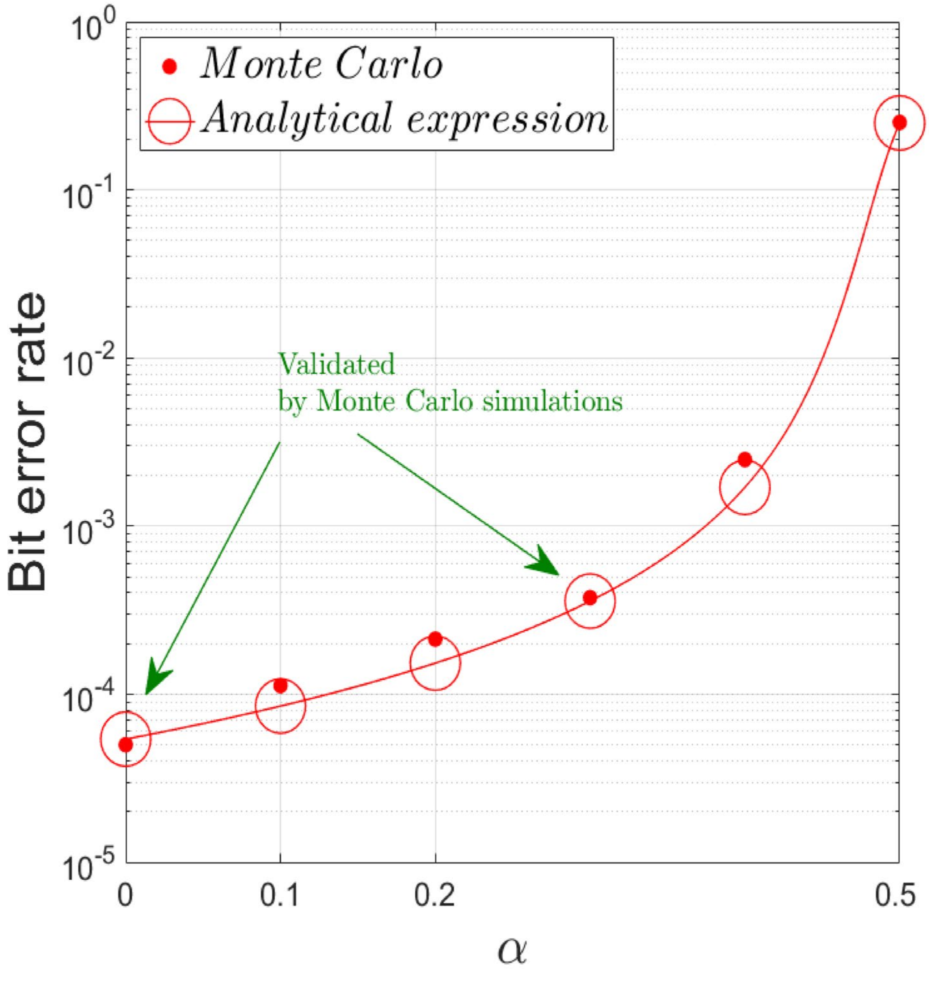

Figure 1. Monte Carlo simulations and analytical expression for identical phase-shifts IRS-NOMA

As shown in Figure 1, the proposed analytical expression for the average BER of identical phase-shifts 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 the BER improvement, we depict the BERs versus the power allocation, $0 \leq \alpha \leq 0.5$ (dB), with $N = 100$, in Figure 2.

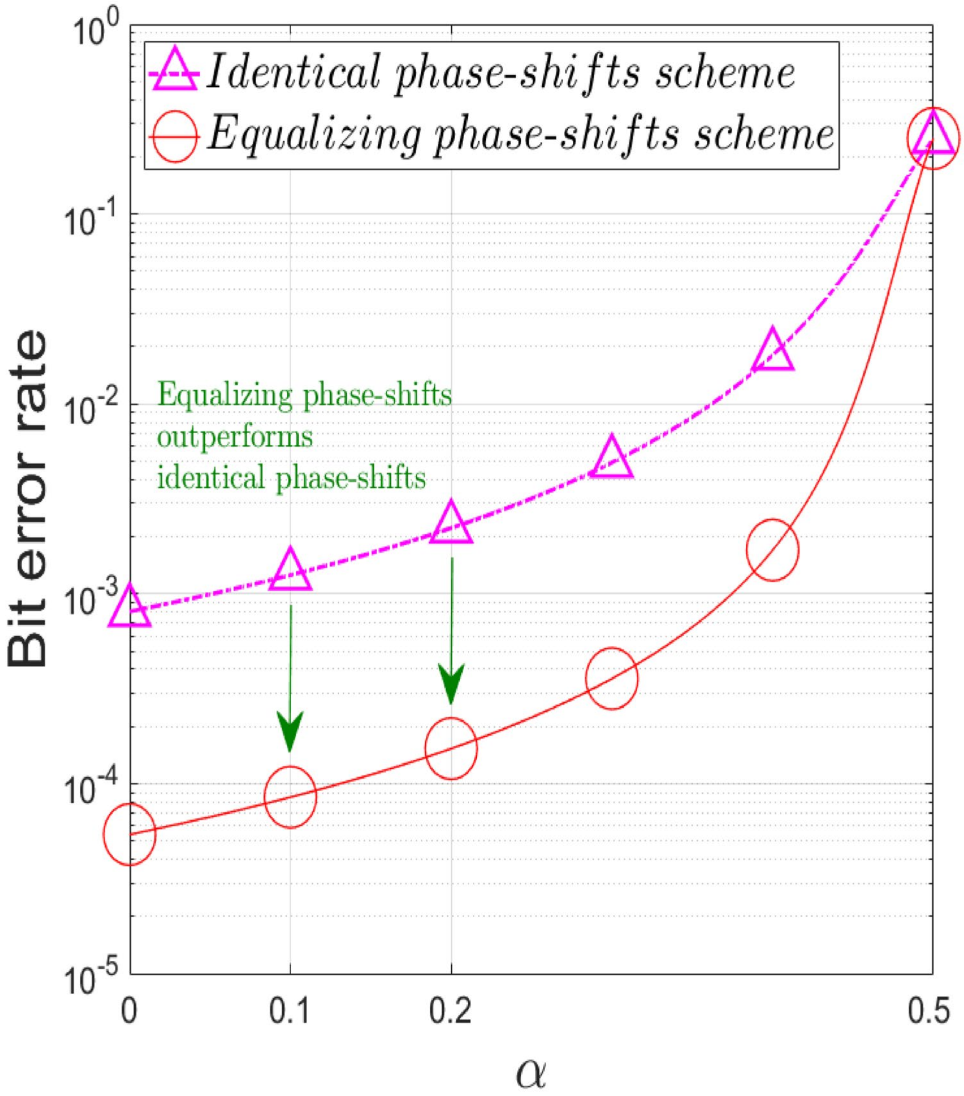

Figure 2. Comparison of BERs for equalizing phase-shift scheme and identical phase-shift scheme in IRS-NOMA, ($0 \leq \alpha \leq 0.5$)

As shown in Figure 2, the BER of the equalizing phase-shift scheme IRS NOMA improves compared to that of the identical phase-shift scheme IRS NOMA.

5. Conclusion

In the paper, we compared the BER performances for phase-shift schemes of IRS non-orthogonal multiple access (NOMA). First, we derived a BER expression for the equalizing phase-shift scheme in IRS-NOMA networks. Then we compared the BER of the equalizing phase-shift scheme to that of the identical phase-shift scheme in IRS-NOMA networks, and showed the BER improvement of the equalizing phase-shift scheme IRS

NOMA over the identical phase-shift scheme IRS NOMA. Furthermore, we also validated the proposed analytical BER for the equalizing phase-shift scheme in IRS-NOMA by Monte Carlo simulations, and demonstrated that they well match each other.

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