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Correlated Intelligent Reflecting Surface and Improved BER Performance of NOMA

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Abstract

Towards the sixth generation (6G) mobile networks, spectrum and energy efficiency of non-orthogonal multiple access (NOMA) transmissions in the fifth generation (5G) wireless system have been improved by intelligent reflecting surface (IRS) technologies. However, the reflecting devices of an IRS tend to be correlated because they are placed close on the surface each other. In this paper, we present an analysis on the correlated IRS in NOMA cellular networks. Specifically, we consider the bit-error rate (BER) performances for correlated-IRS in NOMA networks. First, based on the central limit theorem, we derive an approximate analytical expression of the BER for correlated-IRS NOMA systems, by using the second moment of the channel gain. Then we validate the proposed analytical BER by Monte Carlo simulations, and show that they are in good agreement. In addition, we also show numerically the BER improvement of the correlated-IRS NOMA over the conventional independent-IRS NOMA.

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

1. Introduction

In the fifth-generation (5G) networks, advanced multiple access (MA) technologies have been deployed for boosting spectrum efficiency [1]. Non-orthogonal multiple access (NOMA) has been envisioned as such one of MA technologies in 5G [2-4]. However, the energy and spectral efficiency in the sixth-generation (6G) network have required a cost-effective solution [5]. Intelligent reflecting surface (IRS) has been attracting growing attention [6-8]. The performance for non-uniform sources was derived in NOMA [9]. A bit-to-symbol mapping scheme has been investigated for NOMA [10]. The bit-error rate (BER) expression for IRS-assisted NOMA was derived [11]. Spatial correlations have been investigated for IRS in the context of simultaneous wireless information and power transfer (SWIPT) [12]. In this paper, we present an analysis on the correlated IRS in NOMA cellular networks. First, we derive an approximate analytical expression of the BER for correlated-IRS NOMA systems. Then we validate the proposed analytical BER by Monte Carlo simulations, and show that they are in good agreement. In addition, we also show numerically the BER improvement of the correlated-IRS NOMA over the conventional independent-IRS NOMA.

This paper is organized as follows. In Section 2, the system and channel model are described. An

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approximate analytical expression for the BER for correlated-IRS NOMA systems is derived in Section 3. The results and Monte Carlo simulations are addressed in Section 4. Finally, we conclude this paper in Section 5.

The main contributions are summarized as follows:

- We address the correlation of IRS and an improved BER for NOMA.
- We derive an approximate analytical expression of the BER for correlated-IRS NOMA systems.
- Then, we validate the proposed analytical BER by Monte Carlo simulations, and show that they are in good agreement.
- In addition, we also show numerically the BER improvement of the correlated-IRS NOMA over the conventional independent-IRS NOMA.

2. System and Channel Model

This paper considers an IRS-NOMA system with one 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 $\Sigma_2 = \mathbb{E}\left[|h_2|^2\right]$. 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 mth user's signal with the unit power, $m = 1, 2$, 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 $h = h_2 + \mathrm{h}_{br}^H \Theta \mathrm{h}_{ru}$ and $n_2 \sim N(0, N_0/2)$ is additive white Gaussian noise (AWGN). For a given number N of reflecting devices, $\mathrm{h}_{br} \sim CN(\mathbf{0}, \mathbf{K}_{br})$ denotes the $N \times 1$ Rayleigh fading channel 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 channel from the IRS to the cell-edge user. The IRS is represented by the diagonal matrix $\Theta = \omega\,\mathrm{diag}\left(e^{j\theta_1}, \cdots, e^{j\theta_N}\right)$, where $\omega \in (0,1]$ is the fixed amplitude reflection coefficient and $\theta_1, \cdots, \theta_N$ are the phase-shift variables.

3. Derivation of Average BER for Correlated IRS NOMA

In this section, we provide an analytical expression for the average BER of correlated-IRS NOMA. Specifically, Rayleigh fading channels are considered. We start with the distribution of h. For arbitrary phase shifts, the second moment of the channel gain is given as

$$\begin{aligned} E\left[|h|^2\right] &= E\left[\left|h_2 + \mathrm{h}_{br}^H \Theta \mathrm{h}_{ru}\right|^2\right] \\ &= \Sigma_2 + \mathrm{tr}\left(\mathbf{K}_{ru}\Theta^H \mathbf{K}_{br}\Theta\right) \\ &\triangleq \Sigma_h \end{aligned} \tag{2}$$

Then we resort to the central limit theorem, and we approximate the distribution of h by the normal distribution, i.e., $h \sim CN\left(0, \Sigma_h\right)$. Hence, by using Σ_h and the BER expression in [11], the average BER of the correlated-IRS NOMA system is given by

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

where

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

4. Numerical Results and Discussions

A popular scenario concerns the identical phase shifts, i.e., $\theta_1 = \ldots = \theta_N$. In this case, the second moment of the channel gain is simplified as

$$\Sigma_h = \Sigma_2 + \operatorname{tr}\left(\mathbf{K}_{ru} \mathbf{K}_{br}\right) \tag{5}$$

Furthermore, we express $\mathbf{K}_{br}$ and $\mathbf{K}_{ru}$ as

$$\left(\mathbf{K}_{br}\right)_{i,j} = d_{br}^{\alpha_{br}} e^{-\frac{|i-j|}{N}} \tag{6}$$

and

$$\left(\mathbf{K}_{ru}\right)_{i,j} = d_{ru}^{\alpha_{ru}} e^{-\frac{|i-j|}{N}} \tag{7}$$

where $(\mathbf{A})_{i,j}$ denotes the entry in the *i*th row and *j*th column of a matrix $\mathbf{A}$. Note that for independent-IRS NOMA systems, $\mathbf{K}_{br}$ and $\mathbf{K}_{ru}$ are simplified as $\mathbf{K}_{br} = d_{br}^{\alpha_{br}} \mathbf{I}_N$ and $\mathbf{K}_{ru} = d_{ru}^{\alpha_{ru}} \mathbf{I}_N$. In simulations, parameters are set as follows: $P/\sigma^2 = 70\,\text{dB}$, $d_{br}^{\alpha_{br}}$ = 120 m, $d_{ru}^{\alpha_{ru}}$ = 120 m and $d_d^{\alpha_d}$ = 150 m, $\alpha_{br} = 1.5$, $\alpha_{ru} = 1.5$, $\alpha_d = 2.0$, $N = 20$, and $\omega = 1$. The number of independent simulations is 10^6.

First, to validate the derived analytical expression for the BER over Rayleigh fading channels, we present Monte Carlo simulations in Figure 1.

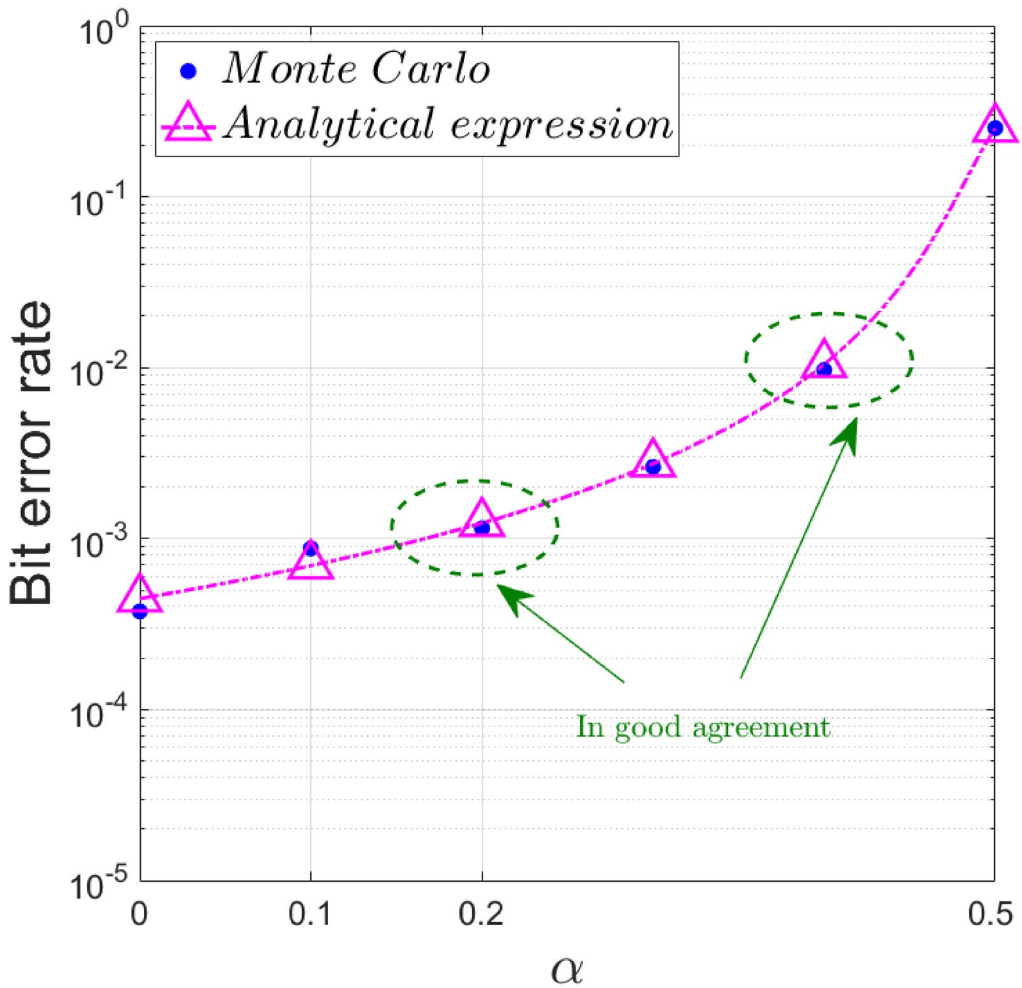

Figure 1. Analytical expression and Monte Carlo simulations for independent-IRS NOMA system

As shown in Figure 1, Monte Carlo simulations are in good agreement with the derived analytical expression for the BER of independent-IRS NOMA; thus, based on the analytical expressions, we compare the BER of independent-IRS NOMA with that of correlated-IRS NOMA in the next results.

Second, to investigate the performance improvement of correlated-IRS NOMA, we depict the BERs of correlated-IRS NOMA and independent-IRS NOMA, in Figure 2.

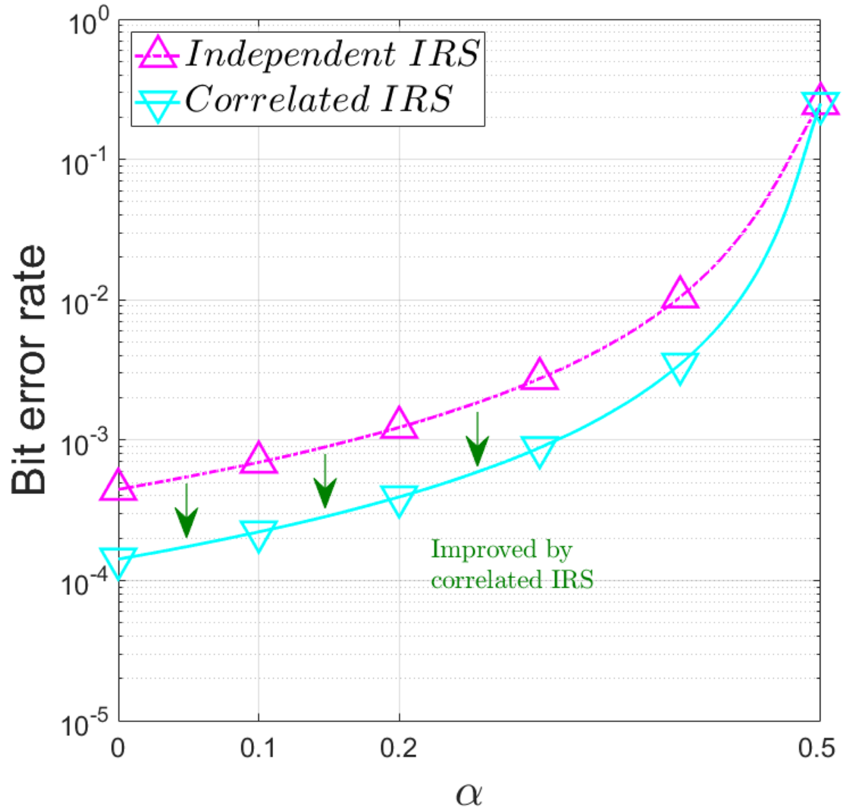

Figure 2. Comparison of BERs of independent-IIRS NOMA and correlated-IRS NOMA systems

As shown in Figure 2, the BER of the correlated-IRS NOMA system improves compared with that of the independent-IRS NOMA system. Such BER improvements have been achieved by using the statistical structure in the correlated IRS.

5. Conclusion

We presented an analysis on the correlation of IRS in NOMA networks. First, based on the central limit theorem, we derived an approximate analytical expression of the BER for correlated-IRS NOMA systems by using the second moment of the channel gain. We then validated the proposed analytical BER by Monte Carlo simulations, and showed that they agree each other. Moreover, we also showed numerically the BER improvement of the correlated-IRS NOMA over the conventional independent-IRS NOMA.

As a result, the correlation in IRS could be considered for performance improvement in NOMA cellular communications.

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