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BER Performance Analysis of Intelligent Reflecting Surface NOMA for Strongest Channel Gain User

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Abstract

Recently, the sixth generation (6G) networks have become tremendous research topics. Intelligent reflecting surface (IRS) technologies have been envisioned, to increase spectrum and energy efficiency for the fifth generation (5G) mobile networks, towards the sixth generation (6G) communications. In this paper, especially for the strongest channel gain user, we investigate the bit-error rate (BER) of non-orthogonal multiple access (NOMA) systems with intelligent reflecting surface (IRS). First, we derive a BER expression in a closed-form of Q functions. Second, we investigate the BER performance improvement of IRS NOMA systems over NOMA systems versus the power allocation. Moreover, we analyze the BER performance improvement of IRS NOMA systems over NOMA systems versus the number of IRS devices. In results, NOMA equipped with IRS technologies could play an important role in the paradigm shift from 5G mobile networks to 6G mobile networks.

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

1. Introduction

Recently, the most of mobile communications have been using the fifth-generation (5G) communications [1]. Non-orthogonal multiple access (NOMA) is considered as key technologies in 5G [2-4]. However, the power efficiency and spectral efficiency have been more required in the sixth-generation (6G) networks [5]. The intelligent reflecting surface (IRS) has been investigated to solve the demands [6-8]. Therefore, this low-cost antenna device can be used to NOMA, i.e., IRS-NOMA. Then, spectral efficiency and the connectivity would be increased by IRS-NOMA. For non-uniform source NOMA, the bit-error rate (BER) was analyzed [9]. A bit-to-symbol (BTS) in NOMA has been proposed [10]. In this paper, especially for the strongest channel gain user, we investigate the bit-error rate (BER) of NOMA systems with IRS. First, we derive a BER expression in a closed-form of Q functions. Second, we investigate the BER performance improvement of IRS NOMA systems over NOMA systems versus the power allocation. Moreover, we analyze the BER performance improvement of IRS NOMA systems over NOMA systems versus the number of IRS devices.

This paper's contributions are summarized as follows:

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- We derive a BER expression in a closed-form of Q functions.
- Then, we investigate the BER performance improvement of IRS NOMA systems over NOMA systems versus the power allocation.
- Moreover, we analyze the BER performance improvement of IRS NOMA systems over NOMA systems versus the number of IRS devices.

2. System and Channel Model

An IRS-NOMA transmission system is considered from a base station to two users. There is a direct channel between the strongest channel gain user and the base station. The direct channel is Rayleigh distributed, denoted by h_1 having the second moment $\Sigma_1 = \mathbb{E}\left[|h_1|^2\right]$. The base station sends the superimposed signal $x = \sqrt{Pa}s_1 + \sqrt{P(1-a)}s_2$, where the total transmitted power is P. the signal s_m is with the unit power for the mth user, $m = 1, 2$, and the power allocation coefficient is α . After successive interference cancellation (SIC), the signal r_1 received by the strongest channel gain user is expressed by

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

where $h = h_1 + \mathrm{h}_{br}^T \Theta \mathrm{h}_{ru}$ and additive white Gaussian noise (AWGN) is $n_1 \sim N(0, N_0/2)$. For a given number N of IRS devices, h_{br} denotes the $N ´ 1$ flat-fading channel from the basestation to the IRS and h_{ru} is the flat $N \times 1$; channel from the IRS to the strongest channel gain user. The IRS is expressed by the diagonal matrix $\Theta = \omega\,\mathrm{diag}\left(e^{j\theta_1}, \cdots, e^{j\theta_N}\right),$, is $\omega \in (0,1]$ plitude reflection coefficient and the phase-shift variables are .. ' $\theta_1, \cdots, \theta_N$ obtains the maximum channel gain:

$$|h|_{\max} = |h_1| + \underbrace{\omega \sum_{n=1}^{N} \left|\left(\mathrm{h}_{br}\right)_n \left(\mathrm{h}_{ru}\right)_n\right|}_{\xi} = |h_1| + \xi, \tag{2}$$

where $\xi = \omega \sum_{n=1}^{N} \left|\left(\mathrm{h}_{br}\right)_n \left(\mathrm{h}_{ru}\right)_n\right|$.

3. BER Expression over Rayleigh Fading for IRS-NOMA

For the strongest channel gain user, an analytical expression for the BER of IRS-NOMA is derived over the Rayleigh fading direct link. We start from The following conditional BER:

$$P_{1||h_1|}^{(\text{IRS-NOMA})} = Q\left(\frac{\left(|h_1| + \xi\right)\sqrt{\alpha P}}{\sqrt{N_0/2}}\right) \tag{3}$$

where $Q(y)=\int_y^{\infty}\frac{1}{\sqrt{2\pi}}e^{-\frac{(z)^2}{2}}dz$. Then we average $P_{1||h_1|}^{(\text{IRS-NOMA})}$ over the Rayleigh fading pdf,

$$P_{1||h_1|}^{(\text{IRS-NOMA})}=\int_0^{\infty}\left(Q\left(\frac{\left(|h_1|+\xi\right)\sqrt{\alpha P}}{\sqrt{N_0/2}}\right)\right)\cdot e^{-\frac{\left(|h_1|\right)^2}{\Sigma_1}}2\frac{\left(|h_1|\right)}{\Sigma_1}d|h_1|. \tag{4}$$

We integrate as follows:

$$\begin{aligned}
P_{1||h_1|}^{(\text{IRS-NOMA})}&=\int_0^{\infty}\left(Q\left(\frac{\left(|h_1|+\xi\right)\sqrt{\alpha P}}{\sqrt{N_0/2}}\right)\right)\cdot e^{-\frac{\left(|h_1|\right)^2}{\Sigma_1}}2\frac{\left(|h_1|\right)}{\Sigma_1}d|h_1|\\
&=\int_0^{\infty}Q\left(\sqrt{2\underbrace{\frac{\alpha P}{N_0}}_{\gamma_{b,\text{norm}}}\Sigma_1\left(\underbrace{\frac{|h_1|}{\sqrt{\Sigma_1}}}_{g_1}+\frac{\xi}{\sqrt{\Sigma_1}}\right)^2}\right)e^{-\frac{\left(\left|\sqrt{\Sigma_1}g_1\right|\right)^2}{\Sigma_1}}2\frac{\left(\sqrt{\Sigma_1}g_1\right)}{\Sigma_1}\left(\sqrt{\Sigma_1}dg_1\right)\\
&=\int_0^{\infty}Q\left(\sqrt{2\underbrace{\gamma_{b,\text{norm}}\Sigma_1}_{\gamma_b}\left(g_1+\underbrace{\frac{\xi}{\sqrt{\Sigma_1}}}_{\xi_{,\text{norm}}}\right)^2}\right)e^{-\frac{\left(\left|\sqrt{\Sigma_2}g_2\right|\right)^2}{\Sigma_2}}2\frac{\left(\sqrt{\Sigma_2}g_2\right)}{\Sigma_2}\left(\sqrt{\Sigma_2}dg_2\right)\\
&=\int_0^{\infty}Q\left(\sqrt{2\gamma_b\underbrace{\left(g_1+\xi_{,\text{norm}}\right)}_{x}{}^2}\right)e^{-\left(|g_1|\right)^2}2g_1dg_1=\int_{\xi_{,\text{norm}}}^{\infty}Q\left(\sqrt{2\gamma_b x^2}\right)e^{-\left(x-\xi_{\text{norm}}\right)^2}2\left(x-\xi_{,\text{norm}}\right)dx
\end{aligned} \tag{5}$$

where the SNR is as $\gamma_{b,\text{norm}}=\frac{\alpha P}{N_0}$ with $\gamma_b=\Sigma_1\gamma_{b,\text{norm}}$, $\xi_{\text{norm}}=\frac{\xi}{\sqrt{\Sigma_1}}$, and the variables are changed by $\sqrt{\Sigma_1}g_1=|h_1|$ and $x=|g_1|+\xi_{,\text{norm}}$. By the integration by parts

$$\begin{aligned}
P_{1||h_1|}^{(\text{IRS-NOMA})}&=\left[\left(-e^{-\left(x-\xi_{\text{norm}}\right)^2}\right)\cdot Q\left(\sqrt{2\gamma_b x^2}\right)\right]_{x=\xi_{\text{norm}}}^{\infty}-\int_{\xi_{\text{norm}}}^{\infty}\frac{d}{dx}\left(\int_{\sqrt{2\gamma_b x^2}}^{\infty}\frac{1}{\sqrt{2\pi}}e^{-\frac{(z)^2}{2}}dz\right)\cdot\left(-e^{-\left(x-\xi_{\text{norm}}\right)^2}\right)dx\\
&=\left[0-(-1)\cdot Q\left(\sqrt{2\gamma_b\xi_{\text{norm}}^2}\right)\right]-\int_{\xi_{\text{norm}}}^{\infty}\left(0-\frac{1}{\sqrt{2\pi}}e^{-\gamma_b x^2}\cdot\left(\sqrt{2\gamma_b}\right)\right)\cdot\left(-e^{-\left(x-\xi_{\text{norm}}\right)^2}\right)dx\\
&=Q\left(\sqrt{2\gamma_b\xi_{\text{norm}}^2}\right)-\sqrt{\gamma_b}\frac{1}{\sqrt{\pi}}e^{-\left(\frac{\gamma_b}{(1+\gamma_b)}\right)\xi_{\text{norm}}^2}\int_{\xi_{\text{norm}}}^{\infty}e^{-(1+\gamma_b)\left(x-\frac{\xi_{\text{norm}}}{(1+\gamma_b)}\right)^2}dx.
\end{aligned} \tag{6}$$

By changing $x-\frac{\xi_{\text{norm}}}{(1+\gamma_b)}=y$, we have

$$P_{1||h_1|}^{(\text{IRS-NOMA})}=Q\left(\sqrt{2\gamma_b\xi_{\text{norm}}^2}\right)-\sqrt{\gamma_b}\frac{1}{\sqrt{\pi}}e^{-\left(\frac{\gamma_b}{(1+\gamma_b)}\right)\xi_{\text{norm}}^2}\int_{\xi_{\text{norm}}-\frac{\xi_{\text{norm}}}{(1+\gamma_b)}}^{\infty}e^{-\frac{\left(\sqrt{2(1+\gamma_b)}y\right)^2}{2}}dy. \tag{7}$$

By changing the variable $\sqrt{2(1+\gamma_b)}y = x$, finally, we have

$$\begin{aligned} P_{1\|h_1|}^{(\text{IRS-NOMA})} &= Q\left(\sqrt{2\gamma_b\xi_{\text{norm}}^2}\right) - \sqrt{\gamma_b}\frac{1}{\sqrt{\pi}}e^{-\left(\frac{\gamma_b}{(1+\gamma_b)}\right)\xi_{\text{norm}}^2}\int_{\sqrt{2(1+\gamma_b)}\xi_{\text{norm}}\left(1-\frac{1}{(1+\gamma_b)}\right)}^{\infty} e^{-\frac{(x)^2}{2}}\frac{1}{\sqrt{2(1+\gamma_b)}}dx \\ &= Q\left(\sqrt{2\gamma_b\xi_{\text{norm}}^2}\right) - Q\left(\sqrt{2(1+\gamma_b)\xi_{\text{norm}}^2}\left(\frac{\gamma_b}{1+\gamma_b}\right)\right)e^{-\left(\frac{\gamma_b}{(1+\gamma_b)}\right)\xi_{\text{norm}}^2}\sqrt{\frac{\gamma_b}{1+\gamma_b}}. \end{aligned} \tag{8}$$

4. Numerical Results and Discussions

Numerical results are presented; to this end, we assume that $W=1$, $\Sigma_1 = 1$, $(\mathrm{h}_{br})_n = 0.01$ and $(\mathrm{h}_{ru})_n = 0.01$. First, we depict the BERs versus $0 \# a \quad 0.5$, to investigate the BER improvement, with $N = 100$, in Figure 2.

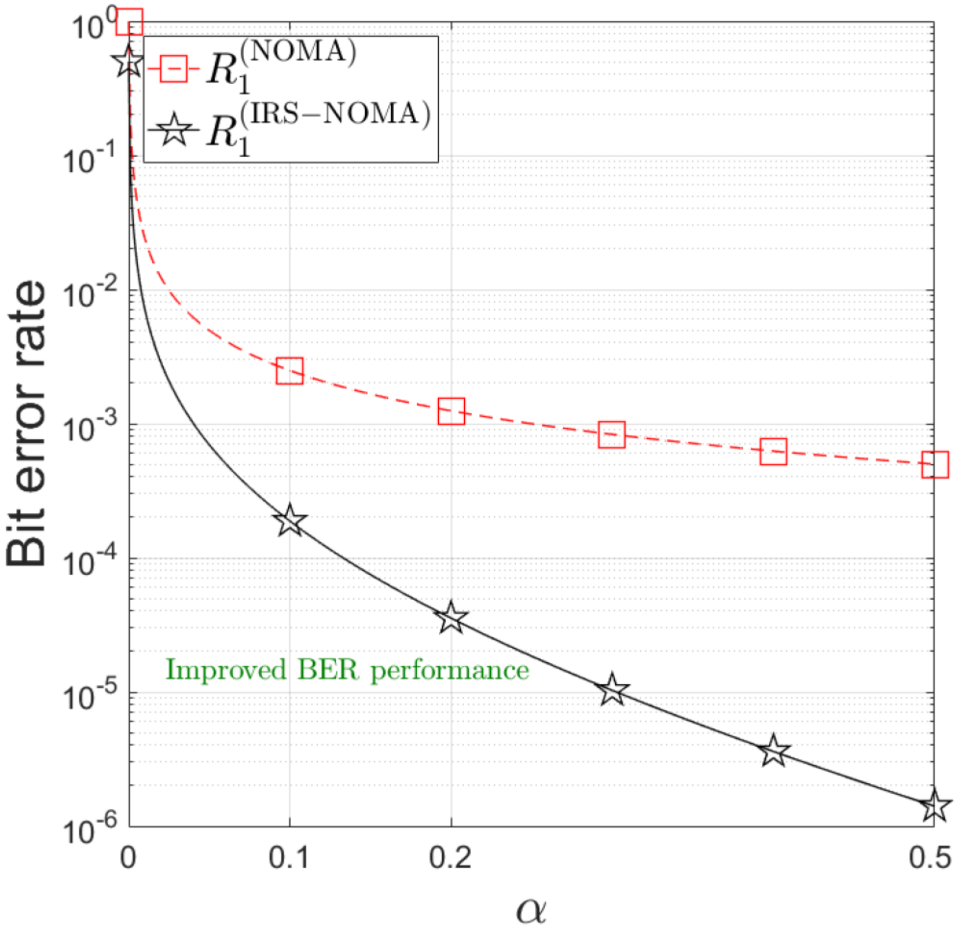

Figure 1. Comparison of BERs of IRS-NOMA and NOMA systems for strongest channel gain user, $(0 \# a \quad 0.5)$

The BER performance of the IRS-NOMA network improves over $0 \# a \quad 0.5$, compared to that of the NOMA system, as shown in Figure 2.

Second, to verify the BER improvement for reflecting elements *N*, we show the BERs versus *N*, with $a = 0.1$, in Figure 2.

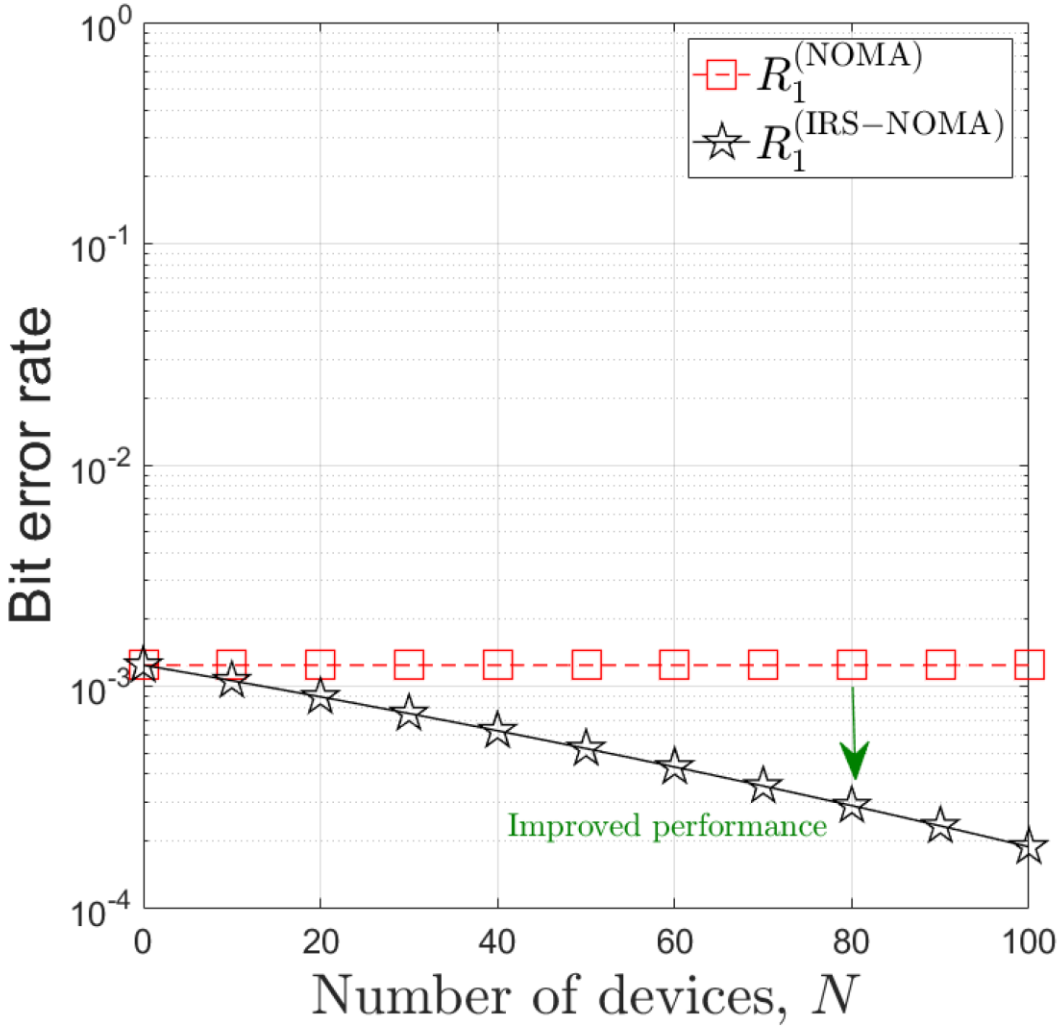

Figure 2. Comparison of BERs of IRS-NOMA and NOMA systems for strongest channel gain user, $(0 \# N \quad 100)$

We observe that the BER of IRS-NOMA improves greatly with the number of IRS elements *N*, with respect to IRS system, as shown in Figure 3,

5. Conclusion

In this paper, especially for the strongest channel gain user, we investigate BER of NOMA systems with IRS. First, we derive a BER expression in a closed-form of Q functions. Second, we investigate the BER performance improvement of IRS NOMA systems over NOMA systems versus the power allocation. Moreover, we analyze the BER performance improvement of IRS NOMA systems over NOMA systems versus the number of IRS devices.

As a result, IRS NOMA have been considered as promising technology to enhance spectral efficiency and the energy for wireless communication networks. Especially, IRS NOMA is able to reconfigure signal propagation environment to intelligently perform tuning IRS units for changing the phase or magnitude of the incident signal. Therefore, the reflected signal over IRS can be focused toward the desired user and removed out the others.

References

[1] L. Chettri and R. Bera, “A comprehensive survey on internet of things (IoT) toward 5G wireless systems,” *IEEE Internet of Things Journal*, vol. 7, no. 1, pp. 16–32, Jan. 2020. DOI: https://doi.org/10.1109/JIOT.2019.2948888

[2] Y. Saito, Y. Kishiyama, A. Benjebbour, T. Nakamura, A. Li, and K. Higuchi, “Non-orthogonal multiple access (NOMA) for cellular future radio access,” in *Proc. IEEE 77th Vehicular Technology Conference (VTC Spring)*, pp. 1–5, 2013. DOI: https://doi.org/10.1109/VTCSpring.2013.6692652

[3] Z. Ding, P. Fan, and H. V. Poor, “Impact of user pairing on 5G nonorthogonal multiple-access downlink transmissions,” *IEEE Trans. Veh. Technol.*, vol. 65, no. 8, pp. 6010–6023, Aug. 2016. DOI: https://doi.org/10.1109/TVT.2015.2480766

[4] Z. Ding, X. Lei, G. K. Karagiannidis, R. Schober, J. Yuan, and V. Bhargava, “A survey on non-orthogonal multiple access for 5G networks: Research challenges and future trends,” *IEEE J. Sel. Areas Commun.*, vol. 35, no. 10, pp. 2181–2195, Oct. 2017. DOI: https://doi.org/10.1109/JSAC.2017.2725519

[5] E. C. Strinati *et al*., “6G: The next frontier: From holographic messaging to artificial intelligence using subterahertz and visible light communication,” *IEEE Veh. Technol. Mag*., vol. 14, no. 3, pp. 42–50, Sept. 2019. DOI: https://doi.org/10.1109/MVT.2019.2921162

[6] Q. Wu and R. Zhang, “Intelligent reflecting surface enhanced wireless network via joint active and passive beamforming,” *IEEE Trans. Wireless Commun*., vol. 18, no. 11, pp. 5394–5409, Nov. 2019.

[7] C. Huang, A. Zappone, G. C. Alexandropoulos, M. Debbah, and C. Yuen, “Reconfigurable intelligent surfaces for energy efficiency in wireless communication,” *IEEE Trans. Wireless Commun*., vol. 18, no. 8, pp. 4157–4170, Aug. 2019.

[8] Q. Wu and R. Zhang, “Towards smart and reconfigurable environment: Intelligent reflecting surface aided wireless network,” *IEEE Commun. Mag*., vol. 58, no. 1, pp. 106–112, Jan. 2020.

[9] K. Chung, “Impacts of Non-Uniform Source on BER for SSC NOMA (Part II): Improved BER Performance Analysis,” *International Journal of Internet, Broadcasting and Communication (IJIBC)*, vol. 13, no. 4, pp. 48–54, Nov. 2021. DOI: http://dx.doi.org/10.7236/IJIBC.2021.13.4.48

[10] K. Chung, “BTS Based Improved BER for Stronger Channel User in Non-Uniform Source SSC NOMA,” *International Journal of Internet, Broadcasting and Communication (IJIBC)*, vol. 14, no. 1, pp. 78–84, Feb. 2022. DOI: http://dx.doi.org/10.7236/IJIBC.2022.14.1.78

[11] K. Chung, “Performance Analysis for Weaker Channel User in Non-Uniform Source SSC NOMA with Novel BTS,” *International Journal of Advanced Smart Convergence (IJASC)*, vol. 11, no. 1, pp. 36-41, Mar. 2022. DOI: http://dx.doi.org/10.7236/IJASC.2022.11.1.36