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Near-BER lossless Asymmetric 2PAM non-SIC NOMA with Low-Complexity and Low-Latency under User-Fairness

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Abstract

As the number of mobile devices has been increasing tremendously, system capacity should be enlarged in future next generation communication, such as the fifth-generation (5G) and beyond 5G (B5G) mobile networks. For such future networks, non-orthogonal multiple access (NOMA) has been considered as promising multiple access technology. In this paper, to reduce both latency and complexity in existing NOMA, we propose non-successive interference cancellation (SIC) NOMA with asymmetric binary pulse amplitude modulation (2PAM), nearly without bit-error rate (BER) loss.

First, we derive the closed form of BER expressions for non-SIC NOMA with asymmetric 2PAM, especially under Rayleigh fading channels. Then, it is shown that the BER performance of the stronger channel user who is supposed to perform SIC in conventional NOMA can be nearly achieved by the proposed non-SIC NOMA with asymmetric 2PAM, especially without SIC. Furthermore, we also show that the BER performance of the weaker channel user in conventional NOMA can be more closely achieved by the proposed non-SIC NOMA with asymmetric 2PAM. These BERs are shown to be achieved over the part of the power allocation range, which is consistent with the NOMA principle of user fairness. As a result, the non-SIC NOMA scheme with asymmetric 2PAM could be considered as a promising NOMA scheme toward next generation communication.

Keywords: *NOMA, B5G, User-fairness, Superposition coding, Successive interference cancellation, Power allocation.*

1. Introduction

From the fourth-generation (4G) communication [1, 2], toward the fifth-generation (5G) and beyond 5G (B5G) communication, non-orthogonal multiple access (NOMA) [3-5] has been playing a significant role, even to the sixth-generation (6G) communication [6]. However, successive interference cancellation (SIC) is decoding complexity and latency in NOMA receivers, especially such as small mobile devices [7, 8]. Thus, to reduce such latency and complexity, non-SIC NOMA has been studied in discrete-input lattice-based NOMA [9-12]. Impacts of correlation on superposition coding were considered in [13], and channel estimation errors were studied in NOMA [14]. Unipodal binary pulse amplitude modulation (2PAM) NOMA without SIC was proposed in [15]. Also, the non-SIC NOMA schemes were investigated for correlated information sources [16].

In this paper, we propose the non-SIC decoding scheme for asymmetric 2PAM NOMA, to reduce latency

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and complexity, especially near-bit-error rate (BER) lossless. First, we derive the closed-form expression for the non-SIC decoding for the stronger channel user, who is supposed to perform SIC. Then, it is shown that under Rayleigh fading channels, the BER performance of the stronger channel user in conventional NOMA is nearly achieved by the proposed non-SIC NOMA with asymmetric 2PAM. Furthermore, we also show that the BER performance of the weaker channel user in conventional NOMA is more closely achieved by the proposed non-SIC NOMA with asymmetric 2PAM. In addition, the power allocation range to be achieved is shown to be consistent with that of the NOMA principle of user-fairness.

The remainder of this paper is organized as follows. In Section 2, the system and channel model are described. The review of the related previous works is presented in Section 3. The BERs for asymmetric 2PAM non-SIC NOMA are derived in Section 4. The numerical results are presented and discussed in Section 5. Finally, the conclusions are presented in Section 6.

The main contributions of this paper is summarized as follows:

- We propose the non-SIC decoding scheme for asymmetric 2PAM NOMA.
- Under Rayleigh fading channels, we derive the analytical expressions of BERs for non-SIC asymmetric 2PAM NOMA.
- It is shown under Rayleigh fading channels that the BER performance of the stronger channel user in conventional NOMA is nearly achieved by the proposed non-SIC NOMA with asymmetric 2PAM.
- Furthermore, we also show that under Rayleigh fading channels, the BER performance of the weaker channel user in conventional NOMA can be more closely achieved by the proposed non-SIC NOMA with asymmetric 2PAM.
- In addition, the power allocation range to be achieved is shown to be consistent with that of the NOMA principle of user-fairness.

2. System and Channel Model

In block fading channels, the complex channel coefficient between the *m*th user and the base station is denoted by $h_m \sim \mathcal{CN}\left(0,\Sigma_m\right)$, $m=1,2$, which is Rayleigh faded with $\Sigma_1 > \Sigma_2$. The base station will transmit the superimposed signal $x=\sum_{m=1}^{M}\sqrt{\alpha_m P_A}s_m$, where s_m is the message for the *m*th user with unit power, α_m is the power allocation coefficient (we use β_m for asymmetric 2PAM NOMA), with $\sum_{m=1}^{M}\alpha_m=1$, $M=2$, P is an average total transmitted power at the base station, and P_A is an average total allocated power. The observation at the *m*th user is given by

$$r_m = \left|h_m\right| x + n_m, \tag{1}$$

where $n_m \sim \mathcal{N}\left(0,N_0/2\right)$ is additive white Gaussian noise (AWGN). It should be noted that all the receivers in this study are equipped with one single antenna. In this letter we assume that the standard 2PAM, $s_2 \in \{+1,-1\}$, and the asymmetric 2PAM $s_1 \in \{\pm\sqrt{2-v},\pm\sqrt{v}\}$, are used, for the weaker and stronger channel users, respectively, where v is the asymmetric factor, $0 \leq v \leq 1$. Remark that in the conventional NOMA, the standard 2PAM, $s_1, s_2 \in \{+1, -1\}$, are used for both users. It is assumed that for the given information bits $b_1, b_2 \in \{0,1\}$, the bit-to-symbol mapping of the standard 2PAM SIC NOMA with $v=1$ is given by

$$\begin{cases} s_1(b_1=0)=+1 \\ s_1(b_1=1)\ =-1 \end{cases} \quad \begin{cases} s_2(b_2=0)=+1 \\ s_2(b_2=1)\ =-1 \end{cases}, \tag{2}$$

whereas the bit-to-symbol mapping of the asymmetric 2PAM with $v=0$ is given by

$$\begin{cases} s_1(b_1=0\,|\,b_2=0)=+\sqrt{2-v} \\ s_1(b_1=1\,|\,b_2=0)\ =-\sqrt{v} \end{cases}, \quad \begin{cases} s_2(b_2=0)=+1 \\ s_2(b_2=1)\ =-1 \end{cases}, \quad \begin{cases} s_1(b_1=0\,|\,b_2=1)=-\sqrt{2-v} \\ s_1(b_1=1\,|\,b_2=1)\ =+\sqrt{v}. \end{cases} \tag{3}$$

Remark that although we only consider the asymmetric 2PAM with $v=0$ in the rest of this paper, we keep the notation v for $v=0$, to clarify the derivation. For the average total transmitted power P at the base station, P_A is given by

$$P_A = \frac{P}{1+2\dfrac{\sqrt{1-v}-\sqrt{v}}{2}\sqrt{\alpha}\sqrt{(1-\alpha)}}. \tag{4}$$

In the rest of this paper, we mainly consider the power allocation range $0 \leq \alpha \leq 0.5$ for user-fairness.

3. Review of Related Previous Works

In this section, we summarize BERs of both users for the standard 2PAM SIC NOMA. The perfect SIC BER performance of user-1 in the standard 2PAM SIC NOMA is given by

$$P_{1|(\mathrm{SIC})}^{(\text{standard 2PAM SIC NOMA})} = F\left(\frac{\Sigma_1 P\alpha}{N_0}\right), \tag{5}$$

where $\Sigma_1 = \mathbb{E}\left[|h_1|^2\right]$, and for simplicity of Rayleigh fading BER performance, we use the notation:

$$F(\gamma_b) = \frac{1}{2}\left(1-\sqrt{\frac{\gamma_b}{1+\gamma_b}}\right). \tag{6}$$

And the BER performance of user-2 in the standard 2PAM SIC NOMA is given by

$$P_{2|\text{(non-SIC)}}^{\text{(standard 2PAM SIC NOMA)}} = \frac{1}{2}F\left(\frac{\Sigma_2 P\left(\sqrt{1-\alpha}-\sqrt{\alpha}\right)^2}{N_0}\right) + \frac{1}{2}F\left(\frac{\Sigma_2 P\left(\sqrt{1-\alpha}+\sqrt{\alpha}\right)^2}{N_0}\right). \tag{7}$$

On the other hand, BERs of both users for the asymmetric 2PAM SIC NOMA are expressed as

$$P_{1|\text{(SIC)}}^{\text{(asymmetric 2PAM SIC NOMA)}} = F\left(\frac{\Sigma_1 P_A\left(\frac{\sqrt{2-v}+\sqrt{v}}{2}\right)^2 \alpha}{N_0}\right), \tag{8}$$

and

$$P_{2|\text{(non-SIC)}}^{\text{(asymmetric 2PAM SIC NOMA)}} = \frac{1}{2}F\left(\frac{\Sigma_2 P\left(\sqrt{1-\alpha}+\sqrt{2-v}\sqrt{\alpha}\right)^2}{N_0}\right) + \frac{1}{2}F\left(\frac{\Sigma_2 P\left(\sqrt{1-\alpha}-\sqrt{v}\sqrt{\alpha}\right)^2}{N_0}\right). \tag{9}$$

4. Derivations of BERs for Asymmetric 2PAM non-SIC NOMA

In this section, we derive only $P_{1|\text{(non-SIC)}}^{\text{(asymmetric 2PAM non-SIC NOMA)}}$ in the asymmetric 2PAM non-SIC NOMA, because $P_{2|\text{(non-SIC)}}^{\text{(asymmetric 2PAM non-SIC NOMA)}} = P_{2|\text{(non-SIC)}}^{\text{(asymmetric 2PAM SIC NOMA)}}$. For this, the likelihood for the first user is expressed as

$$p_{R_1|B_1}(r_1 \mid b_1) = \frac{1}{2}\frac{1}{\sqrt{2\pi N_0/2}} e^{-\frac{\left(r_1-|h_1|\sqrt{P_A}\left(\sqrt{\alpha}s_1(b_1)+\sqrt{(1-\alpha)}s_2(b_2=0)\right)\right)^2}{2N_0/2}} + \frac{1}{2}\frac{1}{\sqrt{2\pi N_0/2}} e^{-\frac{\left(r_1-|h_1|\sqrt{P_A}\left(\sqrt{\alpha}s_1(b_1)+\sqrt{(1-\alpha)}s_2(b_2=1)\right)\right)^2}{2N_0/2}}. \tag{10}$$

We then perform the maximum likelihood (ML) detection: $\hat{b}_1 = \arg\max_{b_1\in\{0,1\}} p_{R_1|B_1}(r_1 \mid b_1)$. Here we solve the equal likelihood equation $p_{R_1|B_1}(r_1 \mid b_1=0) = p_{R_1|B_1}(r_1 \mid b_1=1)$, which have two approximate decision boundaries:

$$r_1 \simeq \pm|h_1|\sqrt{P_A}\left(\frac{\sqrt{2-v}-\sqrt{v}}{2}\sqrt{\alpha}+\sqrt{(1-\alpha)}\right). \tag{11}$$

Based on the afore-mentioned decision boundaries, in this study, we obtain the following decision regions:

$$\begin{cases} r_1 > +|h_1|\sqrt{P_A}\left(\frac{\sqrt{2-v}-\sqrt{v}}{2}\sqrt{\alpha}+\sqrt{(1-\alpha)}\right) \\ r_1 < -|h_1|\sqrt{P_A}\left(\frac{\sqrt{2-v}-\sqrt{v}}{2}\sqrt{\alpha}+\sqrt{(1-\alpha)}\right) \end{cases} \text{for } b_1=0, \quad \begin{cases} r_1 < +|h_1|\sqrt{P_A}\left(\frac{\sqrt{2-v}-\sqrt{v}}{2}\sqrt{\alpha}+\sqrt{(1-\alpha)}\right) \\ r_1 > -|h_1|\sqrt{P_A}\left(\frac{\sqrt{2-v}-\sqrt{v}}{2}\sqrt{\alpha}+\sqrt{(1-\alpha)}\right) \end{cases} \text{for } b_1=1. \quad (12)$$

Based on the decision regions, the conditional BER of user-1 in the asymmetric 2PAM non-SIC NOMA given the channel gain realization $|h_1|$ is given by

$$\begin{aligned} &P_{1||h_1|,(\text{non-SIC})}^{(\text{asymmetric 2PAM SIC NOMA})} = \\ &Q\left(\sqrt{\frac{|h_1|^2 P_A\left(\frac{\sqrt{2-v}+\sqrt{v}}{2}\right)^2\alpha}{N_0/2}}\right) - \frac{1}{2}Q\left(\sqrt{\frac{|h_1|^2 P_A\left(2\sqrt{1-\alpha}+2\left(\frac{\sqrt{2-v}-\sqrt{v}}{2}\right)\sqrt{\alpha}+\left(\frac{\sqrt{2-v}+\sqrt{v}}{2}\right)\sqrt{\alpha}\right)^2}{N_0/2}}\right) \\ &+\frac{1}{2}Q\left(\sqrt{\frac{|h_1|^2 P_A\left(2\sqrt{1-\alpha}+2\left(\frac{\sqrt{2-v}-\sqrt{v}}{2}\right)\sqrt{\alpha}-\left(\frac{\sqrt{2-v}+\sqrt{v}}{2}\right)\sqrt{\alpha}\right)^2}{N_0/2}}\right). \end{aligned} \quad (13)$$

where $Q(x)=\int_x^\infty e^{-\frac{z^2}{2}}/\sqrt{2\pi}\,dz$. Then we can use the well-known Rayleigh fading integration formula:

$$\int_0^\infty Q\left(\sqrt{2\gamma}\right)\frac{1}{\gamma_b}e^{-\frac{\gamma}{\gamma_b}}d\gamma = \frac{1}{2}\left(1-\sqrt{\frac{\gamma_b}{1+\gamma_b}}\right), \quad (14)$$

where the random variable (RV) γ is exponentially distributed with $\gamma_b = \mathbb{E}[\gamma]$. Then the average BER is expressed by

$$\begin{aligned} &P_{1|(\text{non-SIC})}^{(\text{asymmetric 2PAM SIC NOMA})} = \\ &F\left(\frac{\Sigma_1 P_A\left(\frac{\sqrt{2-v}+\sqrt{v}}{2}\right)^2\alpha}{N_0}\right) - \frac{1}{2}F\left(\frac{\Sigma_1 P_A\left(2\sqrt{1-\alpha}+2\left(\frac{\sqrt{2-v}-\sqrt{v}}{2}\right)\sqrt{\alpha}+\left(\frac{\sqrt{2-v}+\sqrt{v}}{2}\right)\sqrt{\alpha}\right)^2}{N_0}\right) \\ &+\frac{1}{2}F\left(\frac{\Sigma_1 P_A\left(2\sqrt{1-\alpha}+2\left(\frac{\sqrt{2-v}-\sqrt{v}}{2}\right)\sqrt{\alpha}-\left(\frac{\sqrt{2-v}+\sqrt{v}}{2}\right)\sqrt{\alpha}\right)^2}{N_0}\right). \end{aligned} \quad (15)$$

4. Numerical Results and Discussions

It is assumed that $\Sigma_1 = \mathbb{E}\left[|h_1|^2\right] = 1.8$ and $\Sigma_2 = \mathbb{E}\left[|h_2|^2\right] = 0.2$. We consider the average total transmitted signal power to noise power ratio (SNR) $P/N_0 = 40\,\text{dB}$. Before presenting the numerical results, we first calculate the power allocation range of the standard 2PAM SIC NOMA scheme to be near-achieved by the proposed asymmetric 2PAM non-SIC NOMA scheme. For this, we observe the dominant term $F\left(\Sigma_1 P_A\left(\left(\sqrt{2-v}+\sqrt{v}\right)/2\right)^2 \beta / N_0\right)$ of the BER expression $P_{1|\text{(non-SIC)}}^{\text{(asymmetric 2PAM SIC NOMA)}}$ in equation (15). Then by comparing $P_{1|\text{(SIC)}}^{\text{(standard 2PAM SIC NOMA)}}$ in equation (5) to the afore-mentioned dominant term, we have $P\alpha = P_A\left(\left(\sqrt{2-v}+\sqrt{v}\right)/2\right)^2 \beta.$ Using equation (4), we simplify further the above-mentioned equation and obtain

$$\alpha = \frac{1}{1+2\dfrac{\sqrt{1-v}-\sqrt{v}}{2}\sqrt{\beta}\sqrt{(1-\beta)}}\left(\frac{\sqrt{2-v}+\sqrt{v}}{2}\right)^2 \beta. \tag{16}$$

Then by using the above-mentioned equation, we calculate the power allocation range to be near-achieved by the proposed asymmetric 2PAM non-SIC NOMA in the following numerical results. In addition, because we derive the closed-form expressions for BERs, we do not simulate BERs, but present the numerical results, based on the derived expressions.

For the first user, the BERs of the asymmetric 2PAM non-SIC NOMA and the standard 2PAM NOMA with SIC are shown in Fig. 1.

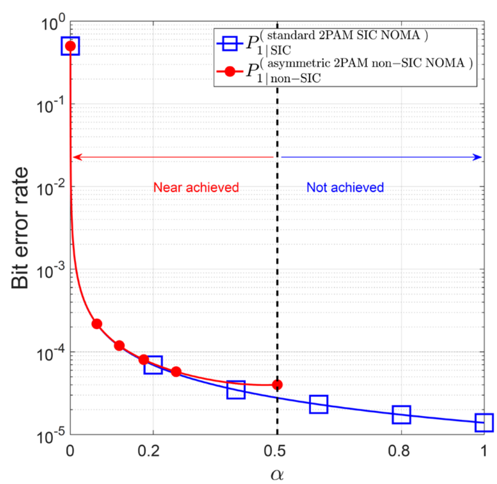

Figure 1. Comparison of BERs for standard 2PAM SIC NOMA and asymmetric 2PAM non-SIC NOMA for first user, under Rayleigh fading channels.

As shown in Fig. 1, It is observed that over the power allocation range by equation (16), the BER of the asymmetric 2PAM non-SIC NOMA is very close to that of the standard 2PAM SIC NOMA. It should be noted that this BER performance of the proposed asymmetric 2PAM non-SIC NOMA is achieved without SIC, which is decoding complexity and latency in existing standard 2PAM SIC NOMA. Notably, our target is to achieve BERs of SIC NOMA without SIC, i.e., non-SIC NOMA, not to outperform BERs of OMA.

Then, for the second user, the BERs of the asymmetric 2PAM non-SIC NOMA and the standard 2PAM SIC NOMA are shown in Fig. 2.

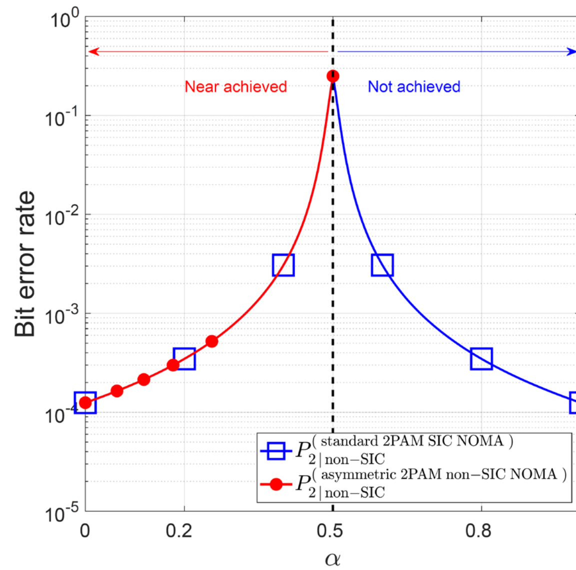

Figure 2. Comparison of BERs for standard 2PAM SIC NOMA and asymmetric 2PAM non-SIC NOMA for second user, under Rayleigh fading channels.

As shown in Fig. 2, for the second user, the BER of the asymmetric 2PAM non-SIC NOMA is almost the same as that of the standard 2PAM SIC NOMA, over the power allocation range $0 \le \alpha < 0.5$. It should be noted that user-fairness in the conventional NOMA scheme is established with $0 \le \alpha_1 \ll 0.5$. Typical values of $0 \le \alpha_1 < 0.25$ can be found in the NOMA literature.

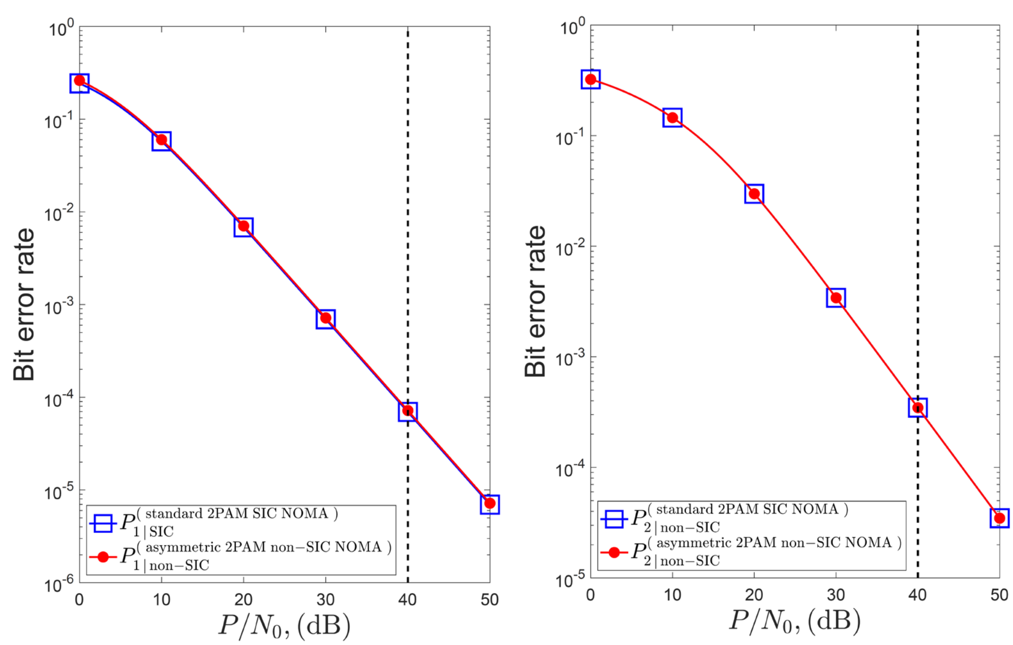

Figure 3. Comparison of BERs for standard 2PAM SIC NOMA and asymmetric 2PAM non-SIC NOMA for both users, under Rayleigh fading channels (a) first user (b) second user.

To analyze the BERs of both users further, we depict the BERs versus P/N_0 with the fixed power allocation, i.e., $\alpha = 0.2$, in Fig. 3. As shown in Fig. 3, we observe similar results to those shown in Fig. 1 and Fig. 2, i.e., the BER of the asymmetric 2PAM non-SIC NOMA is almost the same as that of the standard 2PAM SIC NOMA.

5. Conclusion

In this paper, we proposed the non-SIC NOMA scheme for asymmetric 2PAM, to reduce latency and complexity in existing SIC NOMA schemes.

First, we derived the closed form of BER expressions for non-SIC NOMA with asymmetric 2PAM, especially under Rayleigh fading channels. Then, it was shown by numerical results that the average fading channel BER performance of the stronger channel user's receiver which is intended to perform SIC in conventional NOMA is nearly achieved by the proposed non-SIC NOMA with asymmetric 2PAM, especially without SIC. Furthermore, we also showed that the average fading channel BER performance of the weaker channel user in conventional NOMA is more closely achieved by the proposed non-SIC NOMA with asymmetric 2PAM. These BERs are shown to be achieved over the part of the power allocation range, which is consistent with the NOMA principle of user fairness. As a result, the non-SIC NOMA scheme with asymmetric 2PAM could be considered as a promising NOMA scheme toward next generation communication.

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