

Analysis on Bit Error Rate Performance of Negatively Asymmetric Binary Pulse Amplitude Modulation Non-Orthogonal Multiple Access in 5G Mobile Networks

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Abstract

Recently, positively asymmetric binary pulse amplitude modulation (2PAM) has been proposed to improve the bit error rate (BER) performance of the weak channel gain user, with a tolerable BER loss of the strong channel gain user, for non-orthogonal multiple access (NOMA). However, the BER loss of the stronger channel gain user is inevitable in such positively asymmetric 2PAM NOMA scheme. Thus, we propose the negatively asymmetric 2PAM NOMA scheme. First, we derive closed-form expressions for the BERs of the negatively asymmetric 2PAM NOMA. Then, simulations demonstrate that for the stronger channel gain user, the BER of the proposed negatively asymmetric 2PAM NOMA improves, compared to that of the conventional positively asymmetric 2PAM NOMA. Moreover, we also show that for the weaker channel gain user, the BER of the proposed negatively asymmetric 2PAM NOMA is comparable to that of the conventional positively asymmetric 2PAM NOMA, over the power allocation range less than about 10 %.

Keywords: *Non-orthogonal multiple access, Beyond fifth-generation, User-fairness, Successive interference cancellation, Power allocation*

1. INTRODUCTION

The future sixth-generation (6G) mobile networks have been considered recently, as the mobile devices have demanded faster networks than the fifth-generation (5G) and beyond 5G (B5G) network [1, 2]. To this end, the spectral efficiency needs to be increased via non-orthogonal multiple access (NOMA) [3-5]. To reduce decoding latency, discrete-input lattice-based NOMA was studied without successive interference cancellation (SIC) [6-9]. Unipodal binary pulse amplitude modulation was investigated in NOMA [10]. Also, negatively-correlated information sources were considered in [11]. Asymmetric binary pulse amplitude modulation (2PAM) non-SIC NOMA was proposed [12], and achievable power allocation interval of asymmetric 2PAM was studied for rate-lossless NOMA [13]. Quadrature correlated superposition modulation was investigated [14]. Low-correlated superposition coding for NOMA was studied [15]. The inflated achievable sum rate was investigated for 3-user low-correlated NOMA [16], and the higher spectral efficiency was studied for 3-user cross correlated superposition coding (CSC) NOMA [17]. The non-SIC NOMA scheme has been considered for correlated information sources [18]. CSC has been investigated to implement NOMA without SIC, in contrast to conventional independent superposition coding [19]. In addition, the cross-correlated quadrature amplitude modulation scheme was studied for NOMA in [20].

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Recently, the positively asymmetric 2PAM NOMA has been investigated to improve the bit error rate (BER) performance of the weaker channel gain user, with a tolerable BER loss of the stronger channel gain user. Thus, this paper proposes the negatively asymmetric 2PAM NOMA, to improve the degraded BER performance of the stronger channel gain user.

First, we derive the closed-form expressions for the BERs of the negatively asymmetric 2PAM NOMA. Then, simulations demonstrate that for the stronger channel gain user, the BER of the proposed negatively asymmetric 2PAM NOMA improves, with respect to that of the conventional positively asymmetric 2PAM NOMA. Moreover, we also show that for the weaker channel gain user, the BER of the proposed negatively asymmetric 2PAM NOMA is comparable to that of the conventional positively asymmetric 2PAM NOMA, over the power allocation range less than about 10 %.

The remainder of this paper is organized as follows. In Section 2, the system and channel model are described. The BERs of the proposed negatively asymmetric 2PAM NOMA scheme are derived in Section 3. The simulation results are presented in Section 4. Finally, the conclusions are addressed in Section 5.

The main contributions of this paper are summarized as follows:

- We propose a negatively asymmetric 2PAM NOMA scheme, in contrast to a conventional positively asymmetric 2PAM NOMA scheme.
- Then, we derive the BERs of the proposed negatively asymmetric 2PAM NOMA scheme, under Rayleigh fading channels.
- It is shown that for the stronger channel gain user, the BER of the proposed negatively asymmetric 2PAM NOMA improves, compared to that of the conventional positively asymmetric 2PAM NOMA.
- Furthermore, we also show that for the weaker channel gain user, the BER of the proposed negatively asymmetric 2PAM NOMA is comparable to that of the conventional positively asymmetric 2PAM NOMA, over the power allocation range less than about 10 %.

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_1 and h_2 with $|h_1| > |h_2|$. The base station transmits the superimposed signal $x = \sqrt{P_A \alpha} s_1 + \sqrt{P_A (1 - \alpha)} s_2$, where s_m is the signal for the m th user with unit power, α is the power allocation coefficient. The observation at the m th user is given by

$$r_m = |h_m| x + n_m, \quad (1)$$

where $n_m \sim \mathcal{N}(0, N_0/2)$ is additive white Gaussian noise (AWGN). It is assumed that for the given information bits $b_1, b_2 \in \{0, 1\}$, the bit-to-symbol mapping of the proposed negatively asymmetric 2PAM with $0 \leq v < 1$ is given as

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

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

Given the average total transmitted power P at the base station, the average allocated total power P_A^- for the proposed negatively asymmetric 2PAM is calculated by

$$P_A^- = \frac{P}{1 + (\sqrt{v} - \sqrt{1-v})\sqrt{\alpha}\sqrt{(1-\alpha)}} \quad (3)$$

3. DERIVATION OF BERS FOR PROPOSED NEGATIVELY ASYMMETRIC 2PAM NOMA

In this section, we derive the BERs of the proposed negatively asymmetric 2PAM NOMA. For this, the likelihood for the first user is expressed as

$$p_{R_1|B_1}(r_1|b_1) = \frac{1}{2\sqrt{2\pi N_0/2}} e^{-\frac{\left(r_1 - |h_1|\sqrt{P_A^-}(\sqrt{\alpha}s_1(b_1) + \sqrt{(1-\alpha)}s_2(b_2=0))\right)^2}{2N_0/2}} + \frac{1}{2\sqrt{2\pi N_0/2}} e^{-\frac{\left(r_1 - |h_1|\sqrt{P_A^-}(\sqrt{\alpha}s_1(b_1) + \sqrt{(1-\alpha)}s_2(b_2=1))\right)^2}{2N_0/2}}. \quad (4)$$

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

$$r_1 \simeq \pm |h_1|\sqrt{P_A^-} \left(\frac{\sqrt{v} - \sqrt{2-v}}{2} \sqrt{\alpha} + \sqrt{(1-\alpha)} \right). \quad (5)$$

Based on these decision boundaries, we obtain the following decision regions:

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

$$\begin{cases} r_1 < +|h_1|\sqrt{P_A^-} \left(\frac{\sqrt{v} - \sqrt{2-v}}{2} \sqrt{\alpha} + \sqrt{(1-\alpha)} \right) \\ r_1 > -|h_1|\sqrt{P_A^-} \left(\frac{\sqrt{v} - \sqrt{2-v}}{2} \sqrt{\alpha} + \sqrt{(1-\alpha)} \right) \end{cases} \text{ for } b_1 = 1. \quad (6)$$

By these decision regions, the conditional BER of user-1 given the channel gain realization $|h_1|$ is expressed by

$$P_{1| |h_1|}^{(\text{asymmetric 2PAM NOMA; negatively})} \simeq Q \left(\sqrt{\frac{|h_1|^2 P_A^- \left(\frac{\sqrt{v} + \sqrt{2-v}}{2} \right)^2 \alpha}{N_0/2}} \right)$$

$$\begin{aligned}
& -\frac{1}{2}Q\left(\sqrt{\frac{|h_1|^2 P_A^- \left(2\sqrt{1-\alpha} + 2\left(\frac{\sqrt{v}-\sqrt{2-v}}{2}\right)\sqrt{\alpha} + \left(\frac{\sqrt{v}+\sqrt{2-v}}{2}\right)\sqrt{\alpha}\right)^2}{N_0/2}}\right) \\
& + \frac{1}{2}Q\left(\sqrt{\frac{|h_1|^2 P_A^- \left(2\sqrt{1-\alpha} + 2\left(\frac{\sqrt{v}-\sqrt{2-v}}{2}\right)\sqrt{\alpha} - \left(\frac{\sqrt{v}+\sqrt{2-v}}{2}\right)\sqrt{\alpha}\right)^2}{N_0/2}}\right). \quad (7)
\end{aligned}$$

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

$$\int_0^\infty Q(\sqrt{2\gamma}) \frac{1}{\gamma_b} e^{-\frac{\gamma}{\gamma_b}} d\gamma = \frac{1}{2} \left(1 - \sqrt{\frac{\gamma_b}{1+\gamma_b}}\right), \quad (8)$$

the average BER for the stronger channel gain user is expressed by

$$\begin{aligned}
P_1^{(\text{asymmetric 2PAM NOMA; negatively})} & \simeq \\
& F\left(\frac{\Sigma_1 P_A^- \left(\frac{\sqrt{v}+\sqrt{2-v}}{2}\right)^2 \alpha}{N_0}\right) \\
& - \frac{1}{2}F\left(\frac{\Sigma_1 P_A^- \left(2\sqrt{1-\alpha} + 2\left(\frac{\sqrt{v}-\sqrt{2-v}}{2}\right)\sqrt{\alpha} + \left(\frac{\sqrt{v}+\sqrt{2-v}}{2}\right)\sqrt{\alpha}\right)^2}{N_0}\right) \\
& + \frac{1}{2}F\left(\frac{\Sigma_1 P_A^- \left(2\sqrt{1-\alpha} + 2\left(\frac{\sqrt{v}-\sqrt{2-v}}{2}\right)\sqrt{\alpha} - \left(\frac{\sqrt{v}+\sqrt{2-v}}{2}\right)\sqrt{\alpha}\right)^2}{N_0}\right). \quad (9)
\end{aligned}$$

where

$$F(\gamma_b) = \frac{1}{2} \left(1 - \sqrt{\frac{\gamma_b}{1+\gamma_b}}\right). \quad (10)$$

Similarly, the average BER for the weaker channel gain user is expressed by

$$\begin{aligned}
P_2^{(\text{asymmetric 2PAM NOMA; negatively})} & \\
& = \frac{1}{2}F\left(\frac{\Sigma_2 P_A^- (\sqrt{1-\alpha} - \sqrt{2-v}\sqrt{\alpha})^2}{N_0}\right) \\
& + \frac{1}{2}F\left(\frac{\Sigma_2 P_A^- (\sqrt{1-\alpha} + \sqrt{v}\sqrt{\alpha})^2}{N_0}\right). \quad (11)
\end{aligned}$$

4. NUMERICAL RESULTS AND DISCUSSIONS

It is assumed that $\Sigma_1 = \mathbb{E}[|h_1|^2] = 1.8$ and $\Sigma_2 = \mathbb{E}[|h_2|^2] = 0.2$. We consider the average total transmitted signal power to noise power ratio (SNR) $P/N_0 = 40$ dB,

First, we depict the BERs of the first user, both for the proposed negatively asymmetric 2PAM with $v = 0$

and the existing positively asymmetric 2PAM with $v = 0$, in Fig. 1, to compare the BER of the proposed negatively asymmetric 2PAM to that of the existing positively asymmetric 2PAM. As shown in Fig. 1, we observe that over the power allocation range of $0 \leq \alpha \leq 0.2$, the BER of the proposed negatively asymmetric 2PAM NOMA improves largely, compared with that of the existing positively asymmetric 2PAM NOMA. Note that this BER improvement of the proposed negatively asymmetric 2PAM NOMA can be obtained by the increased average total allocated power, owing to the proposed negative asymmetry of 2PAM.

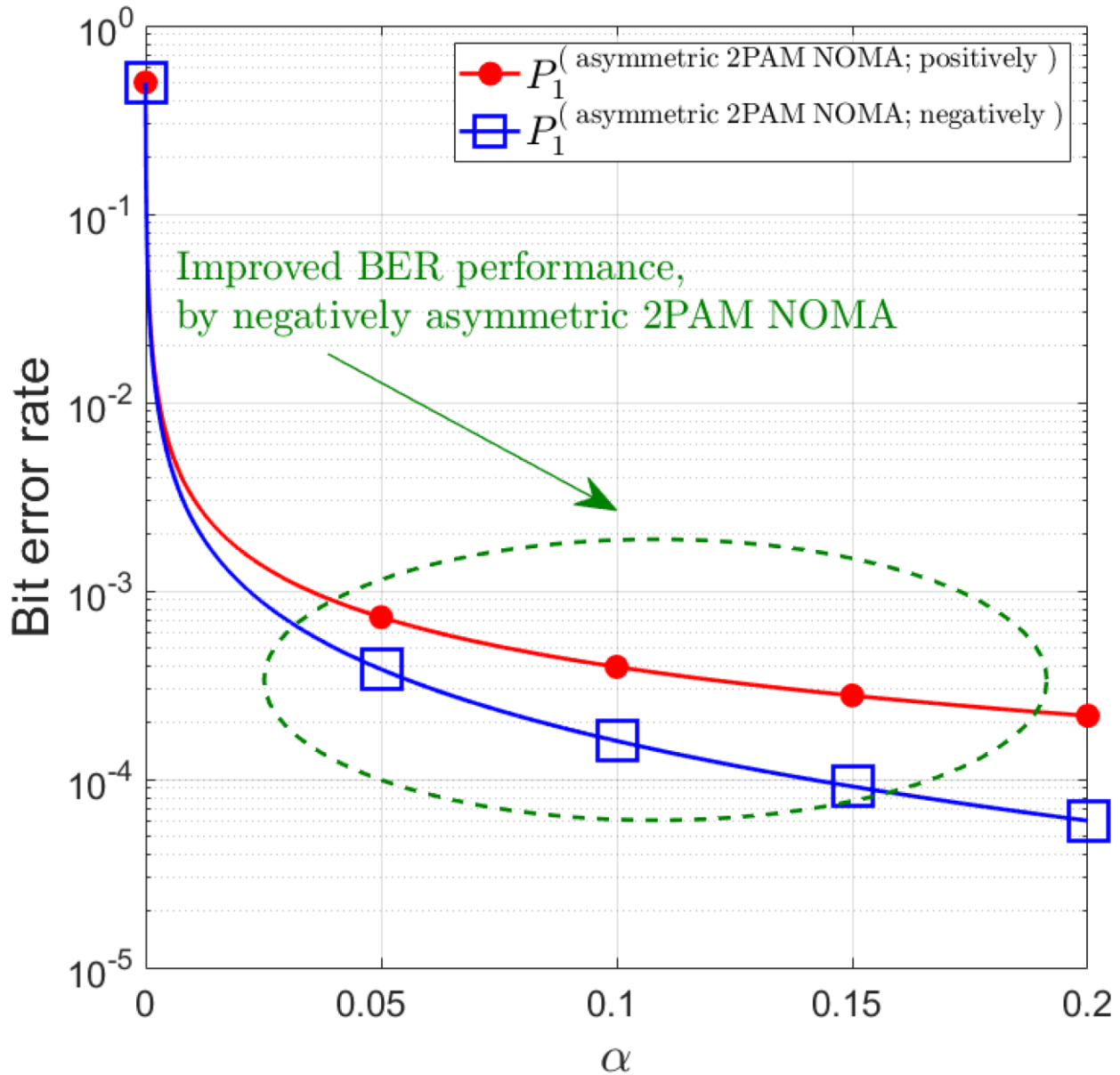


Figure 1. Comparison of BERs of proposed negatively asymmetric 2PAM and existing positively asymmetric 2PAM, for first user, under Rayleigh fading channels

Then, for the weaker channel gain's user, the BERs of the proposed negatively asymmetric 2PAM and the existing positively asymmetric 2PAM are depicted in Fig. 2, to compare the BERs of both two systems. As shown in Fig. 2, over the power allocation range of $0 \leq \alpha \leq 0.1$, the BER of the proposed negatively

asymmetric 2PAM NOMA is comparable with that of the existing positively asymmetric 2PAM NOMA, whereas over the power allocation range of $0.1 \leq \alpha \leq 0.2$, it is observed that the BER of the proposed negatively asymmetric 2PAM NOMA is slightly worse than that of the existing positively asymmetric 2PAM NOMA. Note that the BER degradation of the proposed negatively asymmetric 2PAM NOMA is due to the negativity of the asymmetric 2PAM NOMA scheme.

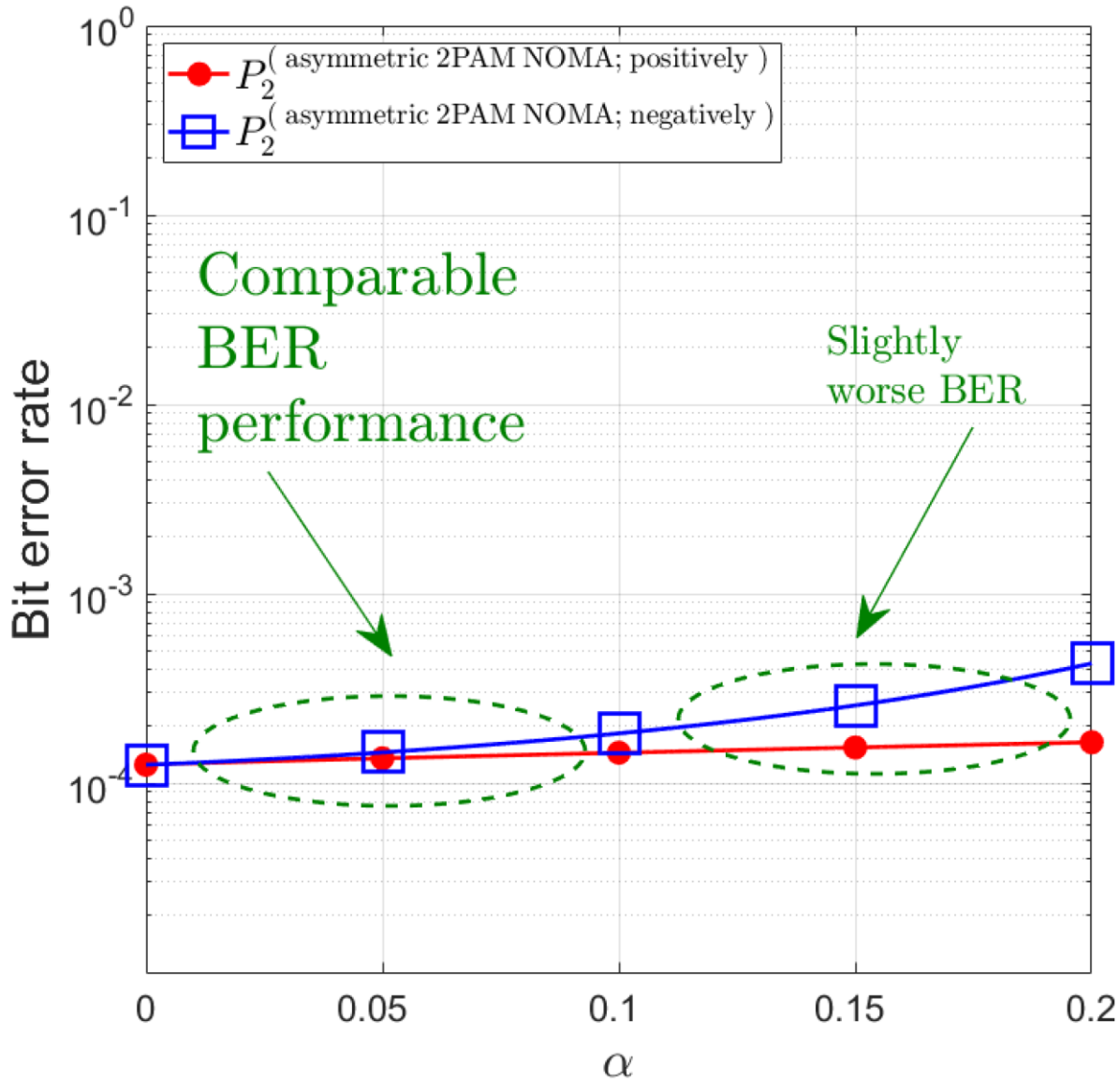


Figure 2. Comparison of BERs of proposed negatively asymmetric 2PAM and existing positively asymmetric 2PAM, for second user, under Rayleigh fading channels

5. CONCLUSION

To improve the degraded BER performance of the stronger channel gain user in the positively asymmetric 2PAM NOMA, in this paper, we proposed a negatively asymmetric 2PAM NOMA scheme. First, we derived the closed-form expressions for the BERs of the negatively asymmetric 2PAM NOMA. Then, simulations demonstrated that for the stronger channel gain user, the BER of the proposed negatively asymmetric 2PAM

NOMA improves, compared to that of the conventional positively asymmetric 2PAM NOMA. Moreover, we also showed that for the weaker channel gain user, the BER of the proposed negatively asymmetric 2PAM NOMA is comparable to that of the conventional positively asymmetric 2PAM NOMA, over the power allocation range less than about 10 %. As a result, the proposed negatively asymmetric 2PAM scheme could be a promising NOMA scheme in 5G and future generation communications, with the improved BER performance of the stronger channel gain user.

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