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Correlated Superposition Coding for 3-User NOMA

Kyuhyuk Chung◆

ABSTRACT

In this letter, the authors propose the correlated superposition coding (SC) for 3-user non-orthogonal multiple access (NOMA). It is shown that the proposed SC not only achieves the near-perfect successive interference cancellation (SIC) bit error-rate (BER) performance, but also mitigates the performance degradation in the standard 3-user NOMA. In result, the correlated SC could be a promising SC for NOMA.

Key Words : NOMA, superposition coding, SIC, power allocation, correlation coefficient.

Ⅰ. Introduction

As a promising new radio (NR) mobile access technology, non-orthogonal multiple access (NOMA) has gained tremendous attention in the fifth generation (5G) mobile communication [1-6]. In NOMA, successive interference cancellation (SIC) is performed at the stronger channel users, to remove the inter-user interference (IUI) due to superposition coding (SC). We present the correlated SC, for the conventional 3-user binary pulse amplitude modulation (2PAM) NOMA.

- Our contributions: 1. The proposed scheme achieves the near-perfect SIC bit error-rate (BER) performance for the stronger channel users. 2. We mitigates the performance degradation for the weaker channel users in the standard 2PAM NOMA.

Ⅱ. System and Channel Model

Assume that the constant total transmitted power is *P*, and the power of the user-1 signal s_1, the user-2 signal s_2, and the user-3 signal s_3 is normalized as $\mathbb{E}\left[|s_1|^2\right]=\mathbb{E}\left[|s_2|^2\right]=\mathbb{E}\left[|s_3|^2\right]=1$, with the correlation coefficients $\rho_{12}=\mathbb{E}\left[s_1 s_2^*\right]$, $\rho_{13}=\mathbb{E}\left[s_1 s_3^*\right]$, and $\rho_{23}=\mathbb{E}\left[s_2 s_3^*\right]$. The power allocation factors are α and β with $0\le\alpha,\beta,\alpha+\beta\le 1$. Then the superimposed signal is expressed by

$$x=\sqrt{\alpha P_A}s_1+\sqrt{\beta P_A}s_2+\sqrt{(1-\alpha-\beta)P_A}s_3 \quad (1)$$

where the total allocated power P_A is given by

$$\begin{aligned}\frac{P}{P_A}&=1+2\,\mathrm{Re}\{\rho_{12}\}\sqrt{\alpha}\sqrt{\beta}+2\,\mathrm{Re}\{\rho_{13}\}\sqrt{\alpha}\sqrt{1-\alpha-\beta}\\&+2\,\mathrm{Re}\{\rho_{23}\}\sqrt{\beta}\sqrt{1-\alpha-\beta}.\end{aligned} \quad (2)$$

Before the SIC is performed on the user-1 and user-2 with the better channel conditions, the received signals of the user-1, user-2, and user-3 are represented as, for i=1,2,3

$$\begin{aligned}r_i&=\\&|h_i|\sqrt{\alpha P_A}s_1+|h_i|\sqrt{\beta P_A}s_2+|h_i|\sqrt{(1-\alpha-\beta)P_A}s_3+n_i\end{aligned} \quad (3)$$

where h_1, h_2, and h_3 are the channel gains, with $|h_1|>|h_2|>|h_3|$, n_1, n_2, and $n_3\sim\mathcal{N}(0,N_0/2)$ are additive white Gaussian noise (AWGN), and N_0 is one-sided power spectral density. The notation $\mathcal{N}(\mu,\Sigma)$ denotes the normal distribution with mean μ and variance Σ.

Ⅲ. Correlated Superposition Coding

First, we start the independent SC in the standard 2PAM NOMA, and then design the correlated SC. Let the bits for the user-1, user-2, and user-3 be

◆ First Author : (ORCID:0000-0001-5429-2254)Department of Software Science, Dankook University, khchung@dankook.ac.kr, 교수, 종신회원
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$m_1, m_2, m_3 \in \{0,1\}$, with

$$s_1, s_2, s_3 \in \{+1,-1\}. \tag{4}$$

Then the independently superimposed signal in the standard 2PAM NOMA can be represented as

$$\begin{aligned} & x_s(m_1, m_2, m_2) = \\ & (-1)^{m_1}\sqrt{\alpha P} + (-1)^{m_2}\sqrt{\beta P} + (-1)^{m_3}\sqrt{(1-\alpha-\beta)P}. \end{aligned} \tag{5}$$

Note that the order of the 8 superimposed signals changes, dependent on the power allocation.

Now, we design the user-2 and user-3 signal, in the power domain, dependent on the standard 2PAM user-1 signal. Thus, the correlated SC is represented by

$$\begin{aligned} & x_c(m_1, m_2, m_3) = \\ & (-1)^{m_1}\sqrt{\alpha P_A} + (-1)^{m_1} m_2 \sqrt{2\beta P_A} \\ & +(-1)^{m_1}(m_2 + (m_2 \oplus m_3))\sqrt{2(1-\alpha-\beta)P_A / 3}. \end{aligned} \tag{6}$$

The motivation of the correlated SC is as follows in detail. For the standard independent SC NOMA, for example, the amplitude of the independently superimposed signal is reduced

$$\begin{aligned} & x_s(m_1 = 0, m_2 = 1, m_3 = 1) \\ & = +\sqrt{\alpha P_A} - \sqrt{\beta P_A} - \sqrt{(1-\alpha-\beta)P_A}. \end{aligned} \tag{7}$$

Therefore, the correlated SC is designed for the amplitude not to be reduced

$$\begin{aligned} & x_c(m_1 = 0, m_2 = 1, m_3 = 1) \\ & = +\sqrt{\alpha P_A} + \sqrt{2\beta P_A} + \sqrt{2(1-\alpha-\beta)P_A / 3}. \end{aligned} \tag{8}$$

Thus, the SIC BER performance of the user-1 is not degraded by SC. In addition, in order to mitigate the severe performance degradation for the user-3, the bit-to-symbol mapping is carefully designed, for example,

$$\begin{aligned} & x_c(m_1 = 0, m_2 = 1, m_3 = 0) = +\sqrt{\alpha P_A} + \sqrt{2\beta P_A} + 2\sqrt{2(1-\alpha-\beta)P_A / 3} \\ & x_c(m_1 = 0, m_2 = 1, m_3 = 1) = +\sqrt{\alpha P_A} + \sqrt{2\beta P_A} + \sqrt{2(1-\alpha-\beta)P_A / 3} \\ & x_c(m_1 = 0, m_2 = 0, m_3 = 1) = +\sqrt{\alpha P_A} + 0 + \sqrt{2(1-\alpha-\beta)P_A / 3} \\ & x_c(m_1 = 0, m_2 = 0, m_3 = 0) = +\sqrt{\alpha P_A} + 0 + 0. \end{aligned} \tag{9}$$

Note that the $x_c(m_1 = 0, m_2 = 0, m_3 = 1)$ and $x_c(m_1 = 0, m_2 = 1, m_3 = 1)$ for the user-3 bit $m_3 = 1$ do not interfere each other, which prevents the severe performance degradation in the standard NOMA. And for the user-2, above two design rules are applied simultaneously.

Ⅳ. BER Derivation

The correlation coefficients of the correlated SC are calculated by

$$\begin{aligned} \rho_{12} &= \mathbb{E}\left[s_1 s_2^*\right] \\ &= \frac{1}{8}\left(1 \times \sqrt{2} + 1 \times \sqrt{2} + 0 + 0\right) \\ &+ \frac{1}{8}\left(0 + 0 + (-1) \times \left(-\sqrt{2}\right) + (-1) \times \left(-\sqrt{2}\right)\right) \\ &= \frac{1}{8}\left(4\sqrt{2}\right) \\ &= \frac{\sqrt{2}}{2} \\ &= \frac{1}{\sqrt{2}} \simeq 0.7071, \end{aligned} \tag{10}$$

$$\begin{aligned} \rho_{13} &= \mathbb{E}\left[s_1 s_3^*\right] \\ &= \frac{1}{8}\left(0 + 1 \times \sqrt{2/3} + 1 \times \sqrt{2/3} + 1 \times 2\sqrt{2/3}\right) \\ &+ \frac{1}{8}\left(0 + (-1) \times \left(-\sqrt{2/3}\right)\right) \\ &+ \frac{1}{8}\left((-1) \times \left(-\sqrt{2/3}\right) + (-1) \times \left(-2\sqrt{2/3}\right)\right) \\ &= \frac{1}{8}\left(8\sqrt{2/3}\right) \\ &= \sqrt{2/3} \simeq 0.8165, \end{aligned} \tag{11}$$

and

$$\begin{aligned} \rho_{23} &= \mathbb{E}\left[s_2 s_3^*\right] \\ &= \frac{1}{8}\left(0 + 0 + \sqrt{2} \times \sqrt{2/3} + \sqrt{2} \times 2\sqrt{2/3}\right) \\ &+ \frac{1}{8}\left(0 + 0 + \left(-\sqrt{2}\right) \times \left(-\sqrt{2/3}\right) + \left(-\sqrt{2}\right) \times \left(-2\sqrt{2/3}\right)\right) \\ &= \frac{1}{8}\left(6 \times 2 / \sqrt{3}\right) \\ &= \frac{1}{2}\sqrt{3} \simeq 0.8660. \end{aligned} \tag{12}$$

Consider Rayleigh fading channels with $\mathbb{E}\left[|h_1|^2\right] = \Sigma_1$, $\mathbb{E}\left[|h_2|^2\right] = \Sigma_2$, and $\mathbb{E}\left[|h_3|^2\right] = \Sigma_3$. For the simplification of Rayleigh fading BER performance, we define the notation as

$$F\left(\gamma_b\right) = \frac{1}{2}\left(1 - \sqrt{\frac{\gamma_b}{1+\gamma_b}}\right). \tag{13}$$

Now, we derive the optimal receiver. The likelihood for the user-1 is expressed as

$$p_{R_1|M_1}(r_1 \mid m_1) = \frac{1}{4}\frac{1}{\sqrt{2\pi N_0 / 2}}\sum_{m_2=0}^{1}\sum_{m_3=0}^{1} e^{-\frac{\left(r_1 - |h_1| x_c(m_1, m_2, m_3)\right)^2}{2N_0/2}}. \tag{14}$$

The optimum detection is made, based on the maximum likelihood (ML), as

$$\hat{m}_1 = \underset{m_1 \in \{0,1\}}{\arg\max}\, p_{R_1|M_1}(r_1 \mid m_1). \tag{15}$$

The one exact decision boundary is

$$r_1 = 0. \tag{16}$$

Then, the decision regions are given by

$$\begin{cases} m_1 = 0: & 0 < r_1 \\ m_1 = 1: & r_1 < 0. \end{cases} \tag{17}$$

Therefore, the BER performance for the user-1 is calculated by

$$P_e^{(1;\, correlated\ NOMA;\, ML;\, optimal)} = \frac{1}{4}\sum_{m_2=0}^{1}\sum_{m_3=0}^{1} F\left(\frac{P_A\left((m_2 + (m_2 \oplus m_3))\sqrt{2(1-\alpha-\beta)/3} + m_2\sqrt{2\beta} + \sqrt{\alpha}\right)^2 \Sigma_1}{N_0}\right). \tag{18}$$

Similarly, the likelihood for the user-2 is expressed as

$$p_{R_2|M_2}(r_2 \mid m_2) = \frac{1}{4}\frac{1}{\sqrt{2\pi N_0 / 2}}\sum_{m_1=0}^{1}\sum_{m_3=0}^{1} e^{-\frac{\left(r_1 - |h_1| x_c(m_1, m_2, m_3)\right)^2}{2N_0/2}}. \tag{19}$$

The two approximate decision boundaries are

$$r_2 = \pm|h_2|\sqrt{\alpha P_A} \pm \frac{|h_2|\sqrt{2\beta P_A}}{2} \pm |h_2|\sqrt{2(1-\alpha-\beta)P_A / 3}. \tag{20}$$

Then, the decision regions are given by

$$\begin{cases} m_2 = 0: & r_2 < +|h_2|\sqrt{\alpha P_A} + \frac{|h_2|\sqrt{2\beta P_A}}{2} + |h_2|\sqrt{2(1-\alpha-\beta)P_A / 3}, \\ & -|h_2|\sqrt{\alpha P_A} - \frac{|h_2|\sqrt{2\beta P_A}}{2} - |h_2|\sqrt{2(1-\alpha-\beta)P_A / 3} < r_2. \\ m_2 = 1: & r_2 > +|h_2|\sqrt{\alpha P_A} + \frac{|h_2|\sqrt{2\beta P_A}}{2} + |h_2|\sqrt{2(1-\alpha-\beta)P_A / 3}, \\ & r_2 < -|h_2|\sqrt{\alpha P_A} - \frac{|h_2|\sqrt{2\beta P_A}}{2} - |h_2|\sqrt{2(1-\alpha-\beta)P_A / 3}. \end{cases} \tag{21}$$

Therefore, the BER performance for the user-2 is calculated by

$$P_e^{(2;\, correlated\ NOMA;\, ML;\, optimal)} \simeq \frac{1}{2}F\left(\frac{P_A\left(\sqrt{\beta / 2}\right)^2 \Sigma_2}{N_0}\right). \tag{22}$$

Remark that there are two causes of the approximation; the initial cause is the decision boundary approximation, and the secondary cause is the dominant term approximation. The decision boundary approximation is tolerated by the following observation; the approximate decision boundary $r_2 = +|h_2|\sqrt{\alpha P_A} + \frac{|h_2|\sqrt{2\beta P_A}}{2} + |h_2|\sqrt{2(1-\alpha-\beta)P_A / 3}$ is obtained from the equation

$$p_{R_2|M_2}(r_2 \mid m_2 = 0) = p_{R_2|M_2}(r_2 \mid m_2 = 1) \tag{23}$$

which is given by

$$\begin{aligned} &\frac{1}{4}\frac{1}{\sqrt{2\pi N_0 / 2}} e^{-\frac{\left(r_1 - |h_1|\left(+\sqrt{\alpha P_A} + 0 + \sqrt{2(1-\alpha-\beta)P_A/3}\right)\right)^2}{2N_0/2}} \\ &+ \frac{1}{4}\frac{1}{\sqrt{2\pi N_0 / 2}} e^{-\frac{\left(r_1 - |h_1|\left(+\sqrt{\alpha P_A} + 0 + 0\right)\right)^2}{2N_0/2}} \\ &+ \frac{1}{4}\frac{1}{\sqrt{2\pi N_0 / 2}} e^{-\frac{\left(r_1 - |h_1|\left(-\sqrt{\alpha P_A} - 0 - 0\right)\right)^2}{2N_0/2}} \\ &+ \frac{1}{4}\frac{1}{\sqrt{2\pi N_0 / 2}} e^{-\frac{\left(r_1 - |h_1|\left(-\sqrt{\alpha P_A} - 0 - \sqrt{2(1-\alpha-\beta)P_A/3}\right)\right)^2}{2N_0/2}} \\ &= \\ &\frac{1}{4}\frac{1}{\sqrt{2\pi N_0 / 2}} e^{-\frac{\left(r_1 - |h_1|\left(+\sqrt{\alpha P_A} + \sqrt{2\beta P_A} + 2\sqrt{2(1-\alpha-\beta)P_A/3}\right)\right)^2}{2N_0/2}} \\ &+ \frac{1}{4}\frac{1}{\sqrt{2\pi N_0 / 2}} e^{-\frac{\left(r_1 - |h_1|\left(+\sqrt{\alpha P_A} + \sqrt{2\beta P_A} + \sqrt{2(1-\alpha-\beta)P_A/3}\right)\right)^2}{2N_0/2}} \\ &+ \frac{1}{4}\frac{1}{\sqrt{2\pi N_0 / 2}} e^{-\frac{\left(r_1 - |h_1|\left(-\sqrt{\alpha P_A} - \sqrt{2\beta P_A} - \sqrt{2(1-\alpha-\beta)P_A/3}\right)\right)^2}{2N_0/2}} \\ &+ \frac{1}{4}\frac{1}{\sqrt{2\pi N_0 / 2}} e^{-\frac{\left(r_1 - |h_1|\left(-\sqrt{\alpha P_A} - \sqrt{2\beta P_A} - 2\sqrt{2(1-\alpha-\beta)P_A/3}\right)\right)^2}{2N_0/2}}. \end{aligned} \tag{24}$$

Note that, at

$$r_2 = +|h_2|\sqrt{\alpha P_A} + \frac{|h_2|\sqrt{2\beta P_A}}{2} + |h_2|\sqrt{2(1-\alpha-\beta)P_A / 3},$$

$$\begin{aligned}
&\frac{1}{4}\frac{1}{\sqrt{2\pi N_0 / 2}} e^{-\frac{\left(r_1 - |h_1|\left(+\sqrt{\alpha P_A} + 0 + \sqrt{2(1-\alpha-\beta)P_A/3}\right)\right)^2}{2N_0/2}} \\
&+\frac{1}{4}\frac{1}{\sqrt{2\pi N_0 / 2}} e^{-\frac{\left(r_1 - |h_1|\left(+\sqrt{\alpha P_A} + 0 + 0\right)\right)^2}{2N_0/2}} \\
&= \\
&\frac{1}{4}\frac{1}{\sqrt{2\pi N_0 / 2}} e^{-\frac{\left(r_1 - |h_1|\left(+\sqrt{\alpha P_A} + \sqrt{2\beta P_A} + 2\sqrt{2(1-\alpha-\beta)P_A/3}\right)\right)^2}{2N_0/2}} \\
&+\frac{1}{4}\frac{1}{\sqrt{2\pi N_0 / 2}} e^{-\frac{\left(r_1 - |h_1|\left(+\sqrt{\alpha P_A} + \sqrt{2\beta P_A} + \sqrt{2(1-\alpha-\beta)P_A/3}\right)\right)^2}{2N_0/2}}.
\end{aligned} \tag{25}$$

And the four terms approximated to zero are so small, that we could not obtain the numerical values, for $P / N_0 = 40\,\text{dB}$ in our case. Instead, for $P / N_0 = 20\,\text{dB}{=}100$, we give the numerical values, at $r_2 = +|h_2|\sqrt{\alpha P_A} + \frac{|h_2|\sqrt{2\beta P_A}}{2} + |h_2|\sqrt{2(1-\alpha-\beta)P_A / 3}$, with $\alpha = 0.1$, $\beta = 0.2$, and $|h_2| = 1.0$, as follows

$$\begin{aligned}
&+\frac{1}{4}\frac{1}{\sqrt{2\pi N_0 / 2}} e^{-\frac{\left(r_1 - |h_1|\left(-\sqrt{\alpha P_A} - 0 - 0\right)\right)^2}{2N_0/2}} \simeq 1.9049 \times 10^{-52}, \\
&+\frac{1}{4}\frac{1}{\sqrt{2\pi N_0 / 2}} e^{-\frac{\left(r_1 - |h_1|\left(-\sqrt{\alpha P_A} - 0 - \sqrt{2(1-\alpha-\beta)P_A/3}\right)\right)^2}{2N_0/2}} \simeq 8.4329 \times 10^{-104}, \\
&+\frac{1}{4}\frac{1}{\sqrt{2\pi N_0 / 2}} e^{-\frac{\left(r_1 - |h_1|\left(-\sqrt{\alpha P_A} - \sqrt{2\beta P_A} - \sqrt{2(1-\alpha-\beta)P_A/3}\right)\right)^2}{2N_0/2}} \simeq 3.4147 \times 10^{-167}, \\
&+\frac{1}{4}\frac{1}{\sqrt{2\pi N_0 / 2}} e^{-\frac{\left(r_1 - |h_1|\left(-\sqrt{\alpha P_A} - \sqrt{2\beta P_A} - 2\sqrt{2(1-\alpha-\beta)P_A/3}\right)\right)^2}{2N_0/2}} \simeq 8.7810 \times 10^{-253}.
\end{aligned} \tag{26}$$

Therefore, the decision boundary approximation is tolerable. Next, we consider the dominant term approximation. Based on the approximated decision boundaries, the exact $P_e^{(2;\, correlated\ NOMA;\, ML;\, optimal)}$ is given by

$$\begin{aligned}
&P_e^{(2;\, correlated\ NOMA;\, ML;\, optimal)} \\
&= \frac{1}{4} f\left(0;\frac{1}{2};1\right) - \frac{1}{4} f\left(2;\frac{3}{2};3\right) \\
&+\frac{1}{4} f\left(0;\frac{1}{2};0\right) - \frac{1}{4} f\left(2;\frac{3}{2};2\right) \\
&+\frac{1}{4} f\left(0;\frac{1}{2};0\right) + \frac{1}{4} f\left(2;\frac{1}{2};2\right) \\
&+\frac{1}{4} f\left(0;\frac{1}{2};1\right) + \frac{1}{4} f\left(2;\frac{1}{2};1\right)
\end{aligned} \tag{27}$$

where

$$\begin{aligned}
&f(A;B;C) \\
&= F\left(\frac{P_A\left(A\sqrt{\alpha P_A} + B\sqrt{2\beta P_A} + C\sqrt{2(1-\alpha-\beta)P_A / 3}\right)^2 \Sigma_2}{N_0}\right).
\end{aligned} \tag{28}$$

For $P / N_0 = 40\,\text{dB}$ in our case, with $\alpha = 0.1$, $\beta = 0.2$, and $\Sigma_2 = (1.0)^2$, we give the numerical values, as follows

$$\begin{aligned}
&\frac{1}{4} f\left(0;\frac{1}{2};0\right) \simeq 1.4226 \times 10^{-4} \\
&\frac{1}{4} f\left(0;\frac{1}{2};1\right) \simeq 1.4267 \times 10^{-5} \\
&\frac{1}{4} f\left(2;\frac{1}{2};1\right) \simeq 5.3514 \times 10^{-6} \\
&\frac{1}{4} f\left(2;\frac{1}{2};2\right) \simeq 2.6591 \times 10^{-6} \\
&\frac{1}{4} f\left(2;\frac{3}{2};2\right) \simeq 1.6404 \times 10^{-6} \\
&\frac{1}{4} f\left(2;\frac{3}{2};3\right) \simeq 1.0812 \times 10^{-6}.
\end{aligned} \tag{29}$$

Based on the above observations, we approximate the BER as the two dominant terms, in the equation (22).

Similarly, the likelihood for the user-3 is expressed as

$$p_{R_3|M_3}(r_3 \mid m_3) = \frac{1}{4}\frac{1}{\sqrt{2\pi N_0 / 2}} \sum_{m_1=0}^{1} \sum_{m_2=0}^{1} e^{-\frac{\left(r_1 - |h_1| x_c(m_1,m_2,m_3)\right)^2}{2N_0/2}}. \tag{30}$$

The four approximate decision boundaries are

$$\begin{aligned}
r_3 &= \pm|h_3|\sqrt{\alpha P_A} \pm 0 \pm \frac{1}{2}|h_3|\sqrt{2(1-\alpha-\beta)P_A / 3}, \\
&\pm|h_3|\sqrt{\alpha P_A} \pm |h_3|\sqrt{2\beta P_A} \pm \frac{3}{2}|h_3|\sqrt{2(1-\alpha-\beta)P_A / 3}.
\end{aligned} \tag{31}$$

Therefore, the BER performance for the user-3 is calculated by

$$\begin{aligned}
&P_e^{(3;\, correlated\ NOMA;\, ML;\, optimal)} \\
&\simeq F\left(\frac{P_A\left(\sqrt{(1-\alpha-\beta) / 3 / 2}\right)^2 \Sigma_3}{N_0}\right).
\end{aligned} \tag{32}$$

Ⅴ. Results and Discussions

Assume $\Sigma_1 = (1.1)^2$, $\Sigma_2 = (1.0)^2$ and $\Sigma_3 = (0.9)^2$, and the constant total transmitted signal power to noise power ratio $P / N_0 = 40\text{ dB}$, where Σ_1, Σ_2, and Σ_3 are chosen for the average standard deviation to be one, and P / N_0 is selected for the BER performance to be $10^{-4} < P_e < 10^{-3}$.

In the standard NOMA, SIC is performed on the user-1 and user-2. Then the received signal is given by, if the perfect SIC is assumed,

$$\begin{aligned} y_1 &= |h_1|\sqrt{\alpha P}s_1 + n_1 \\ y_2 &= |h_2|\sqrt{\beta P}s_2 + \left(|h_2|\sqrt{\alpha P}s_1 + n_2\right). \end{aligned} \tag{33}$$

Then the ideal perfect SIC BER performance of the user-1 is simply the BER performance of the 2PAM modulation

$$P_e^{(1;\, standard\ NOMA;\, perfect\ SIC;\, ideal)} = F\left(\frac{\alpha P \Sigma_1}{N_0}\right). \tag{34}$$

The ideal perfect SIC plus maximum likelihood (ML) BER performance $P_e^{(2;\, standard\ NOMA;\, perfect\ SIC\ ideal\, +\, ML\ optimal)}$ of the user-2 is given in [7] and the optimal ML BER performance $P_e^{(3;\, standard\ NOMA;\, ML;\, optimal)}$ of the user-3 is calculated with the conditional BER performance in [8].

As shown in Fig. 1, the correlated SC NOMA achieves the near-perfect SIC BER performance of the standard NOMA, for the user-1. For the user-2, as shown in Fig. 2, the correlated SC NOMA achieves the near-perfect SIC BER and mitigates the performance degradation of the standard NOMA. As shown in Fig. 3, for the user-3, the correlated SC NOMA mitigates the severe performance degradation of the standard NOMA.

As shown in Fig .2, the severe BER performance degradation of the user-2 occurs the following power allocation coordinate (α, β),

$$\alpha = \beta,\ \ 0 \le \alpha + \beta \le 1. \tag{35}$$

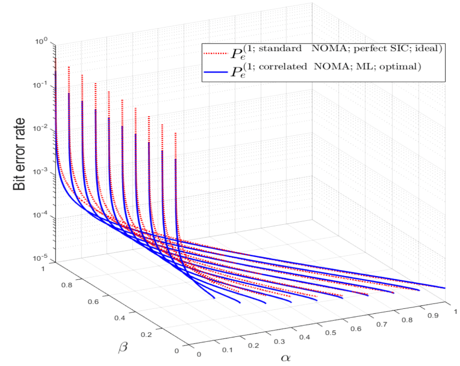

Fig. 1. Comparison of BERs for standard NOMA and correlated NOMA for user-1.

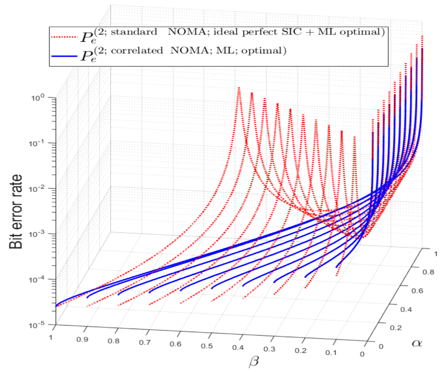

Fig. 2. Comparison of BERs for standard NOMA and correlated NOMA for user-2.

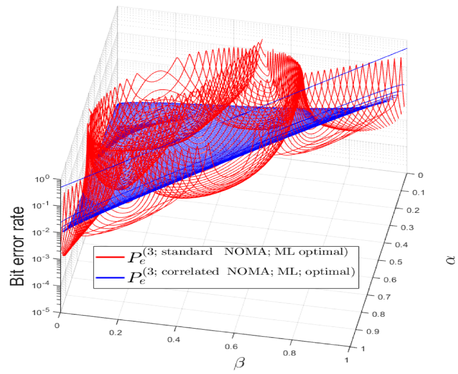

Fig. 3. Comparison of BERs for standard NOMA and correlated NOMA for user-3.

Table 1. Quantitative BER Performance Mitigation

(α, β)	$(0.1, 0.1)$	$(0.3, 0.3)$	$(0.5, 0.5)$
$P_e^{(2;\ standard\ NOMA;\ perfect\ SIC\ ideal\ +\ ML\ optimal)}$	0.25	0.25	0.25
	$\Downarrow$	$\Downarrow$	$\Downarrow$
$P_e^{(2;\ correlated\ NOMA;\ ML;\ optimal)}$	5.2166×10^{-4}	2.1555×10^{-4}	8.5311×10^{-5}

Therefore, in Fig. 2, the mitigation of the severe BER performance degradation of the user-2 is dependent on the power allocation coordinate (α, β), which is tabulated in Table 1, quantitatively.

In addition, for the comparison under the various channel environments, we depict the BER performances with $\Sigma_1 = (2.1)^2, \Sigma_2 = (0.8)^2$ and $\Sigma_3 = (0.1)^2$. As shown in Fig. 4, Fig. 5, and Fig. 6, we observe the similar performances.

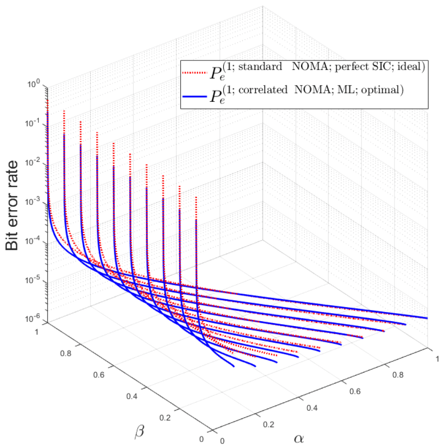

Fig. 4. Comparison of BERs for standard NOMA and correlated NOMA for user-1.

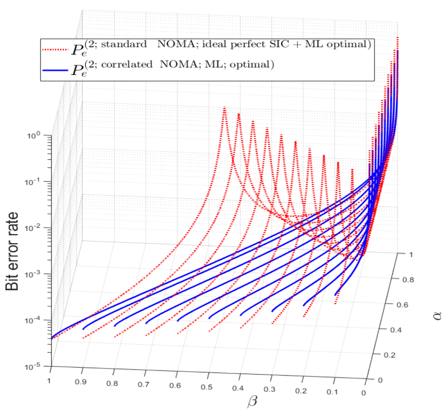

Fig. 5. Comparison of BERs for standard NOMA and correlated NOMA for user-2.

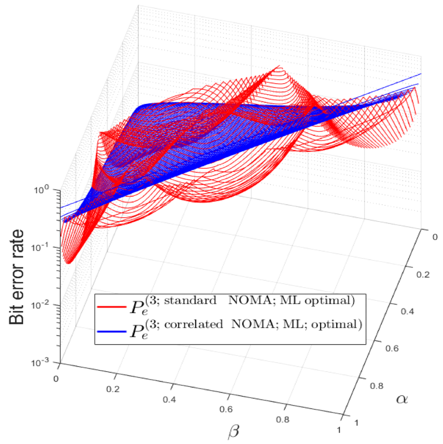

Fig. 6. Comparison of BERs for standard NOMA and correlated NOMA for user-3.

Ⅵ. Conclusion

We presented the correlated SC, for 3-user NOMA. It was shown that the correlated SC NOMA achieves not only the near-perfect SIC BER performance, but also mitigates the performance degradation in the standard NOMA. As a consequence, the correlated SC could be a promising SC for SIC and IUI suppression.

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