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Quadrature Correlated Superposition Modulation: Practical Perspective of Correlated Superposition Coding

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Abstract

Recently, a lossless non-orthogonal multiple access (NOMA) implementation without successive interference cancellation (SIC) has been proposed in the literature of NOMA. This lossless non-SIC NOMA was achieved via correlated superposition coding (CSC), in contrast to conventional independent superposition coding (ISC). However, only the achievable data rates for CSC NOMA were investigated. Thus, this paper proposes a practical CSC NOMA scheme under Rayleigh fading channel environments.

First, we design the practical CSC NOMA scheme, namely quadrature correlated superposition modulation (CSM) NOMA, without channel coding, i.e., uncoded systems. In addition, we calculate the symbol error rates (SERs) for this quadrature CSM NOMA scheme. Then, simulations demonstrate that for the weak channel gain's user, the SER performance of the proposed quadrature CSM NOMA is shown to be improved greatly, compared to that of the conventional quadrature amplitude modulation (QAM) NOMA, whereas for the strong channel gain's user, the SER performance of the proposed quadrature CSM NOMA degrades a little, compared to that of the conventional QAM NOMA.

As a result, the proposed quadrature CSM NOMA scheme could be considered as a practical NOMA scheme for CSC NOMA schemes toward the fifth-generation (5G) and next generation communications.

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

1. Introduction

As the number of mobile devices has been increasing rapidly from the fourth-generation (4G) communication [1, 2] to the fifth-generation (5G) and beyond 5G (B5G) communication, a new multiple access technology, such as non-orthogonal multiple access (NOMA) [3-5], has been a promising technique, toward the future sixth-generation (6G) communication [6]. In NOMA, successive interference cancellation (SIC) is decoding complexity of receivers, especially for small mobile terminals [7, 8]. To reduce latency and complexity, non-SIC NOMA has been investigated in discrete-input lattice-based NOMA [9-12]. In addition, impacts of correlation on superposition coding were studied in [13], and channel estimation errors were considered [14]. Unipodal binary pulse amplitude modulation for NOMA was proposed in [15]. Also, the non-SIC NOMA schemes were studied for correlated information sources [16]. Asymmetric 2PAM non-SIC

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NOMA was also investigated in [17].

Recently, a lossless NOMA implementation without SIC has been proposed for NOMA [18]. Such lossless non-SIC NOMA was achieved via correlated superposition coding (CSC), in contrast to conventional independent superposition coding (ISC). However, only the achievable data rates for CSC NOMA were investigated in [18]. Thus, this paper proposes a practical CSC NOMA scheme under Rayleigh fading channel environments.

First, we design the practical CSC NOMA scheme, namely quadrature correlated superposition modulation (CSM) NOMA, without channel coding, i.e., uncoded systems. In addition, we calculate the symbol error rates (SERs) for this quadrature CSM NOMA scheme. Then, simulations demonstrate that for the weak channel gain's user, the SER performance of the proposed quadrature CSM NOMA is shown to be improved greatly, compared to that of the conventional quadrature amplitude modulation (QAM) NOMA, whereas for the strong channel gain's user, the SER performance of the proposed quadrature CSM NOMA degrades a little, compared to that of the conventional QAM NOMA.

The remainder of this paper is organized as follows. In Section 2, the system and channel model are described. The quadrature CSM for NOMA schemes is designed and the SERs of the proposed quadrature CSM NOMA are calculated in Section 3. The numerical results are presented and discussed in Section 4. Finally, the conclusions are presented in Section 5.

The main contributions of this paper are summarized as follows:

- We propose and design the quadrature CSM for NOMA schemes, for practical uncoded systems and Rayleigh Fading channels.
- Based on this designed quadrature CSM, we calculate the SERs of quadrature CSM NOMA schemes under Rayleigh fading channels.
- It is shown under Rayleigh fading channels that for the weaker channel gain's user, the SER performance of the quadrature CSM NOMA scheme improves greatly, in comparison with that of the conventional QAM NOMA scheme.
- Moreover, we also show that under Rayleigh fading channels, for the strong channel gain's user, the SER performance of the quadrature CSM NOMA scheme degrades only a little, in contrast to that of the conventional QAM NOMA scheme.

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 $h_m \sim \mathrm{CN}\left(0, \mathrm{S}_m\right)$, $m = 1, 2$, which is Rayleigh faded with $\mathrm{S}_1 > \mathrm{S}_2$. The base station will transmit the superimposed signal $z = \sqrt{P_A a_1} c_1 + \sqrt{P_A a_2} c_2$, where c_m is the message's signal for the *m*th user with unit power, a_m is the power allocation coefficient, with $a_1 + a_2 = 1$, 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

$$y_m = h_m z + n_m, \tag{1}$$

where $n_m \sim \mathcal{CN}\left(0, N_0\right)$ is additive white Gaussian noise (AWGN). For the average total transmitted power P at the base station, P_A is given by [16]

$$P_A = \frac{P}{1 + 2\operatorname{Re}\{r_{1,2}\}\sqrt{a}\sqrt{(1-a)}}, \tag{2}$$

where the correlation coefficient of the messages' signals is given by

$$r_{1,2} = E\left[c_1 c_2^*\right] \tag{3}$$

3. Design of Quadrature CSM NOMA and Calculation of SERs

First, we design the quadrature CSM NOMA, and then calculate SERs for the quadrature CSM NOMA. In order to minimize the inter-user interference, the quadrature CSM is given by

$$\begin{aligned}
s_2^{(1)} &= +\frac{1}{\sqrt{2}} + \frac{j}{\sqrt{2}}, & s_2^{(2)} &= +\frac{1}{\sqrt{2}} - \frac{j}{\sqrt{2}}, \\
s_2^{(3)} &= -\frac{1}{\sqrt{2}} + \frac{j}{\sqrt{2}}, & s_2^{(4)} &= -\frac{1}{\sqrt{2}} - \frac{j}{\sqrt{2}},
\end{aligned}$$

$$\left\{\begin{aligned}
s_1^{(1)}\left(s_2^{(1)}\right) &= 0 & s_1^{(1)}\left(s_2^{(2)}\right) &= 0 \\
s_1^{(2)}\left(s_2^{(1)}\right) &= +1 & s_1^{(2)}\left(s_2^{(2)}\right) &= +1 \\
s_1^{(3)}\left(s_2^{(1)}\right) &= +j & s_1^{(3)}\left(s_2^{(2)}\right) &= -j \\
s_1^{(4)}\left(s_2^{(1)}\right) &= +1 + j, & s_1^{(4)}\left(s_2^{(2)}\right) &= +1 - j,
\end{aligned}\right.$$

$$\left\{\begin{aligned}
s_1^{(1)}\left(s_2^{(3)}\right) &= 0 & s_1^{(1)}\left(s_2^{(4)}\right) &= 0 \\
s_1^{(2)}\left(s_2^{(3)}\right) &= -1 & s_1^{(2)}\left(s_2^{(4)}\right) &= -1 \\
s_1^{(3)}\left(s_2^{(3)}\right) &= +j & s_1^{(3)}\left(s_2^{(4)}\right) &= -j \\
s_1^{(4)}\left(s_2^{(3)}\right) &= -1 + j, & s_1^{(4)}\left(s_2^{(4)}\right) &= -1 - j,
\end{aligned}\right. \tag{4}$$

where the subscript stands for the user's index, and the superscript is the signal index of the given user. And in the second part of the above-mentioned equation, the notation in the parentheses stands for the conditional signal, e.g., $s_1^{(1)}\left(s_2^{(1)}\right)$ is the signal of the user-1 conditioned on the signal $s_2^{(1)}$ of the user-2.

Now, to derive SERs for quadrature CSM NOMA, we observe that since the quadrature CSM amounts to the two 1-dimensional CSM modulations in quadrature with the power evenly divided between them, we calculate the SERs for quadrature CSM NOMA with the following equation:

$$P_{1\text{ or }2}^{(\text{ quadrature CSM NOMA })}(P_A) = P_{1\text{ or }2}^{(\text{ 1-dimentional CSM NOMA })}\left(\frac{P_A}{2}\right) \tag{5}$$

with (in [17])

$$P_1^{(\text{ 1-dimentional CSM NOMA })} = F\left(\frac{S_1 P_A \frac{1}{2} a}{N_0}\right) \tag{6}$$

and

$$P_2^{(\text{ 1-dimentional CSM NOMA })} = \frac{1}{2}F\left(\frac{S_2 P_A\left(\sqrt{1-a}+\sqrt{2}\sqrt{a}\right)^2}{N_0}\right) + \frac{1}{2}F\left(\frac{S_2 P_A\left(\sqrt{1-a}\right)^2}{N_0}\right), \tag{7}$$

where

$$F(g_b) = \frac{1}{2}\left(1-\sqrt{\frac{g_b}{1+g_b}}\right) \tag{8}$$

Hence, the SERs for the quadrature CSM NOMA are expressed as

$$P_1^{(\text{ quadrature CSM NOMA })} = F\left(\frac{S_1 \frac{P_A}{2}\frac{1}{2} a}{N_0}\right) \tag{9}$$

and

$$P_2^{(\text{ quadrature CSM NOMA })} = \frac{1}{2}F\left(\frac{S_2 \frac{P_A}{2}\left(\sqrt{1-a}+\sqrt{2}\sqrt{a}\right)^2}{N_0}\right) + \frac{1}{2}F\left(\frac{S_2 \frac{P_A}{2}\left(\sqrt{1-a}\right)^2}{N_0}\right). \tag{10}$$

4. Numerical Results and Discussions

It is assumed that $S_1 = \mathrm{E}\left[|h_1|^2\right] = 1.8$ and $S_2 = \mathrm{E}\left[|h_2|^2\right] = 0.2$. We consider the average total transmitted signal power to noise power ratio (SNR) $P/N_0 = 43\,\mathrm{dB}$. In addition, the correlation coefficient is given as $r_{1,2} = 0.707$. Before presenting the numerical results, we should mention the SNR $P/N_0 = 43\,\mathrm{dB}$: If we want to have the same bit error rate (BER) as the SER in this section, it is enough to use only the SNR

$$P/N_0 = 43\,\mathrm{dB} - 3\,\mathrm{dB} = 40\,\mathrm{dB}, \tag{11}$$

where $P/N_0 = 3\,\text{dB}$ corresponds to the factor $\frac{1}{2}$ in equation (5).

For the weak channel gain's user, the SERs of the proposed practical quadrature CSM NOMA and standard QAM NOMA are shown in Fig. 1.

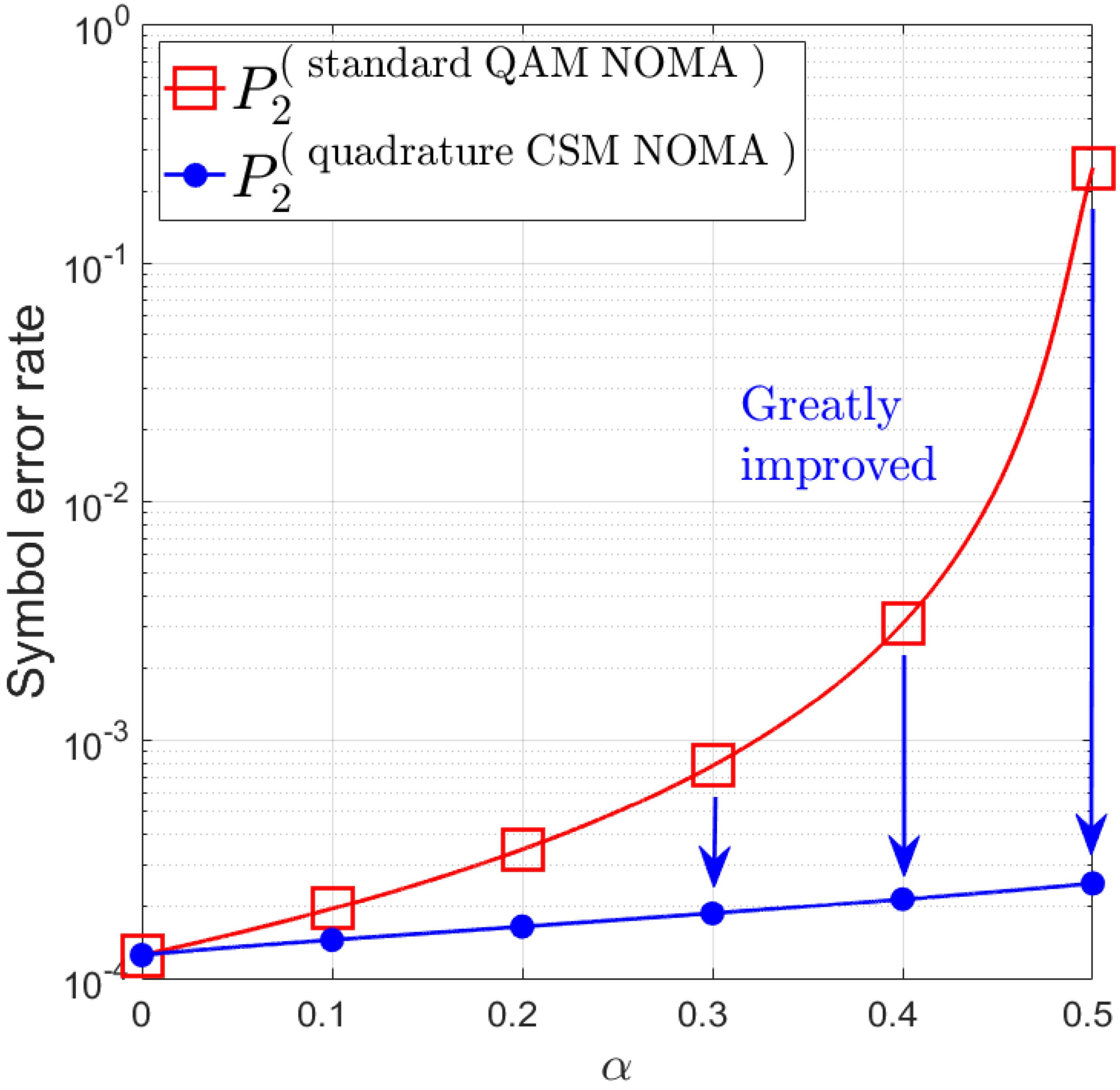

Figure 1. Comparison of SERs for standard QAM NOMA and proposed practical quadrature CSM NOMA for second user, under Rayleigh fading channels.

As shown in Fig. 1, it is observed that over the entire power allocation range of significant user-fairness, the SER of the proposed practical quadrature CSM NOMA is improved greatly, compared to that of the standard QAM NOMA. It should be noted that this SER improvement of the proposed quadrature CSM NOMA can be achieved with the correlation between two quadrature signals' constellations, by signals' design.

Then, for the stronger channel gain's user, the SERs of the proposed practical quadrature CSM NOMA and standard QAM NOMA are shown in Fig. 2.

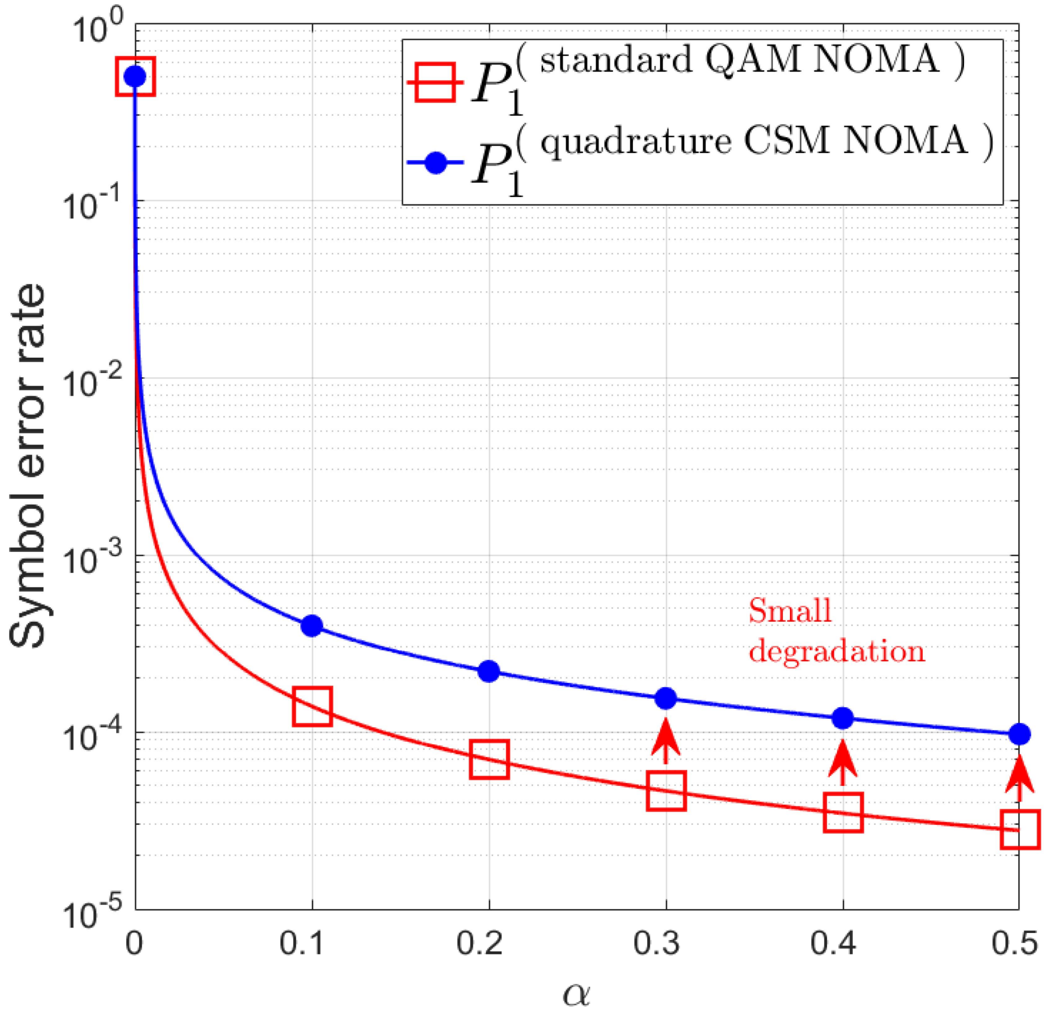

Figure 2. Comparison of SERs for standard QAM NOMA and proposed practical quadrature CSM NOMA for first user, under Rayleigh fading channels.

As shown in Fig. 2, we observe that over the entire power allocation range of significant user-fairness, the SER of the proposed practical quadrature CSM NOMA degrade a little, compared to that of the standard QAM NOMA. Notably, this SER degradation of the proposed quadrature CSM NOMA is due to the same reason as that of the SER improvement, i.e., the correlation between two quadrature signal's constellations.

It is worth mentioning that since we have not included the network-level simulations, it would be interesting to investigate the results with network simulator (NS), based on these theoretical derivations of the proposed quadrature CSM NOMA.

5. Conclusion

In this paper, we proposed a practical CSC NOMA scheme, namely quadrature CSM NOMA scheme, under Rayleigh fading channel environments.

First, we designed the quadrature CSM NOMA, without channel coding. Second, we calculated the SERs for this quadrature CSM NOMA scheme. Then, simulations demonstrated that for the weak channel gain's user, the SER performance is shown to be improved greatly, whereas for the strong channel gain's user, the SER performance degrades a little.

As a result, the quadrature CSM NOMA scheme could be considered as a practical NOMA scheme for CSC NOMA schemes toward the fifth-generation (5G) and next generation communications.

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