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Cross-Correlated Quadrature Amplitude Modulation for Non-Orthogonal Multiple Access in 5G Systems

Kyuhyuk Chung

Professor, Dept. of Software Science, Dankook Univ., Korea
khchung@dankook.ac.kr

Abstract

Recently, correlated superposition coding (CSC) has been proposed to implement non-orthogonal multiple access (NOMA) without successive interference cancellation (SIC), without loss of spectral efficiency, in contrast to conventional independent superposition coding (ISC). However, correlation between signals has reduced the average total allocated power, which results in degraded performance. Thus, in order to avoid the reduction of the average total allocated power owing to correlation between signals, this paper proposes a cross-correlated quadrature amplitude modulation (QAM) NOMA scheme under Rayleigh fading channel surroundings. First, we design the cross-correlated QAM NOMA scheme. Then, simulations demonstrate that for the weaker channel gain's user, the symbol error rate (SER) performance of the proposed cross-correlated QAM NOMA improves largely, whereas for the stronger channel gain's user, the SER performance of the proposed cross-correlated QAM CSM NOMA degrades little, compared to that of the conventional QAM NOMA.

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

1. INTRODUCTION

The global mobile communication companies have been preparing the future sixth-generation (6G) mobile network [1], as the number of mobile users has been increasing tremendously from the fifth-generation (5G) and beyond 5G (B5G) network [2]. For this, non-orthogonal multiple access (NOMA) [3-5] has increased the spectral efficiency. The power splitting was investigated for correlated superposition coding NOMA [6]. Also, power allocation was studied for first and second strongest channel users [7]. In addition, the achievable data rate for the asymmetric binary pulse amplitude modulation (2PAM) NOMA was derived [8]. In NOMA, practical issues on successive interference cancellation (SIC) were considered [9], and signal dependent noise channel capacity was studied in NOMA [10]. For reducing latency, discrete-input lattice-based NOMA was investigated without SIC [11-14]. Correlation on superposition coding (SC) have been studied in NOMA [15]. Channel estimation errors were investigated [16]. Unipodal binary pulse amplitude modulation was studied for NOMA [17]. In addition, negatively-correlated information sources were investigated in [18]. In [18], it was shown that the sum rate of NOMA with negatively-correlated information sources can be larger than that with positively-correlated information sources. Asymmetric 2PAM non-SIC NOMA was studied [19], and

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Corresponding Author: khchung@dankook.ac.kr
Tel:+82-32-8005-3237, Fax: +82-504-203-2043
Professor, Dept. of Software Science, Dankook Univ., Korea

achievable power allocation interval of asymmetric 2PAM was investigated for rate-lossless non-SIC NOMA [20]. The non-SIC NOMA scheme has been proposed for correlated information sources [21]. The authors in [21] demonstrated that the non-SIC NOMA schemes can be more efficient than the SIC NOMA schemes, when the correlation is large.

Recently, in [22], correlated superposition coding (CSC) has been proposed to implement NOMA without SIC, without loss of spectral efficiency, in contrast to conventional independent superposition coding. However, correlation between signals has reduced the average total allocated power, which results in degraded performance. Thus, in order to avoid the reduction of the average total allocated power owing to correlation between signals, this paper proposes a cross-correlated quadrature amplitude modulation (QAM) NOMA scheme under Rayleigh fading channels.

First, we design the cross-correlated QAM NOMA scheme, which does not reduce the average total allocated power but preserves the merits of the correlation between signals. In addition, we derive the symbol error rates (SERs) for this cross-correlated QAM NOMA scheme. Then, simulations demonstrate that for the weaker channel gain's user, the SER performance of the proposed cross-correlated QAM NOMA improves largely, compared to that of the conventional QAM NOMA, whereas for the stronger channel gain's user, the SER performance of the proposed cross-correlated QAM CSM NOMA degrades little, compared with 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 proposed cross-correlated QAM NOMA is designed and the SERs are derived 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 a cross-correlated QAM NOMA scheme, in contrast to a conventional QAM NOMA scheme.
- Then, we derive the SERs to be achieved by the proposed cross-correlated QAM scheme, under Rayleigh fading channels.
- It is shown that for the weaker channel gain's user, the SER performance of the proposed cross-correlated QAM NOMA improves largely, compared with that of the conventional QAM NOMA.
- Moreover, we also show that for the stronger channel gain's user, the SER performance of the proposed cross-correlated QAM CSM NOMA degrades little, compared to that of the conventional QAM NOMA.

2. SYSTEM AND CHANNEL MODEL

In block fading channels, the complex channel coefficients between the *m*th user and base station are denoted by $h_m \sim \mathcal{CN}(0, \Sigma_m)$, $m = 1,2$, which are Rayleigh faded with $\Sigma_1 > \Sigma_2$. This base station transmits the superimposed signal $z = \sqrt{P_A \alpha_1} c_1 + \sqrt{P_A \alpha_2} c_2$, where c_m is the message's signal for the *m*th user with unit power, α_m is the power allocation coefficient, with $\alpha_1 + \alpha_2 = 1$, 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 $n_m \sim \mathcal{CN}(0, N_0)$ is additive white Gaussian noise (AWGN). For the average total transmitted power P at the base station, P_A is given by

$$P_A = \frac{P}{1+2\,Re\{\rho_{1,2}\}\sqrt{\alpha}\sqrt{1-\alpha}}, \quad (2)$$

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

$$\rho_{1,2} = E[c_1 c_2^*]. \quad (3)$$

3. DESIGN OF CROSS-CORRELATED QAM AND DERIVATION OF SERS

Before presenting the design of the proposed cross-correlated QAM NOMA, we address our motivation to consider such cross-correlation: When we introduce a correlation between signals, the correlation reduces the average total allocated power P_A in equation (2). Here we note that this reduction is brought about owing to $Re\{\rho_{1,2}\}$. Thus if we can have $Re\{\rho_{1,2}\} = 0$, then we do not lose P_A. Therefore, we design the signals to have $Re\{\rho_{1,2}\} = 0$, as follow. To have $Re\{\rho_{1,2}\} = 0$, the cross-correlated QAM is given by

$$s_2^{(1)} = +\frac{1}{\sqrt{2}} + \frac{j}{\sqrt{2}}, \quad \begin{cases} s_1\left(s_2^{(1)}\right) = 0 \\ s_1\left(s_2^{(1)}\right) = -1 \\ s_1\left(s_2^{(1)}\right) = +j \\ s_1\left(s_2^{(1)}\right) = -1 + j, \end{cases} \qquad s_2^{(2)} = +\frac{1}{\sqrt{2}} - \frac{j}{\sqrt{2}}, \quad \begin{cases} s_1\left(s_2^{(2)}\right) = 0 \\ s_1\left(s_2^{(2)}\right) = +1 \\ s_1\left(s_2^{(2)}\right) = +j \\ s_1\left(s_2^{(2)}\right) = +1 + j, \end{cases}$$

$$s_2^{(3)} = -\frac{1}{\sqrt{2}} + \frac{j}{\sqrt{2}}, \quad \begin{cases} s_1\left(s_2^{(3)}\right) = 0 \\ s_1\left(s_2^{(3)}\right) = -1 \\ s_1\left(s_2^{(3)}\right) = -j \\ s_1\left(s_2^{(3)}\right) = -1 - j, \end{cases} \qquad s_2^{(4)} = -\frac{1}{\sqrt{2}} - \frac{j}{\sqrt{2}}, \quad \begin{cases} s_1\left(s_2^{(4)}\right) = 0 \\ s_1\left(s_2^{(4)}\right) = +1 \\ s_1\left(s_2^{(4)}\right) = -j \\ s_1\left(s_2^{(4)}\right) = +1 - j. \end{cases} \quad (4)$$

Notably, these signal constellations achieve $Re\{\rho_{1,2}\} = 0$, because we introduce $Im\{\rho_{1,2}\} \neq 0$ instead of $Re\{\rho_{1,2}\} \neq 0$. Thus we use the name "*cross-correlated QAM*" for our proposed QAM signal constellation. In addition, the notation in the parentheses represents 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.

Then, to derive SERs for the cross-correlated QAM NOMA, we use the fact that QAM amounts to the two PAMs in quadrature with the power evenly divided between them. Therefore, we calculate the SERs for the cross-correlated QAM NOMA with the following equation:

$$P_{1\text{ or }2}^{(\text{cross-correlated QAM NOMA})}(P) = P_{1\text{ or }2}^{(\text{cross-correlated PAM NOMA})}\left(\frac{P}{2}\right), \quad (5)$$

with

$$P_1^{(\text{ cross-correlated PAM NOMA })} = F\left(\frac{\Sigma_1 P \frac{1}{2}\alpha}{N_0}\right), \quad (6)$$

and

$$P_2^{(\text{ cross-correlated PAM NOMA })} = \frac{1}{2}F\left(\frac{\Sigma_2 P\left(\sqrt{1-\alpha}+\frac{\sqrt{2}}{2}\sqrt{\alpha}\right)^2}{N_0}\right) + \frac{1}{2}F\left(\frac{\Sigma_2 P\left(\sqrt{1-\alpha}-\frac{\sqrt{2}}{2}\sqrt{\alpha}\right)^2}{N_0}\right), \quad (7)$$

where

$$F(\gamma_b) = \frac{1}{2}\left(1 - \sqrt{\frac{\gamma_b}{1+\gamma_b}}\right). \quad (8)$$

If we replace the average total transmitted power P with $P/2$, then the SER performances can be obtained from equations (6) and (7), directly. Hence, based on (5), the SERs for the cross-correlated QAM NOMA are expressed as

$$P_1^{(\text{ cross-correlated QAM NOMA })} = F\left(\frac{\Sigma_1 \frac{P}{2}\frac{1}{2}\alpha}{N_0}\right), \quad (9)$$

and

$$P_2^{(\text{ cross-correlated PAM NOMA })} = \frac{1}{2}F\left(\frac{\Sigma_2 \frac{P}{2}\left(\sqrt{1-\alpha}+\frac{\sqrt{2}}{2}\sqrt{\alpha}\right)^2}{N_0}\right) + \frac{1}{2}F\left(\frac{\Sigma_2 \frac{P}{2}\left(\sqrt{1-\alpha}-\frac{\sqrt{2}}{2}\sqrt{\alpha}\right)^2}{N_0}\right). \quad (10)$$

4. NUMERICAL RESULTS AND DISCUSSIONS

We assume that $\Sigma_1 = \mathbb{E}[|h_1|^2] = 1.8$ and $\Sigma_2 = \mathbb{E}[|h_2|^2] = 0.2$. The average total transmitted signal power to noise power ratio (SNR) is given as $P/N_0 = 43$ dB. Note that the SNR $P/N_0 = 43$ dB for SERs corresponds the SNR $P/N_0 = 43 \text{ dB} - 3 \text{ dB} = 40$ dB for the same bit error rate (BER), based on equation (5).

For the weaker channel gain's user, the SERs of the proposed cross-correlated QAM NOMA and standard QAM NOMA are depicted in Fig. 1.

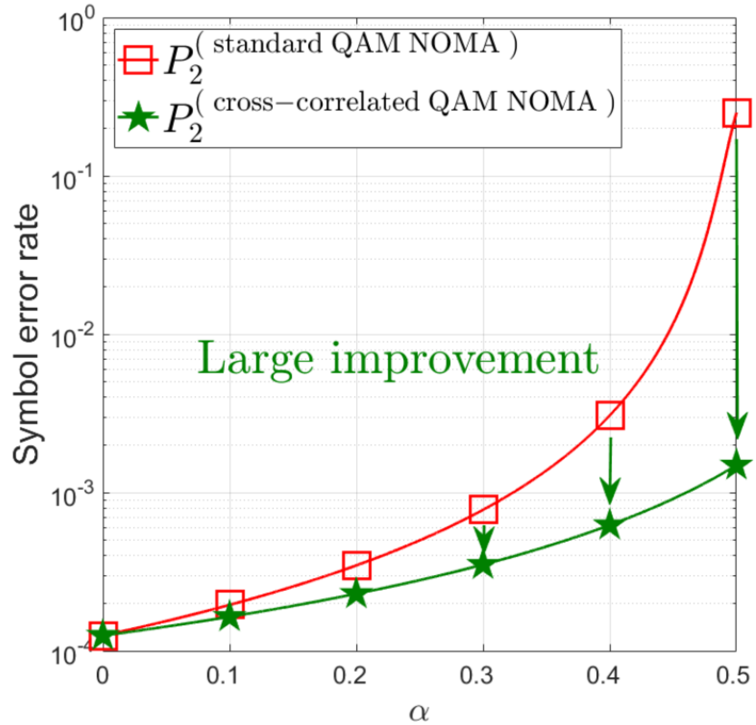

Figure 1. Comparison of SERs for standard QAM NOMA and proposed cross-correlated QAM NOMA for second user, under Rayleigh fading channels

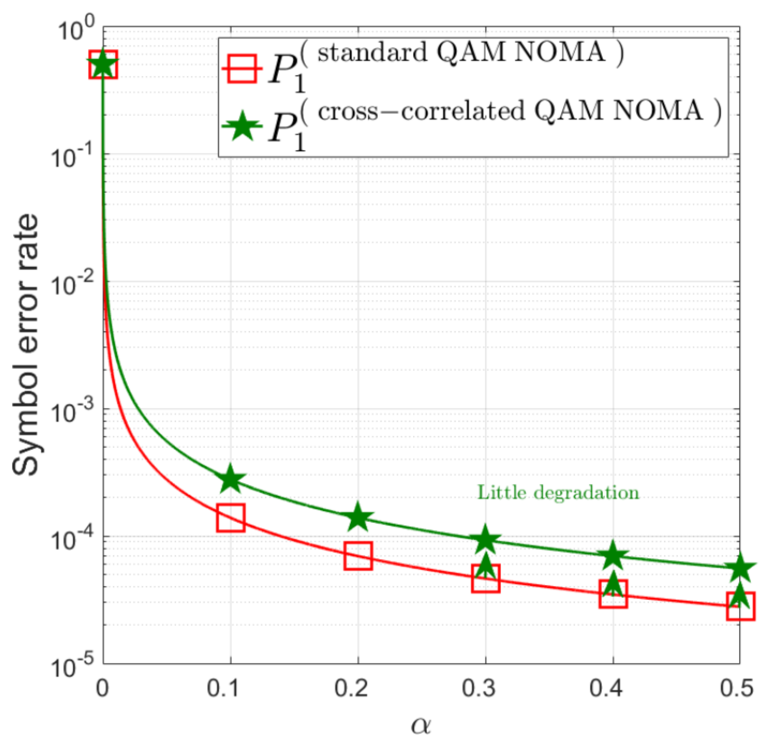

Figure 2. Comparison of SERs for standard QAM NOMA and proposed cross-correlated QAM NOMA for first user, under Rayleigh fading channels

As shown in Fig. 1, we observe that over the entire power allocation range of $\alpha \leq 0.5$, the SER of the proposed cross-correlated QAM NOMA improve largely, compared with that of the standard QAM NOMA. Remark that the SER improvement of the proposed cross-correlated QAM NOMA can be achieved with the cross-correlation between two quadrature signals, because the correlation coefficient with the zero real part, i.e., the purely imaginary correlation coefficient, preserves the performance improvement by the correlated signals.

Then, for the strong channel gain's user, the SERs of the proposed cross-correlated QAM NOMA and standard QAM NOMA are depicted in Fig. 2.

As shown in Fig. 2, over the entire power allocation range of $\alpha \leq 0.5$, the SER of the proposed cross-correlated QAM NOMA degrade little, compared with that of the standard QAM NOMA. Note that the SER degradation of the proposed cross-correlated QAM NOMA is owing to the same reason as that of the SER improvement for the weaker channel gain user, i.e., the cross-correlation between two quadrature signals. Specifically, the purely imaginary correlation coefficient mitigates the SER loss due to the correlation between two signals.

5. CONCLUSION

In this paper, we proposed a cross-correlated QAM NOMA scheme, under practical Rayleigh fading channels, in order to avoid the reduction of the average total allocated power in correlated signals, because the positive real part of the correlation coefficient reduces effectively the average total allocated power.

First, we designed the cross-correlated QAM NOMA, compared with the standard QAM NOMA in conventional communication systems. Note that the cross-correlation uses the correlation between the real part signal and imaginary part signal. Second, we calculated the SERs for this cross-correlated QAM NOMA scheme. Then, simulations demonstrated that for the weak channel gain's user, the SER performance is shown to improve largely, whereas for the strong channel gain's user, the SER performance degrades little.

As a result, the cross-correlated QAM NOMA scheme could be considered as a promising NOMA scheme in 5G and next generation communications.

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