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Achievable Sum Rate of NOMA with Negatively-Correlated Information Sources

Kyuhyuk Chung

Professor, Department of Software Science, Dankook University, Korea
khchung@dankook.ac.kr

Abstract

As the number of connected smart devices and applications increases explosively, the existing orthogonal multiple access (OMA) techniques have become insufficient to accommodate mobile traffic, such as artificial intelligence (AI) and the internet of things (IoT). Fortunately, non-orthogonal multiple access (NOMA) in the fifth generation (5G) mobile networks has been regarded as a promising solution, owing to increased spectral efficiency and massive connectivity.

In this paper, we investigate the achievable data rate for non-orthogonal multiple access (NOMA) with negatively-correlated information sources (CIS). For this, based on the linear transformation of independent random variables (RV), we derive the closed-form expressions for the achievable data rates of NOMA with negatively-CIS. Then it is shown that the achievable data rate of the negatively-CIS NOMA increases for the stronger channel user, whereas the achievable data rate of the negatively-CIS NOMA decreases for the weaker channel user, compared to that of the positively-CIS NOMA for the stronger or weaker channel users, respectively. We also show that the sum rate of the negatively-CIS NOMA is larger than that of the positively-CIS NOMA. As a result, the negatively-CIS could be more efficient than the positively-CIS, when we transmit CIS over 5G NOMA networks.

Keywords: *NOMA, Correlated Information Sources, Sum rate, Superposition coding, Successive interference cancellation, Power allocation.*

1. Introduction

The fifth generation (5G) mobile communications have been enabling the state-of-the-art technologies, such as the internet of things (IoT) and artificial intelligence (AI), to be converged in the various ways [1]. In 5G mobile networks, non-orthogonal multiple access (NOMA) has been considered as a promising multiple access (MA) [2-4]. NOMA has several advantages, such as increased spectral efficiency and massive connectivity, compared to the existing orthogonal multiple access (OMA) in the fourth generation (4G) mobile communications [5-7]. Such superiority was studied in a perspective of optimization [8]. Cooperative NOMA was investigated for full-duplex relaying [9]. Underwater visible light communication (VLC) was considered in NOMA [10]. A power-outage tradeoff of NOMA was studied [11]. The bit-error rate (BER) performances

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

for NOMA were derived [12], while the impact of local oscillator imperfection was investigated for NOMA [13]. The power splitting was studied for correlated superposition coding NOMA [14]. Also, in M-user NOMA systems, power allocation was investigated for first and second strongest channel users [15]. In addition, the achievable data rate for the asymmetric binary pulse amplitude modulation (2PAM) NOMA was analyzed [16].

Recently, the NOMA schemes were investigated for correlated information sources (CIS) [17]. The CIS NOMA schemes can be found in cellular networks with broadcasting common information, such as background screens of interactive mobile games. However, only the positively-CIS was considered in [17]. The positively-CIS stands for the similarity between two information sources. In some cases, such similarity can be negative. Thus, in this paper, we investigate the achievable data rate for NOMA with negatively-CIS. First, based on the linear transformation of independent random variables (RV), we derive the analytical expression for the achievable data rate of NOMA with negatively-CIS. Then it is shown that even though the achievable data rate of the negatively-CIS NOMA decreases for the weaker channel user, the achievable data rate of the negatively-CIS NOMA increases greatly for the stronger channel user. Based on such observations, we demonstrate that the sum rate of the negatively-CIS NOMA is larger than that of the positively-CIS NOMA. Therefore, we reach a meaningful result as follows: the negatively-CIS could be more efficient than the positively-CIS, when we transmit CIS over NOMA networks.

The remainder of this paper is organized as follows. In Section 2, the system and channel model are described. Based on the linear transformation, the achievable data rate for NOMA with negatively-CIS is derived in Section 3. The results are presented and discussed in Section 4. Finally, this paper is concluded in Section 5.

The main contributions of this paper can be summarized as follows:

- We investigate the achievable data rate of NOMA with negatively-CIS.
- Based on the linear transformation of independent RV, we derive analytical expressions of the achievable data rates for the negatively-CIS NOMA.
- It is shown by numerically that the achievable data rate of the negatively-CIS NOMA increases greatly for the stronger channel, whereas the achievable data rate of the negatively-CIS NOMA decreases for the weaker channel user.
- We demonstrate that the negatively-CIS is more efficient than the positively-CIS, when we transmit CIS over NOMA networks, by showing that the sum rate of the negatively-CIS NOMA is larger than that of the positively-CIS NOMA.

2. System and Channel Model

We consider two-user NOMA with one base station, over block fading channels, where the complex channel coefficient between the mth user and the base station is denoted by h_m, $m = 1, 2$. The channels are sorted as $|h_1| \geq |h_2|$. The base station sends the correlated superimposed signal $z = \sqrt{P_A \beta_1} c_1 + \sqrt{P_A \beta_2} c_2$, where c_m is the signal for the mth user with the average unit power. For the given average power P of z, we have $P = \mathbb{E}\left[|z|^2\right] = \mathbb{E}\left[\left|\sqrt{P_A \beta_1} c_1 + \sqrt{P_A \beta_2} c_2\right|^2\right] = P_A\left(1 + 2\rho_{1,2}\sqrt{\beta_1 \beta_2}\right)$. Thus, the average allocated total power P_A of c_1 and c_2 is calculated by

$$P_A = \frac{P}{1+2\rho_{1,2}\sqrt{\beta_1\beta_2}}, \tag{1}$$

where $\rho_{1,2} = \mathbb{E}\left[c_1 c_2^*\right]$ is the correlation coefficient (we assume that the correlated superimposed signal z has only the real positive or negative correlation coefficient, i.e., $\rho_{1,2} = \mathrm{Re}\{\rho_{1,2}\}$, without loss of generality), and β_m is the power allocation coefficient, with $\beta_1 + \beta_2 = 1$. The received signal y_m at *m*th user is expressed as follows:

$$y_m = h_m z + n_m. \tag{2}$$

where $n_m \sim CN(0,\sigma^2)$ is additive white Gaussian noise (AWGN).

3. Linear Transformation Based Derivation of Achievable Data Rate

The similar derivations can be found in our previous work [17]; however, in this paper, we re-derive those here, especially based on the linear transformation of two independent Gaussian RV. First, given two independent Gaussian RV, i.e., s_1 and s_2 with the average unit power, two correlated Gaussian RV with the correlation coefficient $\rho_{1,2}$ can be expressed as, by using the linear transformation,

$$\begin{cases} c_1 = \sqrt{1-\rho_{1,2}^2}\, s_1 + \rho_{1,2} s_2 \\ c_2 = \qquad\qquad\qquad s_2. \end{cases} \tag{3}$$

It should be noted that $\mathbb{E}\left[c_1 c_2^*\right] = \mathbb{E}\left[\left(\sqrt{1-\rho_{1,2}^2}\, s_1 + \rho_{1,2} s_2\right) s_2^*\right] = \mathbb{E}\left[\rho_{1,2} s_2 s_2^*\right] = \rho_{1,2}$. Then, if the perfect successive interference cancellation (SIC) is assumed on the stronger channel user, the achievable data rate of the first user is given by

$$\begin{aligned} R_{1\,||h_1|,\,(\mathrm{SIC})}^{(\mathrm{CIS/SIC})} &= I(y_1;c_1 \mid c_2) = h(y_1 \mid c_2) - h(y_1 \mid c_1, c_2) \\ &= h(h_1\sqrt{P_A\beta_1}\left(\sqrt{1-\rho_{1,2}^2}\, s_1 + \rho_{1,2}s_2\right) + h_1\sqrt{P_A\beta_2}\, s_2 + n_1 \mid s_2) \\ &\quad - h(h_1\sqrt{P_A\beta_1}\left(\sqrt{1-\rho_{1,2}^2}\, s_1 + \rho_{1,2}s_2\right) + h_1\sqrt{P_A\beta_2}\, s_2 + n_1 \mid s_1, s_2) \\ &= h(h_1\sqrt{P_A\beta_1}\sqrt{1-\rho_{1,2}^2}\, s_1 + n_1 \mid s_2) - h(n_1 \mid s_1, s_2) \\ &= h(h_1\sqrt{P_A\beta_1}\sqrt{1-\rho_{1,2}^2}\, s_1 + n_1) - h(n_1) \\ &= \log_2 \pi e\left(|h_1|^2 P_A\beta_1\left(1-\rho_{1,2}^2\right) + \sigma^2\right) - \log_2 \pi e \sigma_2 \\ &= \log_2\left(1 + \frac{|h_1|^2 P_A\beta_1\left(1-\rho_{1,2}^2\right)}{\sigma_2}\right), \end{aligned} \tag{4}$$

where on the fourth equality, we use the independency of s_1 and s_2. It should be noted that the above-mentioned derivation is more intuitive, compared to that in [17].

Second, for the second user, the achievable data rate of the second user is given by

$$\begin{aligned} R_{2\,|\,|h_2|,\,(\text{non-SIC})}^{(\text{CIS/SIC})} &= I(y_2;c_2) \\ &= h(y_2)-h(y_2\,|\,c_2) \\ &= h(h_2 z+n_2)-h(h_2\sqrt{P_A\beta_1}\left(\sqrt{1-\rho_{1,2}^2}s_1+\rho_{1,2}s_2\right)+h_2\sqrt{P_A\beta_2}s_2+n_2\,|\,s_2) \\ &= h(h_2 z+n_2)-h(h_2\sqrt{P_A\beta_1}\sqrt{1-\rho_{1,2}^2}s_1+n_2) \\ &= \log_2\left(\frac{|h_2|^2 P+\sigma^2}{|h_2|^2 P_A\beta_1\left(1-\rho_{1,2}^2\right)+\sigma^2}\right), \end{aligned} \tag{5}$$

where on the fourth equality, we use again the independency of s_1 and s_2. Remark that the above-mentioned derivation does not need the complex conditional variance, as in [17], because after the linear transformation in equation (3), we derive the achievable data rate, based on s_1 and s_2, not c_1 and c_2.

4. Numerical Results and Discussions

It is assumed that the channels are Rayleigh faded with $\mathbb{E}\left[|h_1|^2\right]=2$ and $\mathbb{E}\left[|h_2|^2\right]=0.01$. In this simulation, 10000 channel gains $|h_1|$ and $|h_2|$ are independently generated. We consider the constant total average transmitted signal power to noise power ratio (SNR) $P/\sigma^2=50$. In order to demonstrate numerical results, we select an reasonable correlation coefficient $\rho_{1,2}=\pm 0.819$, for the positively or negatively-CIS, respectively. For the first user, the achievable data rates of NOMA with negatively or positively CIS are shown in Fig. 1.

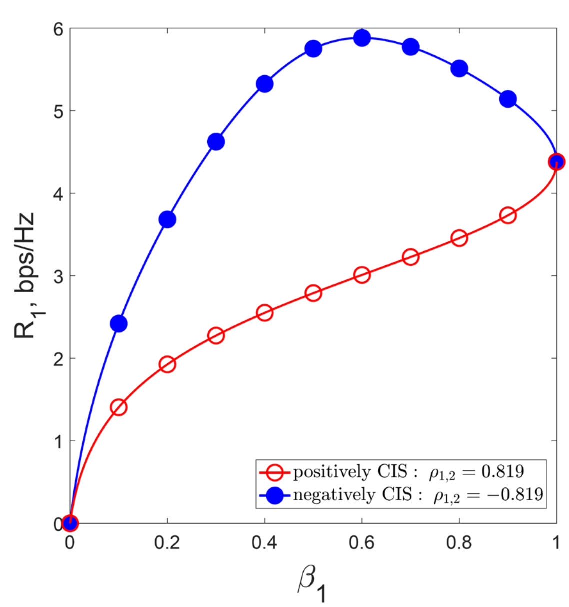

Figure 1. Comparison of achievable data rates for negatively or positively-CIS NOMA for first user.

As shown in Fig. 1, It is observed that for the first user, the achievable data rate of negatively CIS is greatly larger than that of positively CIS, because should be noted that based on equation (1), when $\rho_{1,2} < 0$, P_A increases compared to P. As the power allocation coefficient β_1 increases, $R_{1||h_1|,(\text{SIC})}^{(\text{CIS/SIC})}$ increases up to about $\beta_1 \simeq 0.6$, and then decrease.

Then, for the second user, the achievable data rates of negatively or positively CIS are shown in Fig. 2.

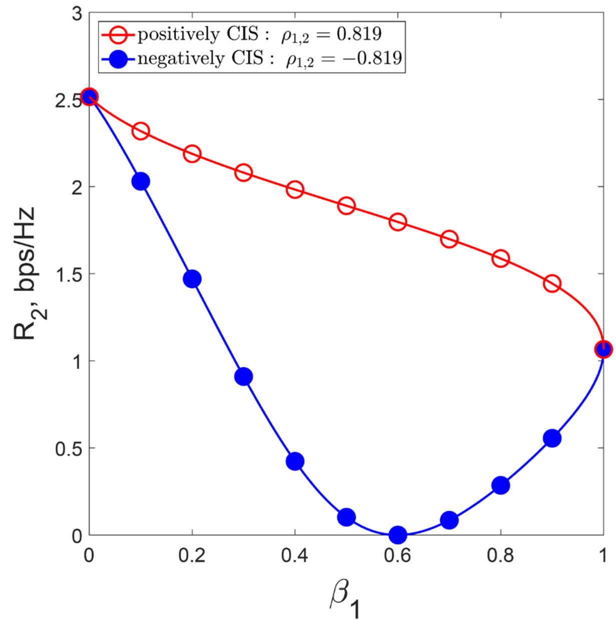

Figure 2. Comparison of achievable data rate for negatively or positively-CIS NOMA for second user.

As shown in Fig. 2, however, for the second user, the achievable data rate of negatively CIS severely degrades, compared to than that of positively CIS, especially at the power allocation $\beta_1 \simeq 0.6$. This is because P_A becomes larger than P.

In order to investigate the total impact of negatively CIS on the achievable data rate, we depict the sum rate of two users in Fig. 3.

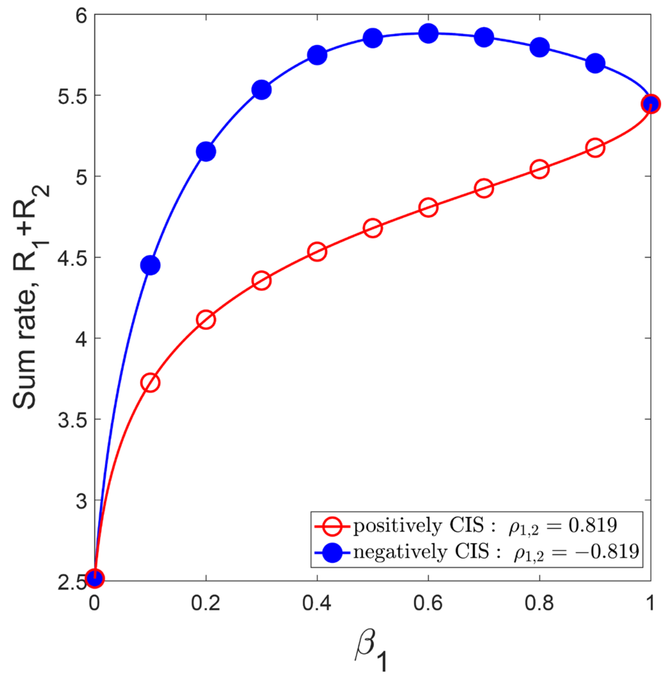

Figure 3. Comparison of sum rate for negatively or positively-CIS NOMA.

As shown in Fig. 3, the sum rate of negatively CIS is larger than that of positively CIS, over the entire power allocation range. It is observed that around $\beta_1 \simeq 0.6$, the superiority is significant.

5. Conclusion

In this paper, we demonstrated that the achievable sum rate for negatively-CIS NOMA is larger than that of positively-CIS NOMA. For this, by the novel model of the linear transformation of independent RV, we derived the closed-form expressions for the achievable data rates of both users for NOMA with negatively-CIS. Then it was shown that the achievable data rate of the negatively-CIS NOMA increases for the stronger channel, whereas the achievable data rate of the negatively-CIS NOMA decreases for the weaker channel user. Finally, we also showed that the sum rate of the negatively-CIS NOMA is larger than that of the positively-CIS NOMA. As a significant result, the negatively-CIS could be more efficient than the positively-CIS, when we transmit CIS over 5G networks, especially with NOMA.

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