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A Study on Improved Sum Rate of Cross-Correlated SC NOMA toward 6G URLLC

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6G URLLC를 지향한 교차 상관 관계 중첩 코딩을 사용하는 비직교 다중 접속의 향상된 총 전송률에 관한 연구

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Abstract Since recently only an auto-correlated superposition coding (SC) scheme for non-orthogonal multiple access(NOMA) has been investigated, this paper proposes a cross-correlated SC scheme for NOMA. First, we derive the closed-form expression of the sum rate of the proposed cross-correlated SC scheme. Then, numerical analyses demonstrate that the sum rate of the proposed cross-correlated SC scheme is larger than that of the conventional auto-correlated SC scheme. We also show that for the stronger channel gain user, the signal-to-noise ratio (SNR) gain of the proposed cross-correlated SC scheme is about 15, compared with the conventional auto-correlated SC scheme. As a result, the proposed cross-correlated SC scheme could be a promising technology for 6G ultra-reliable low-latency communications (URLLC).

Key Words : 6G, NOMA, Superposition coding, Correlation coefficient, Power allocation

요 약 최근 비직교 다중 접속에 대해, 단지 자체 상관 중첩 코딩 기법만 고찰되었기 때문에, 본 논문은 비직교 다중 접속에 대한 교차 상관 관계 중첩 코딩 기법을 제한한다. 먼저, 제안된 교차 상관 관계 중첩 코딩 기법의 총 전송률의 폐쇄형 수식을 유도한다. 다음 수치 해석을 기반으로 하여, 제안된 교차 상관 관계 중첩 코딩 기법의 총 전송률이 기존의 자체 상관 관계 중첩 코딩 기법의 총 전송률보다 향상된 것을 입증한다. 또한, 강 채널 사용자에 대해, 기존의 자체 상관 관계 중첩 코딩 기법과 비교하여, 제안된 교차 상관 관계 중첩 코딩 기법의 SNR 이득이 대략 15 임을 보여준다. 결론적으로, 제안된 교차 상관 관계 중첩 코딩 기법은 6G URLLC를 위한 유망한 기술로 고려될 수 있다.

주제어 : 6G, 비직교 다중 접속, 중첩 코딩, 상관 관계 계수, 전력 할당

1. Introduction

Toward the sixth-generation (6G) ultra-reliable low-latency communications (URLLC), non-orthogonal multiple access (NOMA) has a great attention as a promising technology, due to to its larger spectral efficiency and low latency [1, 2]. For example, in 6G URLLC, frequencies from 100 GHz to 3 THz are promising bands for the next generation wireless communications. NOMA uses superposition coding (SC) and successive

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interference cancellation (SIC) [3, 4]. In addition, NOMA increases system capacity by sharing time or frequency [5]. In NOMA, the bit-error rate (BER) was studied in [6]. Local oscillator imperfection of NOMA was considered [7]. The BER with randomly generated signals was derived [8]. The exact BER was derived for the two or three-user cases [9]. The average symbol error rate was also derived in [10]. The importance of SIC of NOMA was highlighted [11]. The secure NOMA-enabled mobile network was studied [12]. The physical layer security was investigated [13]. The intelligent reflecting surface (IRS) for NOMA was studied [14]. The mutual-aid NOMA was proposed [15]. The higher order modulation for visible light communication systems was investigated [16]. Various receivers' structures for NOMA were studied [17]. Impacts of channel estimation errors were investigated [18]. Asymmetric binary pulse amplitude modulation NOMA was studied in [19]. The total power for achieving capacity region was calculated [20]. In addition, the rate volume of 3-user correlated SC/SIC NOMA scheme was analyzed in [21]. Correlated information sources have been investigated for NOMA [22].

Recently, a correlated SC scheme has been investigated for NOMA [23]. However, only an auto-correlated SC scheme was considered. Thus, this paper proposes a cross-correlated SC scheme, especially in order to improve the sum rate of the correlated SC scheme. We first derive the achievable sum rate of the proposed cross-correlated SC scheme. Then simulations demonstrate that the sum rate of the proposed cross-correlated SC scheme is larger than that of the conventional auto-correlated SC scheme. We also show that the signal-to-noise ratio (SNR) gain of the proposed cross-correlated SC scheme is about 15, compared with the conventional auto-correlated SC scheme.

The remainder of this paper is organized as follows. In Section 2, the system and channel model are described. The sum rate for the proposed cross-correlated SC scheme is derived in Section 3. The numerical results are presented and discussed in Section 4. Finally, the conclusions are presented in Section 5.

2. System and Channel Model

A base station and two users are within the cell of a cellular downlink NOMA network, . The complex channel coefficient between the mth user and 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 superimposed signal $x=\sum_{m=1}^{2}\sqrt{\beta_m P_A}c_m$, where c_m is the message's signal for the mth user with average unit power, $E[|c_m|^2]=1$, where $E[u]$ represents the expectation of the random variable(RV) u, β_m is the power allocation coefficient, with $\sum_{m=1}^{2}\beta_m=1$, and P_A is the average total allocated power. The correlation coefficient between the ith and jth users is denoted by $\rho_{i,j}=E[c_i c_j^*]$. For a average total transmitted power P at the base station, P_A is scaled as

$$P_A=\frac{P}{\sum_{i=1}^{2}\sum_{j=1}^{2}\rho_{i,j}\sqrt{\beta_i}\sqrt{\beta_j}}. \quad (1)$$

The observation at the mth user is given by

$$y_m=h_m x+n_m, \quad (2)$$

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

3. Derivation of Achievable Data Rate for Cross-correlated SC NOMA

First, we define the conventional auto-correlated SC, as follows:

Definition 1: The conventional auto-correlated SC is defined by [23]

$$\rho_{1,2} = Re\{\rho_{1,2}\}. \quad (3)$$

Notably, the correlation coefficient of the conventional auto-correlated SC is purely-real. Then, the achievable data rates for the conventional auto-correlated SC NOMA are given as [23]

$$R_1^{(auto-cor)} = \log_2\left(1 + \frac{|h_1|^2 P_A \beta_1 (1 - |\rho_{1,2}|^2)}{\sigma^2}\right), \quad (4)$$

and

$$R_2^{(auto-cor)} = \log_2\left(\frac{|h_2|^2 P + \sigma^2}{|h_2|^2 P_A \beta_1 (1 - |\rho_{1,2}|^2) + \sigma^2}\right). \quad (5)$$

Now we define the proposed cross-correlated SC, as follows:

Definition 2: The proposed cross-correlated SC is defined by

$$\rho_{1,2} = Im\{\rho_{1,2}\}. \quad (6)$$

Notably, the correlation coefficient of the proposed cross-correlated SC is purely-imaginary. Then, the achievable data rates for the proposed cross-correlated SC NOMA are derived as follows:

$$R_1^{(cross-cor)} = \log_2\left(1 + \frac{|h_1|^2 P \beta_1 (1 - |\rho_{1,2}|^2)}{\sigma^2}\right), \quad (7)$$

and

$$R_2^{(cross-cor)} = \log_2\left(\frac{|h_2|^2 P + \sigma^2}{|h_2|^2 P \beta_1 (1 - |\rho_{1,2}|^2) + \sigma^2}\right), \quad (8)$$

where $P_A = P$ because equation (1) is expressed as

$$\begin{aligned} P_A &= \frac{P}{\sum_{i=1}^{2}\sum_{j=1}^{2} \rho_{i,j}\sqrt{\beta_i}\sqrt{\beta_j}} \\ &= \frac{P}{\beta_1 + \beta_2 + \rho_{1,2}\sqrt{\beta_1}\sqrt{\beta_2} + \rho_{2,1}\sqrt{\beta_2}\sqrt{\beta_1}} \\ &= \frac{P}{1 + 2Re\{\rho_{1,2}\}\sqrt{\beta_1}\sqrt{\beta_2}} \\ &= P. \end{aligned} \quad (9)$$

Note that the last equality in the above-mentioned equation holds, based on definition 2.

4. Numerical Results and Discussions

For numerical analyses, we assume that the channel gains are $|h_1| = \sqrt{2}$ and $|h_2| = 0.1$. In addition, the average total transmitted signal-to-noise power ratio (SNR) is $P/\sigma^2 = 50$. For the proposed cross-correlated SC scheme and the conventional auto-correlated SC scheme, we assume that $\rho_{1,2} = j0.819$ (j represents the complex number $\sqrt{-1}$) and $\rho_{1,2} = 0.819$, respectively, with the equal absolute value of $|\rho_{1,2}| = 0.819$.

First, in Fig. 1 and Fig. 2, we compare the achievable data rates of the proposed cross-correlated SC scheme to those of the conventional auto-correlated SC scheme, for both the stronger and weaker channel gain users. As shown in Fig. 1, for the stronger channel gain user, the achievable data rate of the proposed cross-correlated SC scheme is much larger than that of the conventional auto-correlated SC scheme, whereas as shown in Fig. 2, for the weaker channel gain user, the achievable data rate of the proposed cross-correlated SC scheme is a little smaller than that of the conventional auto-correlated SC scheme.

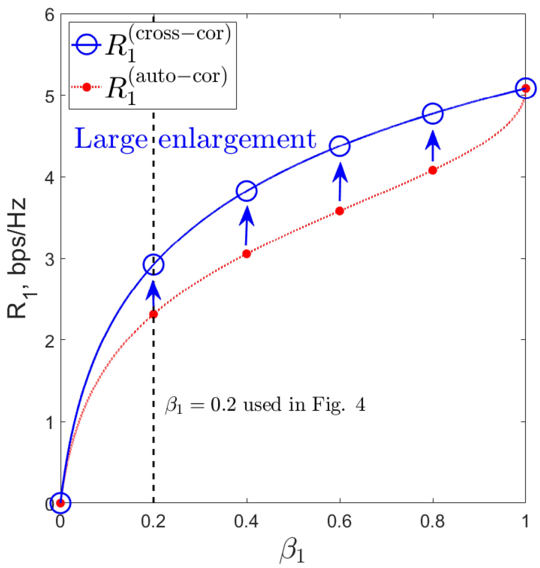

Fig. 1. Comparison of achievable date rates of proposed cross-correlated SC and conventional auto-correlated SC, with varying β_1 and fixed SNR $P/\sigma^2 = 50$

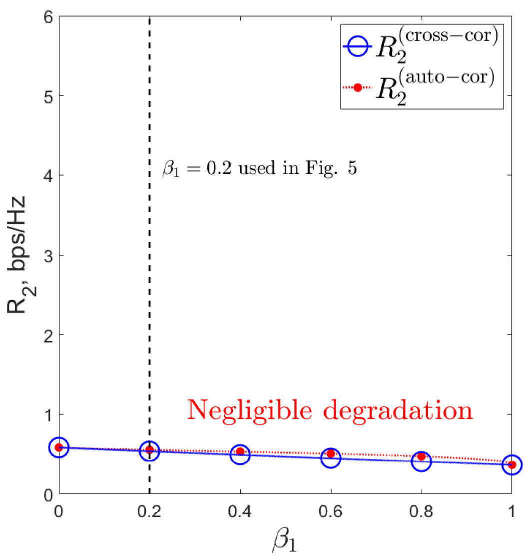

Fig. 2. Comparison of achievable date rates of proposed cross-correlated SC and conventional auto-correlated SC, with varying β_1 and fixed SNR $P/\sigma^2 = 50$.

Second, to investigate the total impact of the proposed cross-correlated SC scheme on the achievable data rates, we depict the sum rates of the proposed cross-correlated SC scheme and the conventional auto-correlated SC scheme, in Fig. 3. As shown in Fig. 3, the sum rate of the proposed cross-correlated SC scheme is greatly improved, compared to that of the conventional auto-correlated SC scheme, owing to the large improvement of the achievable data rate of the stronger channel gain user of the proposed cross-correlated SC scheme, cf., Fig. 1, with the small degradation of the achievable data rate of the weaker channel gain user of the proposed cross-correlated SC scheme, cf., Fig. 2.

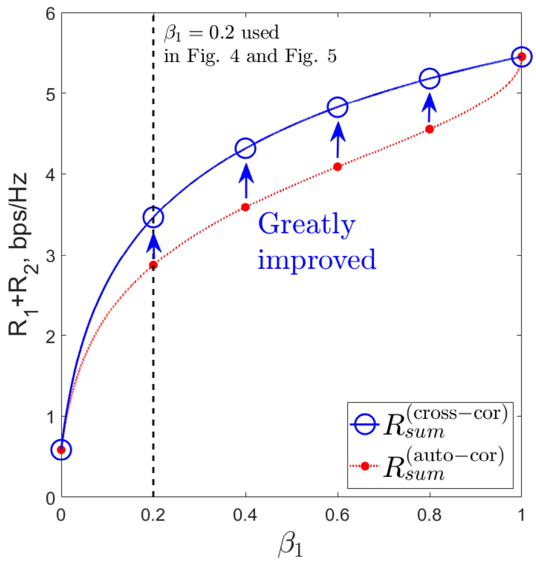

Fig. 3. Comparison of sum rates of proposed cross-correlated SC and conventional auto-correlated SC, with varying β_1 and fixed SNR $P/\sigma^2 = 50$.

Third, in order to investigate the impact of the varying SNR, i.e., $0 \le P/\sigma^2 \le 60$, we compare the achievable data rates of the proposed cross-correlated SC scheme to those of the conventional auto-correlated SC scheme, for both the stronger and weaker channel gain users, in Fig. 4 and Fig. 5, respectively, with the fixed power allocation $\beta_1 = 0.2$. As shown in Fig. 4, for the stronger channel gain user, at the achievable data rate of $R_1 = 2$, we observe that the SNR P/σ^2 gain of the proposed cross-correlated SC scheme over the conventional auto-correlated SC scheme is about 15, whereas as shown in Fig. 5, for the weaker channel gain user, at the most of the achievable data rates, we observe that the SNR P/σ^2 loss of the proposed cross-correlated SC scheme over the conventional auto-correlated SC scheme is negligible.

It should be noted that although a closed-form equation is currently not tractable, the extension of these results for $M \geq 3$ users could be obtained by heavy algebraic manipulation.

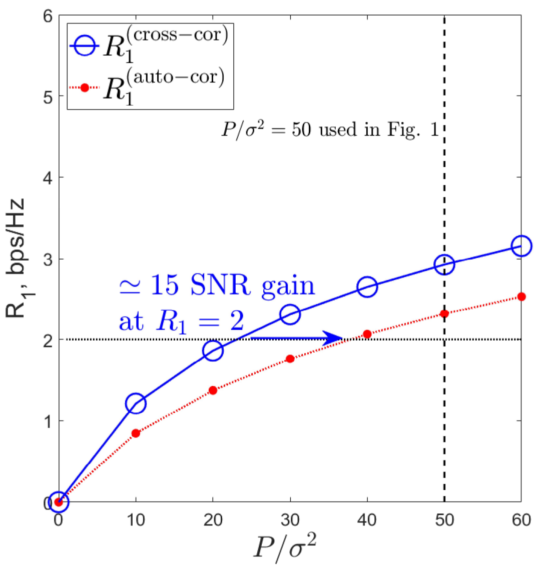

Fig. 4. Comparison of achievable date rates of proposed cross-correlated SC and conventional auto-correlated SC, with varying SNR P/σ^2 and fixed $\beta_1 = 0.2$.

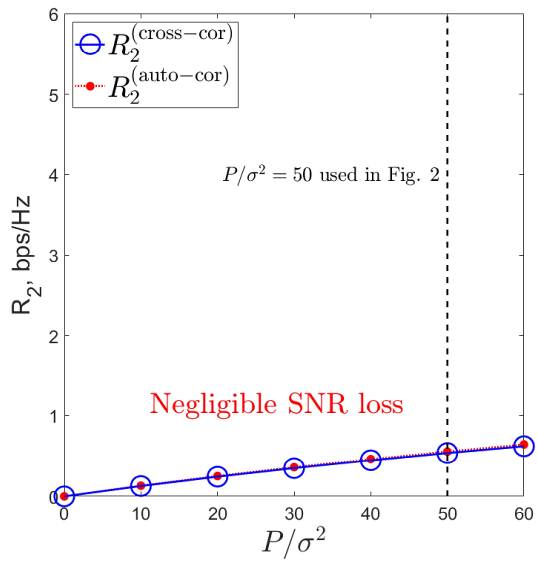

Fig. 5. Comparison of achievable date rates of proposed cross-correlated SC and conventional auto-correlated SC, with varying SNR P/σ^2 and fixed $\beta_1 = 0.2$

5. Conclusion

This paper proposed the cross-correlated SC scheme for NOMA, in order to improve the sum rate of the conventional auto-correlated SC scheme. First, we derived the analytical expression of the sum rate of the proposed cross-correlated SC scheme. Then, numerical analyses demonstrated that the sum rate of the proposed cross-correlated SC scheme is larger than that of the conventional auto-correlated SC scheme. We also showed that for the stronger channel gain user, the SNR gain of the proposed cross-correlated SC scheme is about 15, compared with the conventional auto-correlated SC scheme. As a result, the proposed cross-correlated SC scheme could be a promising technology for 6G URLLC.

As a direction of future researches, it would be significant to investigate a practical modulation scheme based on the analysis of this paper.

Finally, as an application of the proposed scheme, we could consider massive machine-type communications (MMTC) in the Internet of Thing (IoT) framework, especially with ultra low-latency.

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