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Research paper

Performance of user relay cooperative NOMA system with partial and imperfect CSI

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Abstract

In this paper, we consider a cooperative non-orthogonal multiple access (NOMA) system with user relay under partial and imperfect channel state information (CSI). For a user cooperation, a relay is selected among near users using partial CSI to reduce the delay for the selection process. During the relay selection process, the channel errors caused by the imperfect CSI is considered. And selection combining is applied to the far user for spatial diversity. Outage probabilities of the relay and far user are derived separately in closed-form as a function of the channel errors. It is noticed that the max relay selection strategy is recommendable under fewer channel errors. However, as the channel errors increases, the performance of the relay with max selection degrades and finally approaches that of the randomly selected relay. It means the max relay selection strategy is not effective for the performance gain under high channel errors. Though the performance of the far user degrades as the channel errors increases, the degradation is less sensitive due to the selection combining. We noticed that the end-to-end outage probability with max relay selection is slightly increased with channel errors. However, the performance degradation is more sensitive with random relay selection. To demonstrate the accuracy of the developed analytical results, we showed Monte Carlo simulation results are perfectly matched with the analytical results.

Keywords: *Cooperative Non-Orthogonal Multiple Access (NOMA); Imperfect Channel State Information (CSI); NOMA; Partial CSI; Relay Selection.*

1. Introduction

Recently new mobile technologies are introduced for the fast data transfer within the limited spectrum. Especially Non-orthogonal multiple access (NOMA) has been received significant attention for the next generation multiple access technology to achieve high spectral efficiency, low latency, and fairness among users [1], [2]. In NOMA, the information of multiple users is multiplexed with different power levels and transmit simultaneously, which is different to the conventional orthogonal multiple access (OMA), hence the spectral efficiency is increased.

In general, the far user at the cell edge receives weak signal compared with the near user from a base station. For this reason, NOMA system allocates more powers to the far user than that of the near user. A cooperative communication-using relay can extend the transmission range and increases communication reliability. Hence, a cooperative NOMA, which uses a relay, has been studied actively to cope with the fading degradation.

There are two kinds of relay methods, a dedicated relay method and a user relay method in cooperative NOMA systems. The dedicated relay method is conventional, which relays the received signal from a base station to the users in NOMA system [3], [4]. This method requires a fixed dedicated relay which is not a user in NOMA system. Different from the dedicated relay method, the user relay method utilizes a near user for a relay, which exploits the inherent characteristics of a NOMA system [5], [6]. In NOMA system, multiple users transmit simultaneously, hence near user decodes its information after canceling the interference from the other users. During the interference cancellation process, the information of the far user is obtained. The obtained far user information can be used for relaying. For a temporal network, i.e. an Ad-Hoc Network, the user relay method is convenient to configure and deploy compared with the dedicated relay method which requires a fixed relay.

In a cooperative relay system, the performance of a system can be improved by selecting a relay among candidate relays. For the best relay selection, the full channel state information (CSI) and the partial CSI can be used. Generally, the full CSI means all channel information between nodes in a system and the partial CSI denotes a part of the full CSI. The well-known max-min and max relay selection strategies utilize full CSI and partial CSI, respectively. The best relay with max-min relay selection strategy is selected using the full CSI. However, the max-min strategy needs an extra central controller for the relay selection [7]. Consequently, it increases the system complexity and the overhead information for the full CSI. On the other hand, the best relay with max relay selection strategy is selected using the partial CSI. Though the performance improvement of the max relay selection is less than that of the max-min, however it does not require a central controller [8].

Recent studies show the effects of imperfect CSI, which causes channel errors, on the performance of NOMA system. There are various reasons to cause the channel errors; channel estimation error, feedback delay, fading, quantization error, and etc. F. Fang et al. in [9] and W. Cai et al. in [10] discussed the channel errors to NOMA, however did not include cooperative NOMA system. D. Wan et al. studied the channel error in a cooperative NOMA system, which was assumed a dedicated relay system and didn't considered relay selection [11].

In this paper, we consider a cooperative NOMA system with user relay which is selected among near users using partial CSI. During the relay selection process, we considered channel errors, i.e., imperfect CSI. The effect from the imperfect CSI to the outage performance of the cooperative NOMA system is derived in closed-form. We noticed that the effect is very sensitive to the performance. To

demonstrate the accuracy of the developed analytical results, we showed Monte Carlo simulation results are perfectly matched with the analytical results.
The remainder of this paper is organized as follows. In section II, the proposed system model, channel error, relay selection policy, and the transmission protocol are described. The performances of the selected relay, the far user, and the system are derived analytically in closed-form in section III. The numerical examples are given in section IV, and the analytical results are compared with that of the Monte Carlo simulations. Finally, conclusions are given in section V.

2. System model and transmission protocol

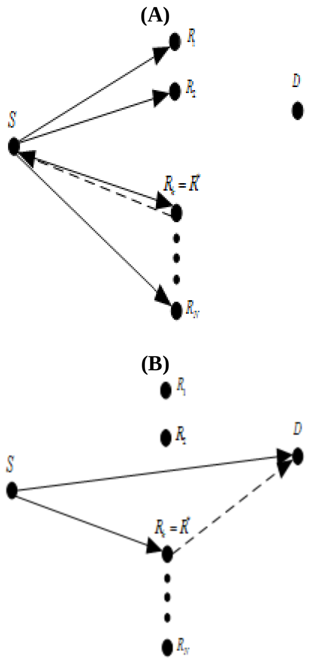

Fig. 1: Down Link Cooperative NOMA System Model.

Fig.1 shows a down link cooperative NOMA system model, which consist of a base station (S), N near users (R_i, $i=1,...,N$), and a far user (D). As mentioned in section I, the users in a NOMA system are multiplexed with different power levels. It means the relay and the far user must be decided before the transmission of the information to each user. Therefore, we assume the best relay to maintain the minimum outage of the far user is selected before information transmission. Also, we assume the near users are closely clustered, consequently the distances from S to R_i, and from R_i to D are identical, respectively [3].
The relay selection process is denoted in Fig. 1(a), where the $k-th$ relay R_i is the selected relay among N near users. The solid lines show S transmits information, and N near users are listen. The dotted line appears feedback from the selected relay. We will describe later the detailed relay selection protocol.
The information transmission steps are shown in Fig. 1(b). At first time slot, the selected relay and the far user listen from S . And next time slot, the selected relay transfers the information to the far user. In a fast fading channel, the channel characteristics change frequently. Therefore, the moment of a relay selection from the actual information transfer is different. This time differences can cause channel errors. As mentioned earlier, channel estimation error, feedback delay, fading, quantization error, and etc. are cause channel errors. The relation between an actual and the estimated channels can be written by [12]

$$h=\rho\hat{h}+\sqrt{1-\rho^2}\varepsilon \quad (1)$$

where h denotes the actual channel coefficient at the information transmission, which is a complex Gaussian random variable $h\sim CN(0,1)$. And the channel coefficient at the relay selection is $\hat{h}\sim CN(0,1)$. ρ is the correlation coefficient between h and $\hat{h}$. ε is the channel error $\varepsilon\sim CN(0,1)$ which is independent to $\hat{h}$. All channels are assumed independent and identically distributed Rayleigh block fading, i.e., the channel coefficient is identical during a time slot and changes next time slot independently. We denote the actual channel coefficient and its estimated channel coefficient between node A and B as h_{AB} and $\hat{h}_{AB}$, respectively.
We adapt max relay selection policy which uses partial CSI; the relay which has the largest channel gain among N paths of $S-R_i$ is selected. The index of the selected relay can be written by

$$k=\arg\max_{i=1,2,...,N}\left(\left|\hat{h}_{SR_i}\right|^2\right). \quad (2)$$

For easy distinction, the selected relay R_k is denoted by R^*.
For the information transmission, it requires two time slots in Fig. 1(b). The following descriptions on time slot1 and 2 are explained detail in [13], [14], and [15]. Here we briefly describe each slot.

1) Time slot 1: S transmit phase

In time slot 1, a base station S transmits the multiplexed signal to the relay and the far user, which can be written by

$$s=\sqrt{P_S}\left\{\sqrt{\alpha_{R^*}}x_{R^*}+\sqrt{\alpha_D}x_D\right\} \quad (3)$$

where P_S denotes transmit power of S . α_{R^*} and α_D are the power allocation coefficients, $\alpha_D>\alpha_{R^*}$ and $\alpha_D+\alpha_{R^*}=1$. x_{R^*} and x_D are information for R^* and D, respectively, and $\left|x_{R^*}\right|^2=\left|x_D\right|^2=1$.
The received signal of the selected relay from $S-R^*$ path can be written by

$$y_{SR^*}=\sqrt{P_{SR^*}}\left\{\sqrt{\alpha_{R^*}}x_{R^*}+\sqrt{\alpha_D}x_D\right\}h_{SR^*}+n_{R^*} \quad (4)$$

where P_{SR^*} is the average received power of the selected relay, $P_{SR^*}=P_Sd_{SR^*}^{-\alpha}$ and where d_{SR^*} denotes the distances between S and R^*, α is the propagation constant which has 3~5 [16]. n_{R^*} is the noise of the relay, $n_{R^*}\sim CN(0,N_0)$ where N_0 is the noise power.
The received signal-to-interference plus noise ratio (SINR) of the relay for the far user information x_D from $S-R^*$ path is given by

$$\gamma_{SR^*}^{x_D}=\frac{\alpha_D\left|h_{SR^*}\right|^2}{\alpha_{R^*}\left|h_{SR^*}\right|^2+1/\rho_{SR^*}} \quad (5)$$

where ρ_{SR^*} denotes the average signal-to-noise ratio (SNR) of the relay from $S-R^*$ path, $\rho_{SR^*}=P_{SR^*}/N_0$. The relay removes the interference component from the received signal by successive interference cancellation (SIC). After SIC, the SNR of the relay for the relay information x_{R^*} can be written by

$$\gamma_{SR^*}^{x_{R^*}}=\alpha_{R^*}\rho_{SR^*}\left|h_{SR^*}\right|^2. \quad (6)$$

Similarly, the received SINR of the far user from the direct path ($S-D$ path) can be given by

$$\gamma_{SD}^{x_D} = \frac{\alpha_D |h_{SD}|^2}{\alpha_{R^*} |h_{SD}|^2 + 1/\rho_{SD}} \tag{7}$$

where ρ_{SD} denotes the average signal-to-noise ratio (SNR) of the relay from $S-D$ path, $\rho_{SD} = P_{SD}/N_0$ and where P_{SD} is the average received power of the far user.

2) Time slot 2: Relaying and combining phase

The decoded information of the far user in SIC process at the relay in time slot 1 is used for the relaying to the far user. Thus the user relay becomes a decode-and-forward relay. Similar to (6), the received SNR of the far user from R^*-D path can be written by

$$\gamma_{R^*D}^{x_D} = \alpha_D \rho_{R^*D} |h_{R^*D}|^2 \tag{8}$$

where ρ_{R^*D} denotes the average SNR of the far user from $S-D$ path, $\rho_{R^*D} = P_{R^*D}/N_0$ and where P_{R^*D} is the average received power of the far user.

The received signals from the indirect path (R^*-D path) and from the direct path ($S-D$ path) are combined for the spatial diversity using selection combining at the far user.

3. Outage probability

Different from the orthogonal multiplexing, NOMA system convey different information to a relay and a destination. Therefore, the outage probability of the relay and the far user should be derived separately. And the end-to-end outage probability is also derived in this section.

3.1. Outage probability of the selected relay

The outage event happens following one of the cases; when the SINR of the far user for x_D at the relay less than the threshold, therefore x_D cannot be decoded. Next, even x_D decoded successfully, when the SNR of the relay for x_{R^*} after SIC cannot be decoded. Therefore, the outage probability of the relay can be written by

$$P_{o,R^*} = \Pr\left(\gamma_{SR^*}^{x_D} < \Gamma_D\right) + \Pr\left(\gamma_{SR^*}^{x_D} \ge \Gamma_D,\ \gamma_{SR^*}^{x_{R^*}} < \Gamma_{R^*}\right) \tag{9}$$

where $\Gamma_D = 2^{2R_D} - 1$ and $\Gamma_{R^*} = 2^{R_{R^*}} - 1$ are the threshold of the far user and the relay, respectively. R_D and R_{R^*} denote the spectral efficiency of the far user and the relay, respectively.

By replacing (5) into the first probability of (9), we have

$$\begin{aligned}\Pr\left(\gamma_{SR^*}^{x_D} < \Gamma_D\right) &= \Pr\left(\frac{\alpha_D |h_{SR^*}|^2}{\alpha_{R^*} |h_{SR^*}|^2 + 1/\rho_{SR^*}} < \Gamma_D\right) \\ &= \Pr\left(|h_{SR^*}|^2 < \varsigma\right)\end{aligned} \tag{10}$$

where $\varsigma = \Gamma_D / (\alpha_D - \Gamma_D \alpha_{R^*})\rho_{SR^*}$ and $\Gamma_D < \alpha_D / \alpha_{R^*}$. The part of the second probability can be given by

$$\begin{aligned}\Pr\left(\gamma_{SR^*}^{x_{R^*}} < \Gamma_{R^*}\right) &= \Pr\left(\alpha_{R^*} \rho_{SR^*} |h_{SR^*}|^2 < \Gamma_{R^*}\right) \\ &= \Pr\left(|h_{SR^*}|^2 < \eta\right)\end{aligned} \tag{11}$$

where $\eta = \Gamma_{R^*} / \alpha_{R^*} \rho_{SR^*}$. The outage probability of the relay R^* can be rewritten by replacing (10) and (11) into (9),

$$\begin{aligned}P_{o,R^*} &= \Pr\left(|h_{SR^*}|^2 < \varsigma\right) + \Pr\left(|h_{SR^*}|^2 \ge \varsigma,\ |h_{SR^*}|^2 < \eta\right) \\ &= \mathrm{F}_{H_{R^*}}\left\{\max(\varsigma, \eta)\right\}\end{aligned} \tag{12}$$

For the notational simplicity, we use $|h_{SR^*}|^2 = H_{R^*}$ in the last equality of (12). $F_{H_{R^*}}\{\max(\varsigma,\eta)\}$ denotes the cumulative distribution function (CDF) of H_{R^*}. To begin with, we derive the probability density function (pdf) $f_{H_{R^*}}(\bullet)$ of H_{R^*}. Then, we can obtain the CDF of H_{R^*} by integrating the pdf. As shown in (1), the pdf at the information transmission of H_{R^*} can be written by

$$f_{H_{R^*}}(z) = \int_0^\infty f_{H_{R^*}|\hat{H}_{R^*}}(z|x) f_{\hat{H}_{R^*}}(x)\, dx \tag{13}$$

where $f_{H_{R^*}|\hat{H}_{R^*}}(z|x)$ is the conditional pdf with channel error, and is given by [17]

$$f_{H_{R^*}|\hat{H}_{R^*}}(z|x) = \frac{1}{1-\rho^2}\, e^{-\frac{z+\rho^2 x}{1-\rho^2}}\, I_o\left(\frac{2\rho\sqrt{zx}}{1-\rho^2}\right). \tag{14}$$

And $f_{\hat{H}_{R^*}}(x)$ is the pdf of the selected relay which has the maximal channel gain among N paths of $S-R_i$, which can be obtained from CDF of

$$F_{\hat{H}_{R^*}}(\mathrm{X}) = \prod_{i=1}^{N} (1 - e^{-\mathrm{X}}). \tag{15}$$

By taking differentiation, the pdf can be written by

$$\begin{aligned}f_{\hat{H}_{R^*}}(x) &= N(1-e^{-x})^{N-1} e^{-x} \\ &= \sum_{i=1}^{N} \binom{N}{i} (-1)^{i-1}\, i e^{-ix}\end{aligned}. \tag{16}$$

Replacing (14) and (16) into (13) and after rearrangement, we can obtain

$$f_{H_{R^*}}(z) = \frac{1}{1-\rho^2} e^{-z/(1-\rho^2)} \sum_{i=1}^{N} \binom{N}{i} (-1)^{i-1} i \int_0^\infty e^{-\left(\frac{\rho^2}{1-\rho^2}+i\right)x} I_o\left(\frac{2\rho\sqrt{zx}}{1-\rho^2}\right) dx. \tag{17}$$

From (6.614.3) and (9.220.2) of [18],

$$\int_0^\infty e^{-\alpha x} I_{2\nu}\left(2\sqrt{\beta x}\right) dx = \frac{1}{\sqrt{\alpha\beta}\,\Gamma(2\nu+1)} e^{\frac{\beta}{2\alpha}} \Gamma(\nu+1) M_{-1/2,\nu}\left(\frac{\beta}{\alpha}\right), \quad \alpha > 0, \nu > -1 \tag{18}$$

where,

$$M_{\lambda,\mu}(z) = z^{\mu+1/2} e^{-z/2} \Phi\left(\mu - \lambda + \frac{1}{2},\ 2\mu+1;\ z\right) \tag{19}$$

and $\Phi(\alpha,\alpha,z) = e^z$ [18, (9.215.1)]. From (18) and (19), we can write the pdf in closed-form,

$$f_{H_{R^*}}(z) = \sum_{i=1}^{N} \binom{N}{i} (-1)^{i-1} i\, \frac{1}{\rho^2 + (1-\rho^2)i}\, e^{-\frac{z}{1-\rho^2}\left\{1 - \frac{\rho^2}{\rho^2 + (1-\rho^2)i}\right\}}. \tag{20}$$

Taking integration of (20), the CDF of H_{R^*} can be derived

$$F_{H_{R^*}}(y) = \int_0^y f_{H_R}(z)dz = \sum_{i=1}^{N} \binom{N}{i} (-1)^{i-1} \frac{i}{\rho^2 + (1-\rho^2)i} \Phi_a(y) \quad (21)$$

where $\Phi_a(y) = \left(1 - e^{-ay}\right)/a$ and $a = \frac{1}{1-\rho^2}\left\{1 - \frac{\rho^2}{\rho^2 + \left(1-\rho^2\right)i}\right\}$.

Therefore, the outage probability of R^* in (12), $F_{H_{R^*}}\left\{\max\left(\varsigma,\eta\right)\right\}$, can be obtained by replacing $\max\left(\varsigma,\eta\right)$ instead of y in (21).

3.2. Outage probability of the far user

The far user combine the received signals both from the indirect path ($R^* - D$ path) and the direct path ($S-D$ path) for the special diversity. Maximal ratio combining (MRC) and selection combining (SC) are frequently used combining techniques. MRC has high diversity gain compared with SC in fading channels. However, MRC has more complex than SC for the implementation issues, also expected more delay for signal processing aspect. In this paper, we consider channel errors caused by fast fading, hence adapt SC for easy implementation and less delay. The outage probability of the far user which has SC can be written by

$$P_{o,D} = P_{o,ind} \times P_{o,dir} \quad (22)$$

where $P_{0,ind}$ and $P_{0,dir}$ denote the outage probability of indirect path and direct path, respectively.

An outage event happens following one of the cases; when the received SNR from $S-R^*$ path less than the threshold or when the received SNR from R^*-D path less than the threshold. Then, the outage probability of the far user from the indirect path can be written by

$$\begin{aligned} P_{o,ind} &= \Pr\left(\min\left(\gamma_{SR^*}^{x_D},\ \gamma_{R^*D}^{x_D}\right) < \Gamma_D\right) \\ &= 1\text{-}\Pr\left(\gamma_{SR^*}^{x_D} \geq \Gamma_D\right)\Pr\left(\gamma_{R^*D}^{x_D} \geq \Gamma_D\right) \\ &= 1\text{-}\Pr\left(H_{R^*} \geq \varsigma\right)\Pr\left(H_{R^*D} \geq \lambda\right) \\ &= 1 - \left\{1 - F_{H_{R^*}}(\varsigma)\right\} e^{-\lambda} \end{aligned} \quad (23)$$

where $H_{R^*D} = \left|h_{R^*D}\right|^2$ and, $\lambda = \Gamma_D / \rho_{R^*D}\alpha_D$, $\rho_{R^*D} = P_{R^*D}/N_0$. $P_{R^*D} = P_{R^*} d_{R^*D}^{-\alpha}$ is the average received power from R^*-D path, P_{R^*} denotes the transmitting power of the relay. The last equality of (23) assumes Rayleigh fading, $F_{H_{R^*}}(\varsigma)$ can be obtained from (21) by replacing ς instead of y.

Similar to (10), the outage probability from the direct path can be derived and written by

$$P_{o,dir} = \Pr\left(\gamma_{SD}^{x_D} < \Gamma_D\right) = \Pr\left(H_{SD} < \chi\right) = 1 - e^{-\chi} \quad (24)$$

where $H_{SD} = \left|h_{SD}\right|^2$, $\chi = \Gamma_D / \rho_{SD}\left(\alpha_D - \alpha_R \Gamma_D\right)$, $\rho_{SD} = P_{SD}/N_0$, and $P_{SD} = P_S d_{SD}^{-\alpha}$ which is the average received power from direct path.

Finally, the outage probability of the far user can be obtained by replacing (23) and (24) into (22).

3.3. End-to-end outage probability

The end-to-end outage, that is the system outage, events happen either the relay or the far user is fail. Therefore the end-to-end outage probability $P_{o,sys}$ is the complementary event of both the relay and the far user success. It can be written by

$$P_{o,sys} = 1 - (1 - P_{o,R^*})(1 - P_{o,D}). \quad (25)$$

From (12) and (22), the system outage probability in (25) is given by

$$P_{o,sys} = 1 - \left[1 - F_{H_{R^*}}\left\{\max(\varsigma,\eta)\right\}\right]\left[1 - \left\{1 - \left(1 - F_{H_{R^*}}(\varsigma)\right)e^{-\lambda}\right\}\left(1 - e^{-\chi}\right)\right]. \quad (26)$$

4. Numerical examples

In this section, the numerical examples of the outage probability as a function of correlation which imply channel errors in (1) are given.

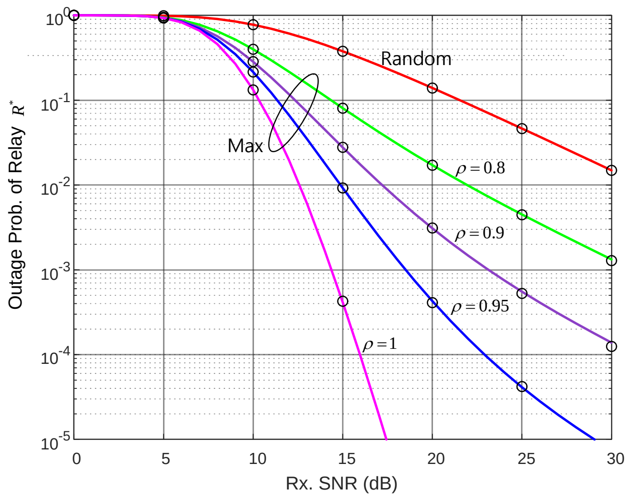

Fig. 2: Outage Probability of the Selected Relay ($R_D = R_{R^*} = 1$, $N = 8$, $\rho_{SR^*} = \rho_{SR_i}$, $\alpha_D = 0.8$).

Fig.2 shows the outage probability of the relay R^*, where the solid lines and "o" denote analytical and Monte Carlo simulation results, respectively. The analytical and the simulation results are perfectly matched. In this figure, "Random" and "Max" means that the randomly selected relay and the max relay in (2), respectively. As expected, the max relay has better performance than the randomly selected relay. It is noticed that $\rho = 0.8$ need 16 dB more SNR to satisfy the outage probability of 1×10^{-3} compared with no channel error ($\rho = 1$).

The outage probability of the relay is sensitive to channel errors. As ρ decreases, the performance improvement with the max relay decreases, and finally the performance is identical to that of the randomly selected relay with $\rho = 0$. On the contrary, as ρ increases the performance improvement is noticeable. It is concluded that the relay with max selection is recommendable under fewer channel errors. However, as the channel errors increases, the performance of the relay with max selection degrades and finally approaches to that of the randomly selected relay.

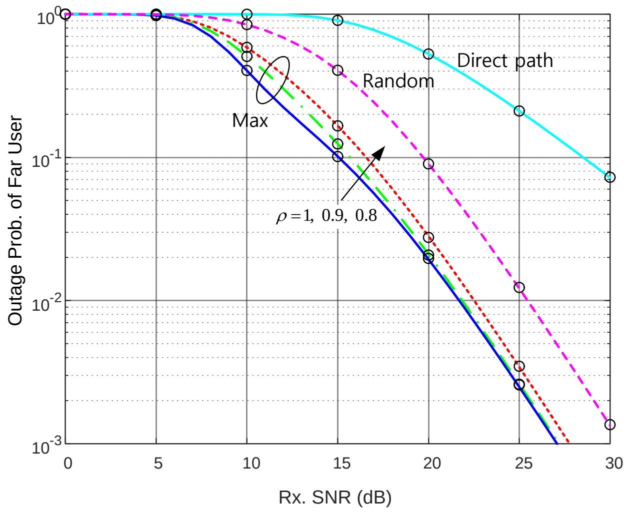

Fig. 3: Outage Probability of Far User ($R_D = R_{R^*} = 1$, $\rho_{SR^*} = \rho_{R^*D}$, $\rho_{SD} = 0.2\rho_{R^*D}$, $\alpha_D = 0.8$).

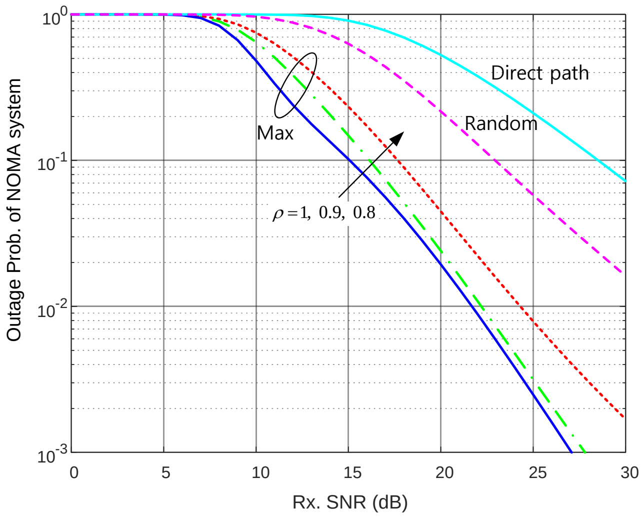

Fig. 4: End-to-End Outage Probability of NOMA System ($R_D = R_{R^*} = 1$, $N = 8$, $\alpha_D = 0.8$, $\rho_{SR^*} = \rho_{R^*D}$, $\rho_{SD} = 0.2\rho_{R^*D}$).

Fig. 3 shows the outage probability of the far user, where "Direct path" means the outage probability with a direct path ($S-D$ path) only. Therefore, the outage probability of "Direct path", which does not receive the signal from the indirect path ($S-R^*-D$ path), is greater than that of a cooperative NOMA. And "Random" means randomly selected relay. Hence, the outage probability of "Random" is greater than that of the max relay.

As in Fig. 2, "Max" means the outage probability of the max relay. As the correlation coefficient decreases the performance continues to degrade, but the degradation is not sensitive compared with that of the relay. It is interpreted that the performance of the far user is affected from R^*-D and $S-D$ paths as well as $S-R^*$ paths. Hence, the effect of the channel errors caused at R^*-D path to the performance is mitigated. Moreover, as the SNR increases, the performance degradation is less sensitive to the correlation coefficient.

The end-to-end outage probability is shown in Fig. 4, where the trend of the outage probability is similar to that of the far user. However, it is noted that the effect of the channel errors on the performance is greater than that of the far user. Especially, the outage probability of "Random" increases noticeably compared with that of the far user. It is interpreted that the increase of the outage probability with the randomly selected relay affects the end-to-end outage probability.

5. Conclusion

In this paper, we consider user relay cooperative NOMA system with partial and imperfect CSI. For the relay selection, max selection strategy which utilizes partial CSI is adapted to reduce the delay for the selection process. The channel error which is caused from imperfect CSI is also included for the performance analysis. The near user which has the maximum channel gain among source-near user paths is selected as a user relay, and selection combining is applied to the far user for spatial diversity.

Due to the information of the near user and far user is different in NOMA system, the outage probability of the near user (i.e., selected relay) and the far user are derived in a closed-form as a function of the correlation coefficient, respectively. Where the correlation coefficient can be used as a measure of the channel errors. The analytically derived performance is verified through Monte Carlo simulation. The results obtained from the analysis and from the simulation are perfectly matched.

It is noticed that the outage probability of the relay is sensitive to the channel errors. To maintain the outage probability of 1×10^{-3} with $\rho=0.8$ compared with $\rho=1$, it requires more than 16 dB of SNR under the given conditions. However, the outage probability of the far user is less sensitive to the channel errors. Obviously, the performance of the far user is affected from R^*-D and $S-D$ paths as well as $S-R^*$ paths. The selection combining, which select strong signal from R^*-D or $S-D$ paths, at the far user mitigates the performance degradations.

Though the end-to-end outage probability with max relay selection is slightly increased with channel errors, the performance degradation is more sensitive to that with random relay selection.

Further research will be focused on the effect with the different kinds of relay selection to the performance of cooperative NOMA systems.

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