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Cooperative Dual Relay Overlay CR NOMA Network with Outdated CSI

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ABSTRACT

In this paper, a dual relaying non-orthogonal multiple access (NOMA) scheme in an overlay cognitive radio network is proposed to improve the performance of a licensed primary receiver (PR) in the shadowing area as well as a NOMA secondary receiver (SR). Closed-form expressions for the outage probability of the PR and the SR are derived, which includes the unavoidable effect of the outdated channel state information (CSI) caused during the relay selection process. Analytical results showed the performance improvement of both of the PR and SR due to the spatial gain obtained from the proposed dual relays. It is also noticed that the less correlation between the actual and the outdated CSI incurred more performance degradation. Also, when the distance of relay-SR is shorter than relay-PR, it was noticed that the optimal power allocation to the PR was increased to maintain the minimum outage probability. The analytical outage probability expressions have been validated through simulations.

Key words: Cognitive radio, NOMA, Overlay CR, Relay selection.

1. INTRODUCTION

Recently, non-orthogonal multiple access (NOMA) is considered as a candidate multiple access technology for 5G wireless networks for efficient spectrum utilization and low latency [1], [2], [3], [4]. Conventional orthogonal multiple access (OMA) needs communication resources such as orthogonal frequency, time slot, and code for an information transfer, however, NOMA transmits multiple information simultaneously with different power levels. Consequently, NOMA can achieve spectral efficiency and low latency.

To achieve further spectrum utilization, cognitive radio (CR) which shares the licensed spectrum with the unlicensed secondary system is highly focused [5], [6]. The representative CR networks are interweave, underlay, and overlay CR networks. In the Interweave CR network, the primary transmitter (PT) and secondary transmitter (ST) do not transmit simultaneously, however, the ST shares the spectrum when the spectrum does not occupy by the PT. While in the underlay CR network, the PT can transmit simultaneously under the limited interference to the PR [7], [8].

On the other hand, in overlay CR networks, the ST can relay the information to the PR while the PR cannot decode the information due to the shadowing, fading, or interference. Conventional relay has been introduced for the communication reliability and extended coverage in fading channel [9]. Also the main role of the relay in an overlay CR network is to extend the coverage of the primary system. Furthermore the overlay CR requires less overhead than the underlay CR which requires much overhead to control the transmit power to sustain the limited interference level.

More recently, several CR NOMA networks have been studied. Especially, in [6], [10], introduce a selected relay in overlay CR NOMA networks to improve the performance of the PR; the best relay is selected to maximize the spatial diversity gain, consequently, the outage probability of the PR in shadowing area is minimized. The best relay has the maximum channel gain of the relay-PR paths is selected among candidate relays. However, in terms of the outage probability of the SR, there are two disadvantages; first, the relay multiplex the messages to the PR and SR in NOMA protocol with more power allocation to PR for the reliable reception. The transmit power of the relay is limited, hence the less power is allocated to the SR. This is the first disadvantage to the performance of the SR. Second, the selected best relay has the maximum channel gain of relay-PR paths. However, the selected relay does not guarantee the maximum channel gain of relay-SR paths, it becomes a simple transmit node that does not have the spatial gain on the side of the SR.

On the other hand, the CSI is constantly changing in a fading channel. The outdated CSI caused from the time differences between the relay selection moment and the relay transmitting moment degrades the receiver performance. Most studies on cooperative CR with relay selection did not include the degradation caused by the outdated CSI, they assumed perfect CSI [6], [10], [11].

Motivated by the above studies, in this paper, we propose a dual relaying overlay CR NOMA network to improve the performance of SR as well as PR. We derive the closed-form expressions for the outage probability of PR and SR. The analytical results are conformed through comparison with simulation. The contributions of this paper can be summarized as follows.

● Propose a dual rely overlay CR NOMA network to improve the performance of PR and SR, and derive the analytical outage probabilities in closed-form.

- Outdate CSI which is unavoidable for relay selection processing is included in the performance analysis. And the degradation is investigated in a fading channel.
- Effect of the power allocation to the performance of the PR and SR is analyzed. And the optimum power allocation is considered.

The remainder of this paper is organized as follows. Section II presents the proposed network model and transmission protocols. The closed-form expressions for the outage probability of the PR and the SR are analytically derived in Section III. In Section IV, numerical and the simulation results are presented and discussed. Finally, the conclusions and further research directions are given in Section V.

2. SYSTEM MODEL

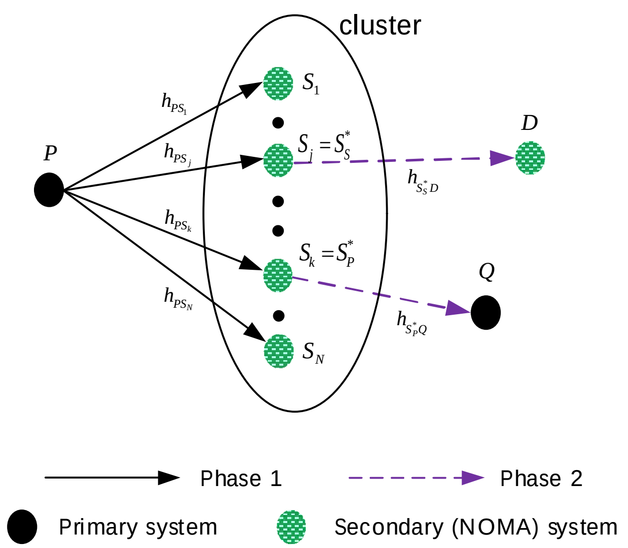

Figure 1: Proposed dual relay overlay CR NOMA network model

Figure1 shows the proposed dual relay overlay CR NOMA network model, where P and Q denote the PT and PR, respectively. Also S_i $(i = 1, 2, .., N)$ and D is the STs and SR, respectively. In an overlay CR network, the STs become decode-and-forward relays for PR and for ST. The selected relays decode the PT signal and multiplex with the message for SR. After multiplexing with NOMA protocol, the dual relays transmit same signal to the PR and the SR. S_j and S_k denote the selected relays for D and Q, respectively. Relay selection will be described later. We assume the relays are clustered [12], hence, the distances of P - S_i path, S_i - D path, and S_i - Q path are identical (i.e., $d_{PS_i} = d_{PS}$, $d_{S_iD} = d_{SD}$, and $d_{S_iQ} = d_{SQ}$), respectively.

The transmission consists of two phases; the solid and partial lines denote phase 1 and phase 2, respectively. In phase1, the PT transmits and S_i receives. We assumed the direct path of P - D path and P - Q path are not exist. The transmitted signal from the PT is $\sqrt{P_P}x_P$, where P_P denotes the transmit power of the PT and x_P is the message for the PR with $E\left[\left|x_P\right|^2\right] = 1$.

The received signal of S_i can be written by

$$y_{S_i} = \sqrt{P_R}\,h_{PS_i}x_P + n_S \tag{1}$$

where P_R is the received power of S_i, $P_R = P_P d_{PS}^{-n}$, and where d_{PS} is the distance of $P - S$ path, n is the propagation loss coefficient. h_{PS_i} is the channel coefficient of $P - S_i$ path, which has the complex Gaussian distribution with zero mean and unit variance, $h_{PS_i} \sim CN(0,1)$. n_S denotes the noise of the relay which has the complex Gaussian distribution with zero mean and variance of N_0, $n_S \sim CN\left(0, N_0\right)$. We assume that the noise power of each node is identical to N_0. The Signal-to-noise ratio (SNR) for decoding x_P at S_i can be given by

$$\gamma_{S_i}^{x_P} = \left|h_{PS_i}\right|^2 \rho_R \tag{2}$$

where the SNR of the relay, $\rho_R = P_R / N_0$. When the received SNR at S_i is greater than the threshold, the successful decoding happens. The successful relays become the candidate relays. And the decoding set ($\mathbf{Z}$) denotes the candidate relay set, where the cardinal of $\mathbf{Z}$ of $\left|\mathbf{Z}\right| = l$, $0 \le l \le N$.

In phase 2, the selected relays transmit and the PR and the SR listen. Prior to the transmission, the transmit relays are determined. Notice that the channel coefficient h at transmission moment and the channel coefficient $\hat{h}$ at relay selection moment is different in fading environment, the conditional distribution can be written by [13]

$$h\left|\hat{h} \sim CN\left(\rho\hat{h},\ 1-\rho^2\right)\right. \tag{3}$$

where ρ denotes the correlation coefficient between two channels, $0 \le \rho \le 1$. Jakes' model defines the correlation, $\rho = J_0\left(2\pi f_D T\right)$ where f_D is Doppler frequency and T is the time delay between two moments. $J_0(\cdot)$ is the zero-order Bessel function of the first kind.

D and Q transmit a pilot tone, respectively, and the relays which have the maximum channel gain are selected among the decoding set. The index of the selected relays is given by

$$j = \arg max\left(\left|\hat{h}_{S_mD}\right|^2\right),\ k = \arg max\left(\left|\hat{h}_{S_mQ}\right|^2\right),\ m = 1, 2, .., l. \tag{4}$$

The selected relays are denoted $S_j = S_S^*$ and $S_k = S_P^*$ for the notational simplicity in Figure 1. The transmit signal of S_S^* and S_P^* is $\sqrt{P_S}\left(\sqrt{\alpha_P}x_P + \sqrt{\alpha_S}x_S\right)$ according to the NOMA protocol, where P_S is the transmit power of the relay, α_P and α_S denote the power allocation coefficients. For the reliable reception probability of the PR, the more power is allocated to the PR than the SR, hence, $\alpha_P > \alpha_S$ with $\alpha_P + \alpha_S = 1$. x_P and x_S represent the message for the PR and SR, and the average of the message are $E\left[|x_P|^2\right] = 1$ and $E\left[|x_S|^2\right] = 1$, respectively. We assume the PR and SR receives the strongest signal only. The received signal of Q can be written by

$$y_Q = \sqrt{P_Q}\left(\sqrt{\alpha_P}h_{S_P^*Q}x_P + \sqrt{\alpha_S}h_{S_P^*Q}x_S\right) + n_Q \tag{5}$$

where P_Q denotes the received power of Q, $P_Q = P_S d_{S_P^*Q}^{-n}$ where $d_{S_P^*Q}$ is the distance of $S_P^* - Q$ path. As denoted in (1), $h_{S_P^*Q}$ can be written as $h_{S_P^*Q} \sim CN(0,1)$, and $n_Q \sim CN\left(0, N_0\right)$. Define the transmit SNR to P_S / N_0. The Signal-to-interference plus noise ratio (SINR) for decoding x_P at Q can be given by

$$\gamma_Q^{x_p} = \frac{\alpha_P \left|h_{S_P^*Q}\right|^2}{\alpha_S \left|h_{S_P^*Q}\right|^2 + 1/\rho_Q} \tag{6}$$

where ρ_Q is the received signal-to-noise ratio (SNR) of Q, $\rho_Q = P_Q / N_0$.

Similarly, the received signal of D, which is the NOMA receiver, can be expressed as

$$y_D = \sqrt{P_D}\left(\sqrt{\alpha_P}h_{S_P^*D}x_P + \sqrt{\alpha_S}h_{S_P^*D}x_S\right) + n_D \tag{7}$$

where P_D denotes the received power of D, $P_D = P_S d_{S_S^*D}^{-n}$ where $d_{S_S^*D}$ is the distance of $S_S^* - D$ path. $h_{S_S^*D}$ is the channel coefficient of $S_S^* - D$ path, $h_{S_S^*D} \sim CN(0,1)$. And the noise of D, $n_D \sim CN\left(0, N_0\right)$. The SINR for decoding x_P at D can be written by

$$\gamma_D^{x_p} = \frac{\alpha_P \left|h_{S_S^*D}\right|^2}{\alpha_S \left|h_{S_S^*D}\right|^2 + 1/\rho_D} \tag{8}$$

where ρ_D is the received SNR at D, $\rho_D = P_D / N_0$. After Successive interference cancellation, the SNR for decoding x_S at D can be written by

$$\gamma_D^{x_S} = \alpha_S \left|h_{S_S^*D}\right|^2 \rho_D . \tag{9}$$

3. OUTAGE ANALYSIS

3.1 Outage Probability of PR

In phase 1, when the received SNR of the relays exceeds the threshold, the relays become the decoding set ($\mathbf{Z}$). The probability of the cardinal of the decoding set equals to l can be written by

$$\Pr\left(|\mathbf{Z}| = l\right) = \binom{N}{l}\left\{\Pr\left(\gamma_{S_i}^{x_P} \geq \Gamma_P\right)\right\}^l \left\{\Pr\left(\gamma_{S_i}^{x_P} < \Gamma_P\right)\right\}^{N-l} \tag{10}$$

where Γ_P represents the threshold, $\Gamma_P = 2^{2R_P} - 1$, and R_P is the spectral efficiency for the PR. When the received SINR/SNR bellows the threshold, then the outage is happening. The outage probability of the PR can be expressed as

$$P_{0,\mathrm{Q}} = \sum_{l=0}^{N} \Pr\left(\gamma_Q^{x_P} < \Gamma_P \middle\| \mathbf{Z}| = l\right)\Pr\left(|\mathbf{Z}| = l\right) \tag{11}$$

where the first conditional probability of (11) can be obtained from (6),

$$\Pr\left(\gamma_Q^{x_P} < \Gamma_P \middle\| \mathbf{Z}| = l\right) = \Pr\left(\left|h_{S_P^*Q}\right|^2 < \eta \middle\| \mathbf{Z}| = l\right) = F_{H_{S_P^*Q}}\left(\eta \middle\| \mathbf{Z}| = l\right),$$
$$\Gamma_P < \frac{\alpha_P}{\alpha_S} \tag{12}$$

where $H_{S_P^*Q} = \left|h_{S_P^*Q}\right|^2$, $\eta = \Gamma_P / \rho_Q\left(\alpha_P - \Gamma_P\alpha_S\right)$. And $F_{H_{S_P^*Q}}(\cdot)$ represents the cumulative distribution function (CDF) of $H_{S_P^*Q}$. The conditional probability density function (PDF) of $H_{S_P^*Q}$ is given by [13]

$$f_{H_{S_P^*Q}|\hat{H}_{S_P^*Q}}\left(z|x\right) = \frac{1}{1-\rho^2} I_0\left(\frac{2\rho\sqrt{zx}}{1-\rho^2}\right) e^{-\frac{z+\rho^2 x}{1-\rho^2}} \tag{13}$$

where $I_0(\cdot)$ stands for the zero-order modified Bessel function of the first kind which is given by [14, (6.19.4)]

$$I_0\left(z\right) = \sum_{n=0}^{\infty} \frac{\left(z/2\right)^{2n}}{\Gamma\left(n+1\right)n!} \tag{14}$$

where $\Gamma(\cdot)$ denotes Gamma function, $\Gamma\left(z\right) = \int_0^{\infty} t^{z-1}e^{-t}dt$. Therefore, the PDF of $H_{S_P^*Q}$ can be obtained from the conditional PDF of (13), which is given by

$$f_{H_{S_P^*Q}}\left(z\right)=\int_0^\infty f_{H_{S_P^*Q}|\hat{H}_{S_P^*Q}}\left(z|x\right)f_{\hat{H}_{S_P^*Q}}\left(x\right)dx \ . \tag{15}$$

While, the PDF of $\hat{H}_{S_P^*Q}$ is given by [15], [16]

$$f_{\hat{H}_{S_P^*Q}}\left(x\right)=\sum_{n=1}^{l}\binom{l}{n}\left(-1\right)^{n-1}ne^{-nx} \ . \tag{16}$$

After replacing (13) and (16), the PDF of (15) can be rearranged by

$$f_{H_{S_P^*Q}}(z)=\sum_{n=1}^{l}\binom{l}{n}(-1)^{n-1}\frac{n}{\rho^2+\left(1-\rho^2\right)n}e^{-\frac{z}{1-\rho^2}\left\{1-\frac{\rho^2}{\rho^2+\left(1-\rho^2\right)n}\right\}} \ . \tag{17}$$

Therefore, we can obtain the CDF by integrating (17), which is the conditional probability of (12) is given by

$$\begin{aligned}F_{H_{S_P^*Q}}(\eta\|\mathbf{Z}|=l)&=\int_0^\eta f_{H_{S_P^*Q}}(z)dz\\&=\sum_{n=1}^{l}\binom{l}{n}(-1)^{n-1}\frac{n}{\rho^2+\left(1-\rho^2\right)n}\Psi_a\left(\eta\right)\end{aligned} \tag{18}$$

where $\Psi_a\left(\eta\right)=\frac{1}{a}\left(1-e^{-a\eta}\right)$, and where

$$a=\frac{1}{1-\rho^2}\left\{1-\frac{\rho^2}{\rho^2+\left(1-\rho^2\right)n}\right\}.$$

3.2 Outage Probability of SR

Similar to the outage probability of the PR, outage probability of the SR can be defined by

$$P_{0,\mathrm{D}}=\sum_{l=0}^{N}\left(\mathrm{P}_{0,S_S^*D}\|\mathbf{Z}|=l\right)\Pr\left(|\mathbf{Z}|=l\right) \tag{19}$$

where $\left(\mathrm{P}_{0,S_S^*D}\|\mathbf{Z}|=l\right)$ is the conditional outage probability of P_{0,S_S^*D} , where $\Pr\left(|\mathbf{Z}|=l\right)$ is given in (10) and P_{0,S_S^*D} is the outage probability of the SR between S_S^* and D path. Since the SR is NOMA receiver, the decoding is done after removing the interference component by SIC. Therefore, the outage happens two cases; Firstly, the SR fails to decode the message for the PR. Secondly, though the message for the PR success, the SR fails to decode the message for the SR. The conditional outage probability of the SR can be written by [17]

$$\begin{aligned}\left(\mathrm{P}_{0,S_S^*D}\middle|\ |\mathbf{Z}|=l\right)&=\Pr\left(\gamma_D^{x_P}<\Gamma_P\middle|\ |\mathbf{Z}|=l\right)\\&\quad+\Pr\left(\gamma_D^{x_P}\geq\Gamma_P,\ \gamma_D^{x_S}<\Gamma_S\middle|\ |\mathbf{Z}|=l\right)\\&=\Pr\left(\left|h_{S_S^*D}\right|^2<\max\left\{\frac{\Gamma_P}{\rho_D\left(\alpha_P-\Gamma_P\alpha_S\right)},\ \frac{\Gamma_S}{\rho_D\alpha_S}\right\}\middle|\ |\mathbf{Z}|=l\right)\\&=F_{H_{S_S^*D}}\left(\varsigma\middle|\ |\mathbf{Z}|=l\right)\\&\quad,\ \Gamma_P<\frac{\alpha_P}{\alpha_S}\end{aligned} \tag{20}$$

where Γ_S denotes the threshold, $\Gamma_S=2^{R_S}-1$, and R_S is the spectral efficiency for the SR. $H_{S_S^*D}$ represents $H_{S_S^*D}=\left|h_{S_S^*D}\right|^2$, and $\varsigma=\max\left\{\frac{\Gamma_P}{\rho_D\left(\alpha_P-\Gamma_P\alpha_S\right)},\ \frac{\Gamma_S}{\rho_D\alpha_S}\right\}$. By replacing η with ς into (18), the conditional outage probability of (20) can be obtained. Finally, from (10) and (20), the outage probability of the SR given in (19) can be obtained.

When $\frac{\Gamma_P}{\rho_D\left(\alpha_P-\Gamma_P\alpha_S\right)}\geq\frac{\Gamma_S}{\rho_D\alpha_S}$ and the distances of relay-PR path and relay-SR path is identical (i.e., $d_{S_Q^*Q}=d_{S_S^*D}$), then $\rho_D=\rho_Q$, consequently, the outage probability of (20) and (21) becomes identical.

3.3 Outage Probability of Proposed System

This paper assumes an overlay CR with cooperative NOMA, where the PR does not receive from the PT through direct path due to the shadowing. Therefore, for the successful reception of the proposed dual relay overlay CR NOMA network, both receivers of the PR and SR must be successful. The outage probability of the proposed system can be defined by

$$P_{0,Sys}=1-\left(1-P_{0,Q}\right)\left(1-P_{0,D}\right) \ . \tag{21}$$

4. NUMERICAL EXAMPLES

In this section, the distances are normalized to the distance between the PT and PR. Figure 2 shows the outage probability of the PR with $d_{PS}=0.6$ and $d_{SQ}=0.4$ of which the distances of P - S_i path is longer than S_i - Q path. The solid lines denote the analytical results, and the "*" denotes the simulated ones. The analysis and simulation results are matched well.

It is noticed that the curb with $N=1$ denotes the worst outage probability, that means no spatial diversity gain exist. As the number of relays increases diversity gain increases, hence, the outage probability decreases. This Figure 2 shows that the outage probability increases as the correlation between the actual and outdated CSI increases, however, the effect is lessened as the number of the relays increases. It is interpreted that the spatial diversity mitigates the degradation due to the less correlation.

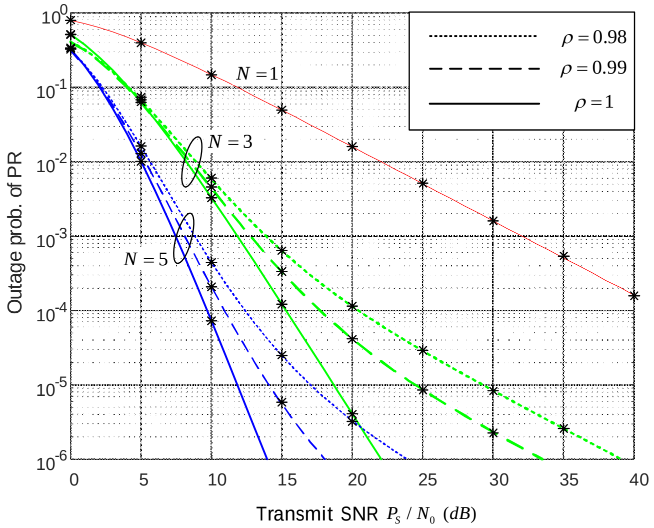

Figure 2: Outage probability of PR with different number of relays ($R_P = R_S = 1$, $n = 3$, $d_{PS} = 0.6$, $d_{SQ} = 0.4$, $\alpha_P = 0.8$, $\alpha_S = 0.2$)

Figure 3 shows the outage probability of the SR with $d_{PS} = 0.6$ and $d_{SD} = 0.8$ of which the distances of S_i - D path is longer than P - S_i path. It is noticed that the performance of the SR in Figure 3 is inferior to that of the PR in Figure 2 due to the less power allocation and the longer distances. As shown in Figure 3, when the case of a single relay ($N=1$), the performance of the SR indicates high outage probability. However, when the additional relay (i.e., $S_j = S_S^*$ in (4)) is adapted which has the maximum channel gain among the candidate relays, the performance of the SR can be improved with the number of relays.

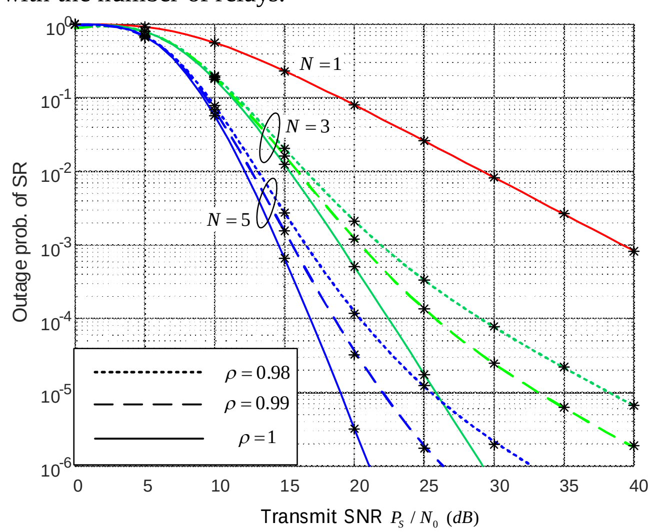

Figure 3: Outage probability of SR with different number of relays ($R_P = R_S = 1$, $n = 3$, $d_{PS} = 0.6$, $d_{SD} = 0.8$, $\alpha_P = 0.8$, $\alpha_S = 0.2$)

The system performance of the proposed network is shown in Figure 4, which has the similar trends to the PR and the SR. As we see in Figure 2 and Figure 3, the performance of the SR is inferior to that of the PR, thus the system performance is nearly identical to that of the SR.

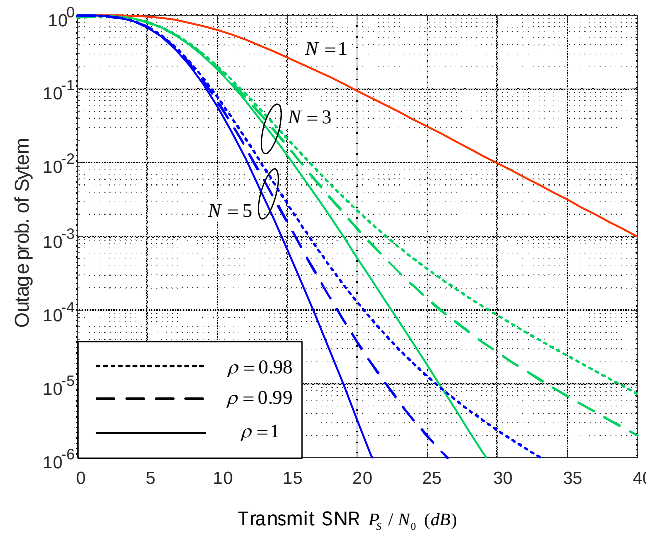

Figure 4: Outage probability of the proposed system ($R_P = R_S = 1$, $n = 3$, $d_{PS} = 0.6$, $d_{SQ} = 0.4$, $d_{SD} = 0.8$, $\alpha_P = 0.8$, $\alpha_S = 0.2$)

Figure 5 shows the performance of the system versus power allocation with the distance of the PT-relay path is fixed to 0.6, where “o” denotes the minimum outage probability with different kinds of distances. This Figure 5 shows two cases. First, the solid lines show the case that the distance of relay-SR (d_{SD}) is shorter than relay-PR (d_{SQ}). Second, the partial lines show the reverse of the first case. Both cases reveal that the performance of the far receiver degrades due to the path loss.

In the first case, as the distance of d_{SQ} increases from 0.6 to 0.8, the optimum power allocation coefficient of α_P which has the minimum outage probability also increases from 0.91 to 0.93. It is interpreted that the distance of d_{SD} is fixed, thus, the performance of the SR is fixed. However, the performance of the PR decreases with the distance of d_{SQ} , accordingly, the optimum α_P increases.

Also in the second case, it is noticed that the optimum α_P is fixed to 0.86 irrespective of the distance of d_{SD} . It is interpreted that the performance of the SR has a logarithmically convex function and is higher than the PR, therefore, the performance of the system is similar to that of the SR. This is the reason why the optimum α_P is fixed.

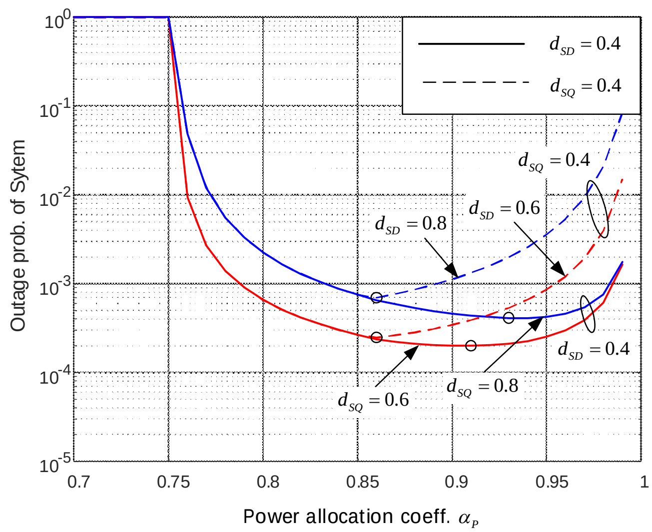

Figure 5: Power allocation vs. outage probability of the proposed system ($R_P = R_S = 1$, $n = 3$, $\rho = 0.98$, $N = 3$, $d_{PS} = 0.6$, Tx $SNR = 20\ dB$)

5. CONCLUSION

Most overlay CR networks have been considered a single relay to improve the reception probability of the PR. Though the single relay can improve the performance of the PR, it does not assure the performance of the SR. In this paper, we propose a dual relay overlay CR NOMA network to improve the performance of the PR as well as the SR. Also, we have considered the effect of the outdated CIS, which is unavoidable for relay selection on the performance. The analytical expression is derived in closed-form. And the analytical results are confirmed through the simulation.
Analytical results were shown that the performance of the PR and the SR improved due to the spatial gain obtained from the proposed dual relays. It was noticed that the less correlation between the actual and the outdated CSI incurred more performance degradation.

On the other hand, when the distance of the relay-SR path is fixed, the optimum power allocation coefficient of α_P increased with the distance of the relay-PR path. On the contrary, when the distance of the relay-PR path is fixed, the optimum α_P is fixed to 0.86.

Future research will be focused on the performance analysis and increase of the spectral efficiency on the CR network with cooperative NOMA under several SRs.

REFERENCES

1. Y. Saito, Y. Kishiyama, A. Benjebbour, T. Nakamura, A. Li, and K. Higuchi, **Non-orthogonal multiple access (NOMA) for cellular future radio access**, in *Proc. 77th Vehicular Technology Conference (VTS spring)*, Dresden, Germany, 2013, pp. 1-5.
https://doi.org/10.1109/VTCSpring.2013.6692652
2. Z. Ding, M. Peng, and H. V. Poor, **Cooperative non-orthogonal multiple access in 5G systems**, *IEEE Communications Letters*, Vol. 19, pp. 1462-1465, Aug. 2015.
https://doi.org/10.1109/LCOMM.2015.2441064
3. Z. Ding, Y. Liu, J. Choi, Q. Sun, M. Elkashlan, C.-L. I, H. V. Poor, **Application of non-orthogonal multiple access in LTE and 5G networks**, *IEEE Communication Magazine*, Vol. 55, pp. 185-191, Feb. 2017.
https://doi.org/10.1109/MCOM.2017.1500657CM
4. S. M. R. Islam, N. Avazov, O. A. Dobre, K.-S. Kwak, **Power domain non-orthogonal multiple access (NOMA) in 5G systems: potentials and challenges**, *IEEE Communications Surveys & Tutorials*, Vol. 19, pp. 721-742, Oct. 2016.
https://doi.org/10.1109/COMST.2016.2621116
5. A. Goldsmith, S. A. Jafar, I. Maric, and S. Srinivasa, **Breaking spectrum gridlock with cognitive radios: an information theoretic perspective**, *Proceedings of the IEEE*, Vol. 97, pp. 894-914, May 2009.
https://doi.org/10.1109/JPROC.2009.2015717
6. L. Lv, J. Chen, Q. Ni, Z. Ding, and H. Jiang, **Cognitive non-orthogonal multiple access with cooperative relaying: a new wireless frontier for 5G spectrum sharing**, *IEEE Communications Magazine*, Vol. 56, pp. 188-195, April 2018.
https://doi.org/10.1109/MCOM.2018.1700687
7. T. M. C. Chu and H.-J. Zepernick, **Non-orthogonal multiple access for DF cognitive cooperative radio networks**, in *Proc. 2018 IEEE International Conference on Communications Workshops (ICC Workshops)*, Kansas City, USA, 2018, pp. 1-6.
8. N. –S. Kim, **Performance of user relaying cooperative NOMA system underlay cognitive radio networks with partial CSI**, *International Journal of Intelligent Engineering and Systems*, Vol. 12, pp. 287-296, April 2019.
https://doi.org/10.22266/ijies2019.0430.28
9. A. N. Rao, B. R. Naik, and L. N. Devi, **Location aware relay node placement for energy constrained wireless sensor networks**, *International Journal of Advanced Trends in Computer Science and Engineering (IJATCSE)*, Vol. 8, No. 3, pp. 519-526, May-June 2019.
https://doi.org/10.30534/ijatcse/2019/28832019
10. W. Liang, S. X. Ng, and L. Hanzo, **Cooperative overlay spectrum access in cognitive radio network**, *IEEE Communications surveys & Tutorials*, Vol. 19, pp. 21924-1944, April 2017.
https://doi.org/10.1109/COMST.2017.2690866
11. L. Lv, J. Chen, and Q. Ni, **Cooperative non-orthogonal multiple access in cognitive radio**, *IEEE Communications Letters*, Vol. 20, pp. 2059-2062, Oct. 2016.
https://doi.org/10.1109/LCOMM.2016.2596763

12. H. Chaurasiya and S.Ghosh, **Performance evaluation of energy-efficient cluster based algorithms in wireless sensor network**, *International Journal of Advanced Trends in Computer Science and Engineering (IJATCSE)*, Vol.7, No.5, pp. 77-81, Sep.-Oct. 2018. https://doi.org/10.30534/ijatcse/2018/03752018
13. J. L. Vicario, A. Bel, J. A. L.-Salcedo, and G. Seco, **Opportunistic relay selection with outdated CSI: outage probability and diversity analysis**, *IEEE Transactions on Wireless Communications*, Vol. 8, pp. 2872-2876, June 2009. https://doi.org/10.1109/TWC.2009.081561
14. D. Zwillinger, ***CRC Standard mathematical tables and formulae*****;** New York: Chapman&Hall/CRC Press, 2003, P. 564. https://doi.org/10.1201/9781420035346
15. K. Tourki, H. –C. Yang, and M. –S. Alouini, **Accurate outage analysis of incremental decode-and-forward opportunistic relaying**, *IEEE Transactions on Wireless Communications*, Vol. 10, pp. 1021-1025, April 2011. https://doi.org/10.1109/TWC.2011.021611.100472
16. N. –S. Kim, **Performance of user relay cooperative NOMA system with partial and imperfect CSI**, *International Journal of Engineering and Technology*, Vol. 7, pp. 4462-4467, Jan. 2019.
17. Y. Liu, Z. Ding, M. Eikashlan, and H. V. Poor, **Cooperative non-orthogonal multiple access in 5G systems with SWIPT**, in *Proc. 23rd European Signal Processing Conference (EUSIPCO)*, Nice, France, 2015, pp. 1999-2003. https://doi.org/10.1109/EUSIPCO.2015.7362734