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Cooperative underlay cognitive radio assisted NOMA: secondary network improvement and outage performance

Dinh-Thuan Do*[1], Chi-Bao Le[2], Anh-Tu Le[3]
[1]Wireless Communications Research Group, Faculty of Electrical and Electronics Engineering,
Ton Duc Thang University, Ho Chi Minh City, Vietnam
[2,3]Faculty of Electronics Technology, Industrial University of Ho Chi Minh City (IUH),
Ho Chi Minh City, Vietnam
*Corresponding author, e-mail: dodinhthuan@tdtu.edu.vn.

Abstract

In this paper, a downlink scenario of a non-orthogonal multiple access (NOMA) scheme with power constraint via spectrum sensing is considered. Such network provides improved outage performance and new scheme of NOMA-based cognitive radio (CR-NOMA) network are introduced. The different power allocation factors are examined subject to performance gap among these secondary NOMA users. To evaluate system performance, the exact outage probability expressions of secondary users are derived. Finally, the dissimilar performance problem in term of secondary users is illustrated via simulation, in which a power allocation scheme and the threshold rates are considered as main impacts of varying system performance. The simulation results show that the performance of CR-NOMA network can be improved significantly.

Keywords*: cognitive radio network, non-orthogonal multiple access, outage probability*

1. Introduction

Recently, as widely consideration on candidates for the fifth generation (5G) wireless communication, a novel multiple access (MA) technique, named non-orthogonal multiple access (NOMA), has been introduced. Main advantages of NOMA can be seen as massive connections, its superior spectral efficiency, balanced user fairness, and low access latency [1, 2]. In contrast to conventional orthogonal multiple access (OMA) relaying networks such as time-division multiple access (TDMA) and frequency-division multiple access (FDMA) [3-6], the non-orthogonal resource allocation is employed in NOMA. The authors in [7-9] developed system model which combines relay scheme in NOMA to introduce novel scheme, namely cooperative NOMA. In principle, the power domain for realizing MA and such key idea of NOMA need to explored to highlight different performance of NOMA users as different power levels allocated [10–12], while the receivers perform the successive interference cancellation (SIC) to eliminate the multiuser interference [13, 14], respectively. Next, the related works in conventional multiuser cognitive radio are explored. The authors in [15–17] studied the multi-antenna problems with single/multiple secondary receivers (SRs) and single/multiple primary receivers (PUs). The authors in [16] studied the multicast multiple antenna cognitive radio network where single data stream is transmitted from secondary transmitter to group of secondary receivers in the presence of multiple single-antenna primary users.

The advantages of cooperative communications have also been deployed to CR-NOMA networks [18, 19]. In [18], the authors studied the NOMA application to transmit unicast and multicast information respectively to primary and secondary users (SUs). In such network, the secondary network (SN) provides the cooperation for the compensation of accessing to the primary spectrum [18]. Furthermore, a two-stage cooperative strategy was studied to enhance the SU fairness and such novel cooperative multicast CR-NOMA scheme was proposed in [19]. Other applications can be seen in [20-25]. Motivated by these works and novel result from [20], this paper studies outage performance of CR NOMA.

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2. System Description

A network consists of a secondary source (S), a relay (R) and two destination users (D1, D2) is considered. We only examine a downlink cooperative underlay CR-NOMA network and existence of a primary destination (P) as shown in Figure 1. The corresponding distances between nodes S-P, R-P, S-R, R-D1, R-D2 are given as d_{SP}, d_{RP}, d_{SR}, d_1 and d_2. Thus, the secondary transmit node k is restricted as $P_k \le min\left(\frac{I d_{kP}^m}{|h_{kP}|^2}, \hat{P}_k\right)$, $\forall k \in \{S, R\}$. In this case, $\hat{P}_k$ denotes the maximum average allowed transmit power at node k while I indicates the interference temperature constraint (ITC) at P.

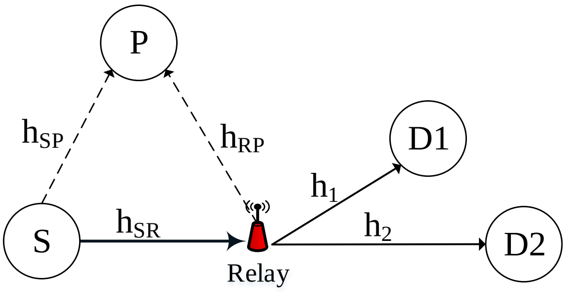

Figure 1. System model for CR NOMA network

In the first time period, S sends its superimposed signal $\sum_{j=1}^{2}\sqrt{P_S\alpha_j}x_j + n_R$ to user D1 through the assistance R. In NOMA, α_j is the power allocation factors with $\sum_{j=1}^{2}\sqrt{\alpha_j} = 1$. Then, the signal received the relay can be express as:

$$y_R = h_{SR}\sqrt{P_S d_{SR}^{-m}}\sum_{j=1}^{2}\sqrt{\alpha_j}x_j + n_R \tag{1}$$

the signal-to-interference-plus-noise ratio (SINR) and signal-to-noise ratio (SNR) of x_1 is decoded and removed from the received signal at R and it can be given as:

$$\gamma_R = \frac{|h_{SR}|^2\alpha_1\rho_S d_{SR}^{-m}}{|h_{SR}|^2\alpha_2\rho_S d_{SR}^{-m} + 1} \tag{2}$$

then the SINR of x_2 when it is decoded from the received signal

$$\gamma_R = |h_{SR}|^2\alpha_2\rho_S d_{SR}^{-m} \tag{3}$$

where $\rho_S = \frac{P_S}{\sigma^2}$. In the second time period, R forwards the detected superimposed signal $\sum_{j=1}^{2}\sqrt{P_r d_j^{-m}\beta_j}\tilde{x}_j$ to both users $\mathrm{D1}$ and $\mathrm{D2}$. Therefore, the signal received by the two destination can be given by:

$$y_{Di} = h_i\sum_{j=1}^{2}\sqrt{P_r d_j^{-m}\beta_j}\tilde{x}_j + n_{Di} \tag{4}$$

where $i = j \in \{1,2\}$, β_j is the power allocation, with $\sum_{j=1}^{2}\sqrt{\beta_j} = 1$ treating x_2 as interference in y_{D1}, the instantaneous SINR at $\mathrm{D2}$ when treating $\tilde{x}_2$ as interference can be obtained as:

$$\gamma_{D2,1} = \frac{|h_2|^2\beta_1\rho_R d_2^{-m}}{|h_2|^2\beta_2\rho_R d_2^{-m} + 1} \tag{5}$$

Based on NOMA scheme, D2 first decodes the message designated for D1 and removes it using SIC, then it decodes its own message without interference. Therefore, the instantaneous SNR at D2 can be expressed as:

$$\gamma_{D2} = |h_2|^2 \beta_2 \rho_R d_2^{-m} \tag{6}$$

next, D1 can detect $\tilde{x}_1$ by treating $\tilde{x}_2$ as a noise with the following SINR

$$\gamma_{D1} = \frac{|h_1|^2 \beta_1 \rho_R d_1^{-m}}{|h_1|^2 \beta_2 \rho_R d_1^{-m} + 1} \tag{7}$$

3. Outage Analysis

3.1. Outage Probability at D1

Consider metric to evaluate system performance, the NOMA users'performance will be examined in term of outage probability. The transmission strategy in CR NOMA is performed related to how success each node in such network can support transmission, which significantly improve quality of the communication for multiple services provided. In this paper, main evaluation metric, namely outage probability is used to characterize the system performance. The outage event for D1 can be expressed by:

$$\begin{aligned} OP_1 &= 1 - \Pr\left(\min\left(\gamma_{R1}, \gamma_{D21}, \gamma_{D1}\right) > \gamma_1\right) \\ &= F_{\gamma_{D21}}\left(\gamma_1\right) + \left(1 - F_{\gamma_{D21}}\left(\gamma_1\right)\right)\left(F_{\gamma_{D1}}\left(\gamma_1\right) + F_{\gamma_{R1}}\left(\gamma_1\right) - F_{\gamma_{D1}}\left(\gamma_1\right) F_{\gamma_{R1}}\left(\gamma_1\right)\right). \end{aligned} \tag{8}$$

Considering x, y as integration variable, by employing exponential distribution for $\left|h_j\right|^2$ and $|h_{SR}|^2$; the Cumulative Distribution Function (CDF) of $|h_{SR}|^2$ is $F_{|h_{SR}|^2}(y) = Pr(|h_{SR}|^2 < y) = 1 - e^{-y}$. So, with help of (2) $F_{\gamma_{R1}}(\gamma_1)$ can be write as:

$$F_{\gamma_{R1}}(\gamma_1) = Pr\left(\frac{|h_{SR}|^2 \alpha_1 \rho_S}{|h_{SR}|^2 \alpha_2 \rho_S + d_{SR}^m} < \gamma_1, \rho_{\bar{S}} < \Delta\right) + Pr\left(\frac{|h_{SR}|^2 \alpha_1 \Delta}{|h_{SR}|^2 \alpha_2 \Delta + d_{SR}^m} < \gamma_1, \rho_{\bar{S}} > \Delta\right) \tag{9}$$

where: $\Delta = \frac{\Omega_{SP}}{|h_{SP}|^2}$, $\Omega_{SP} = \rho_I d_{SP}^m$, $\rho_{\bar{S}} = \frac{P_{\bar{S}}}{\sigma^2}$, $\rho_I = \frac{I}{\sigma^2}$. Now, we can transfer as:

$$\begin{aligned} F_{\gamma_{R1}}(\gamma_1) = &\underbrace{Pr\left(|h_{SR}|^2 < \frac{\gamma_1 d_{SR}^m}{\rho_{\bar{S}}(\alpha_1 - \gamma_1 \alpha_2)}, |h_{SP}|^2 < \frac{\Omega_{SP}}{\rho_{\bar{S}}}\right)}_{A} \\ &+ \underbrace{Pr\left(|h_{SR}|^2 < \frac{\gamma_1 d_{SR}^m |h_{SP}|^2}{(\alpha_1 - \gamma_1 \alpha_2)\Omega_{SP}}, |h_{SP}|^2 > \frac{\Omega_{SP}}{\rho_{\bar{S}}}\right)}_{B} \end{aligned} \tag{10}$$

in this case, we define the first term and the second term of (10) denote A and B respectively. Based on the exponential distribution of $|h_{SR}|^2$, A can be written as:

$$A = \left(1 - e^{-\frac{\gamma_1 d_{SR}^m}{\rho_{\bar{S}}(\alpha_1 - \gamma_1 \alpha_2)}}\right)\left(1 - e^{-\frac{\Omega_{SP}}{\rho_{\bar{S}}}}\right) \tag{11}$$

next, the second term denoted by B can be obtained as:

$$B = \left(e^{-\frac{\Omega_{SP}}{\rho_{\bar{S}}}} - \frac{(\alpha_1 - \gamma_1 \alpha_2)\Omega_{SP} e^{-\left(\frac{\gamma_1 d_{SR}^m + \Omega_{SP}(\alpha_1 - \gamma_1 \alpha_2)}{(\alpha_1 - \gamma_1 \alpha_2)\rho_{\bar{S}}}\right)}}{\gamma_1 d_{SR}^m + (\alpha_1 - \gamma_1 \alpha_2)\Omega_{SP}}\right) \tag{12}$$

therefore, replacing (11) and (12) into (10) $F_{\gamma_{R1}}(\gamma_1)$ can be express as:

$$F_{\gamma_{R1}}(\gamma_1) = \begin{cases} 1 - e^{-\frac{\gamma_1 d_{SR}^m}{\rho_{\bar{S}}(\alpha_1 - \gamma_1\alpha_2)}} + \dfrac{\gamma_1 d_{SR}^m e^{-\left(\frac{\gamma_1 d_{SR}^m + \Omega_{SP}(\alpha_1 - \gamma_1\alpha_2)}{(\alpha_1 - \gamma_1\alpha_2)\rho_{\bar{S}}}\right)}}{\gamma_1 d_{SR}^m + (\alpha_1 - \gamma_1\alpha_2)\Omega_{SP}} & ,\gamma_1 < \dfrac{\alpha_1}{\alpha_2} \\ 1 & ,otherwise \end{cases} \tag{13}$$

similar, with help (5) we can wirte $F_{\gamma_{D21}}(\gamma_1)$ as:

$$F_{\gamma_{D21}}(\gamma_1) = Pr\left(\frac{|h_2|^2\beta_1\rho_{\bar{R}}}{|h_2|^2\beta_2\rho_{\bar{R}} + d_2^m} < \gamma_1, \rho_{\bar{S}} < \Delta\right) + Pr\left(\frac{|h_2|^2\beta_1\Delta}{|h_2|^2\beta_2\Delta + d_2^m} < \gamma_1, \rho_{\bar{S}} > \Delta\right) \tag{14}$$

next, $F_{\gamma_{D21}}(\gamma_1)$ can be transfer as:

$$\begin{aligned} F_{\gamma_{D21}}(\gamma_1) = {} & Pr\left(|h_2|^2 < \frac{\gamma_1 d_2^m}{(\beta_1 - \gamma_1\beta_2)\rho_{\bar{R}}}, |h_{SP}|^2 < \frac{\Omega_{SP}}{\rho_{\bar{S}}}\right) \\ & + Pr\left(|h_2|^2 < \frac{\gamma_1 d_2^m |h_{SP}|^2}{(\beta_1 - \gamma_1\beta_2)\Omega_{SP}}, |h_{SP}|^2 > \frac{\Omega_{SP}}{\rho_{\bar{S}}}\right) \end{aligned} \tag{15}$$

then, following the same steps as in (10)-(12), Based on the exponential distribution of $|h_i|^2$, $F_{\gamma_{D1}}(\gamma_1)$and $F_{\gamma_{D21}}(\gamma_1)$ can be written respectively as:

$$F_{\gamma_{D21}}(\gamma_1) = \begin{cases} 1 - e^{-\frac{\gamma_1 d_2^m}{(\beta_1 - \gamma_1\beta_2)\rho_{\bar{R}}}} + \dfrac{\gamma_1 d_2^m e^{-\left(\frac{\gamma_1 d_2^m + \Omega_{SP}(\beta_1 - \gamma_1\beta_2)}{(\beta_1 - \gamma_1\beta_2)\rho_{\bar{S}}}\right)}}{\gamma_1 d_2^m + (\beta_1 - \gamma_1\beta_2)\Omega_{SP}}, \gamma_1 < \dfrac{\alpha_1}{\alpha_2} \\ 1, \text{otherwise} \end{cases} \tag{16}$$

and

$$F_{\gamma_{D1}}(\gamma_1) = \begin{cases} 1 - e^{-\frac{\gamma_1 d_1^\tau}{(\beta_1 - \gamma_1\beta_2)\rho_{\bar{R}}}} + \dfrac{\gamma_1 d_1^\tau e^{-\left(\frac{\gamma_1 d_1^\tau + \Omega_{SP}(\beta_1 - \gamma_1\beta_2)}{(\beta_1 - \gamma_1\beta_2)\rho_{\bar{S}}}\right)}}{\gamma_1 d_1^\tau + (\beta_1 - \gamma_1\beta_2)\Omega_{SP}}, \gamma_1 < \dfrac{\alpha_1}{\alpha_2} \\ 1, otherwise \end{cases} \tag{17}$$

therefore, OP_1 can be obtained by replacing (13), (16) and (17) into (8)

$$OP_1 = \begin{cases} 1 - \left(e^{-\frac{\gamma_1 d_{SR}^m}{\rho_{\bar{S}}(\alpha_1 - \gamma_1\alpha_2)}} - \dfrac{\gamma_1 d_{SR}^m e^{-\left(\frac{\gamma_1 d_{SR}^m + \Omega_{SP}(\alpha_1 - \gamma_1\alpha_2)}{(\alpha_1 - \gamma_1\alpha_2)\rho_{\bar{S}}}\right)}}{\gamma_1 d_{SR}^m + (\alpha_1 - \gamma_1\alpha_2)\Omega_{SP}}\right) \times \\ \prod_{i=1,2}\left(e^{-\frac{\gamma_1 d_i^m}{(\beta_1 - \gamma_1\beta_2)\rho_{\bar{R}}}} - \dfrac{\gamma_1 d_i^m e^{-\left(\frac{\gamma_1 d_i^m + \Omega_{SP}(\beta_1 - \gamma_1\beta_2)}{(\beta_1 - \gamma_1\beta_2)\rho_{\bar{S}}}\right)}}{\gamma_1 d_i^m + (\beta_1 - \gamma_1\beta_2)\Omega_{SP}}\right), \gamma_1 < \dfrac{\alpha_1}{\alpha_2}, \gamma_1 < \dfrac{\beta_1}{\beta_2} \\ 1, otherwise \end{cases} \tag{18}$$

3.2. Outage Probability at D2

Similarly, the outage event for D2 can be formulated by:

$$\begin{aligned} OP_2 &= 1 - \Pr\left(\min\left(\gamma_{R2}, \gamma_{D2}\right) > \gamma_2\right) \\ &= F_{\gamma_{D2}}\left(\gamma_2\right) + F_{\gamma_{R2}}\left(\gamma_2\right) - F_{\gamma_{D2}}\left(\gamma_2\right)F_{\gamma_{R2}}\left(\gamma_2\right). \end{aligned} \tag{19}$$

with help (3) then we can write $F_{R2}(\gamma_2)$ as:

$$F_{R2}(\gamma_2) = Pr\left(\frac{|h_{SR}|^2\alpha_2\rho_{\bar{S}}}{d_{SR}^m} < \gamma_2, \rho_{\bar{S}} < \Delta\right) + Pr\left(\frac{|h_{SR}|^2\alpha_2\Delta}{d_{SR}^m} < \gamma_2, \rho_{\bar{S}} > \Delta\right) \tag{20}$$

similarly, based on the exponential distribution of $|h_i|^2$. So $F_{\gamma_{R2}}(\gamma_2)$ can be express as:

$$F_{\gamma_{R2}}(\gamma_2) = 1 - e^{-\frac{\gamma_2 \Omega_{SR}}{2\alpha_2 \rho_{\bar{S}}}} + \frac{\gamma_2 d_{SR}^m e^{-\left(\frac{\gamma_2 d_{SR}^m + \alpha_2 \Omega_{SP}}{\alpha_2 \rho_{\bar{S}}}\right)}}{\gamma_2 d_{SR}^m + \alpha_2 \Omega_{SP}} \tag{21}$$

with the help of (6), we can write $F_{\gamma_{D2}}(\gamma_2)$ as:

$$F_{\gamma_{D2}}(\gamma_2) = Pr\left(\frac{|h_2|^2 \beta_2 \rho_R}{d_2^m} < \gamma_2, \rho_{\bar{S}} < \Delta\right) + Pr\left(\frac{|h_2|^2 \beta_2 \Delta}{d_2^m} < \gamma_2, \rho_{\bar{S}} > \Delta\right) \tag{22}$$

applying similar techniques as before, we simplify $F_{\gamma_{D2}}(\gamma_2)$ as:

$$F_{\gamma_{D2}}(\gamma_2) = 1 - e^{-\frac{\gamma_2 d_2^m}{\beta_2 \rho_{\bar{R}}}} + \frac{\gamma_2 d_2^m e^{-\left(\frac{\gamma_2 d_2^m + \beta_2 \Omega_{SP}}{\beta_2 \rho_{\bar{S}}}\right)}}{\gamma_2 d_2^m + \beta_2 \Omega_{SP}} \tag{23}$$

replacing (21) and (23) into (19) OP_2 can be obtain as:

$$OP_2 = 1 - \left(e^{-\frac{\gamma_2 d_2^m}{\beta_2 \rho_{\bar{R}}}} - \frac{\gamma_2 d_2^m e^{-\left(\frac{\gamma_2 d_2^m + \beta_2 \Omega_{SP}}{\beta_2 \rho_{\bar{S}}}\right)}}{\gamma_2 d_2^m + \beta_2 \Omega_{SP}}\right)\left(e^{-\frac{\gamma_2 \Omega_{SR}}{2\alpha_2 \rho_{\bar{S}}}} - \frac{\gamma_2 d_{SR}^m e^{-\left(\frac{\gamma_2 d_{SR}^m + \alpha_2 \Omega_{SP}}{\alpha_2 \rho_{\bar{S}}}\right)}}{\gamma_2 d_{SR}^m + \alpha_2 \Omega_{SP}}\right) \tag{24}$$

4. Performance Evaluation

In this section, we evaluate the performance of resource allocation for NOMA-based cognitive radio network. Consider a geographical area covered by a primary wireless network and a cognitive wireless network. We assume equality noise terms as $\sigma_P^2 = \sigma_R^2 = \sigma_1^2 = \sigma_2^2 = \sigma^2$ and regarding distances we set $d_{SP} = d_{RP} = d_{SR} = d_2 = 2$, $d_1 = 2d_2$. The path loss factor is 3, power allocation fractions are $\alpha_1 = \beta_1 = 0.8$, $\alpha_2 = \beta_2 = 0.2$, $I = 25dB$ and $\sigma = 0.001$

We evaluate the impact of the transmit SNR on the outage performance for NOMA-based cognitive radio network in Figure 2 and Figure 3. At higher SNR, outage performance can be enhanced significantly. With the case *data rate R1 increases*, the outage performance will be worse. In addition, there is strict agreement between analytical result and Monte-Carlo result.

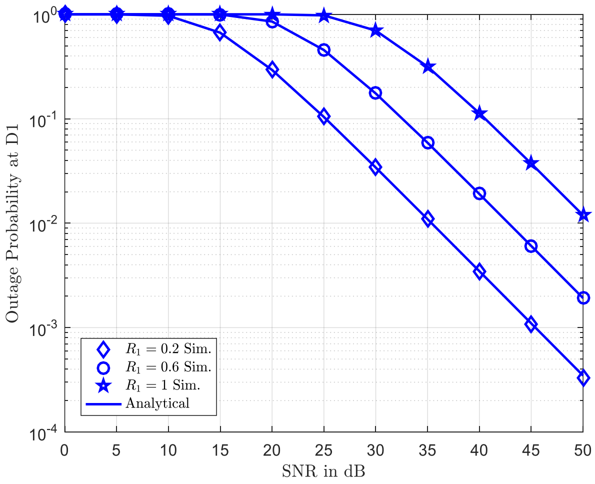

Figure 2. Outage probability of D1 versus SNR as varying R1

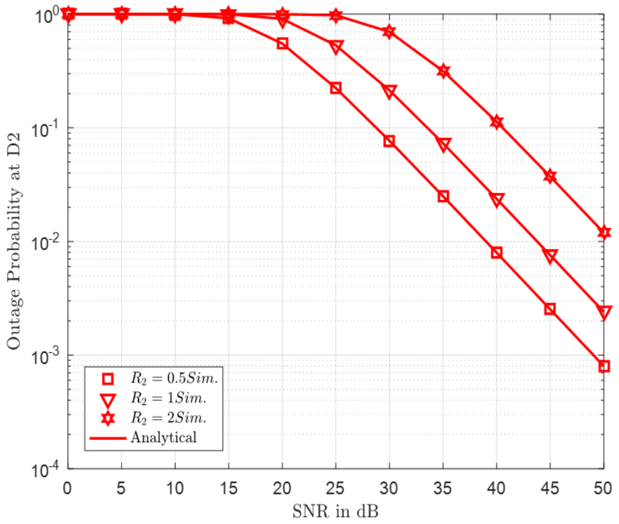

Figure 3. Outage probability of D2 versus SNR as varying R2

From Figure 4 and Figure 5, it can be concluded that the proposed system not only guarantees the minimum transmission rate, but also improves the outage performance significantly. Although NOMA scheme improves the performance of cognitive radio network, it is at the cost of increasing the complexity of secondary user receiver. At high Consequently, designing a proper value for the parameter threshold SNR can achieve the values of the threshold SNRs γ_1 and γ_2, the system meets outage event. The tradeoff between the performance gain and the required transmit SNR of secondary users. This is due to the fact that there is more power for transmitter to improve the outage behavior at the receiver.

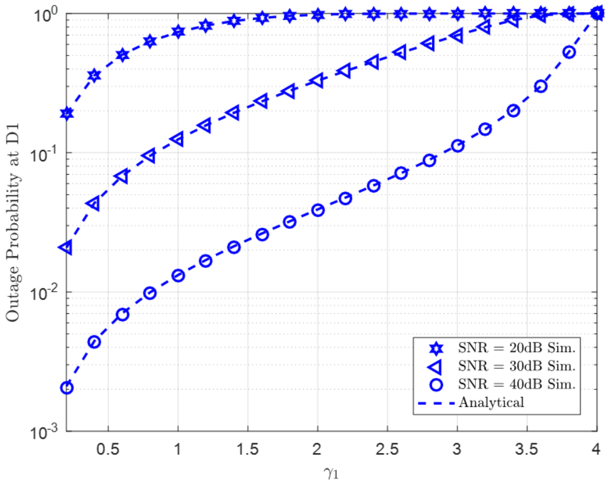

Figure 4. Outage probability of D1 versus γ_1 as varying SNR

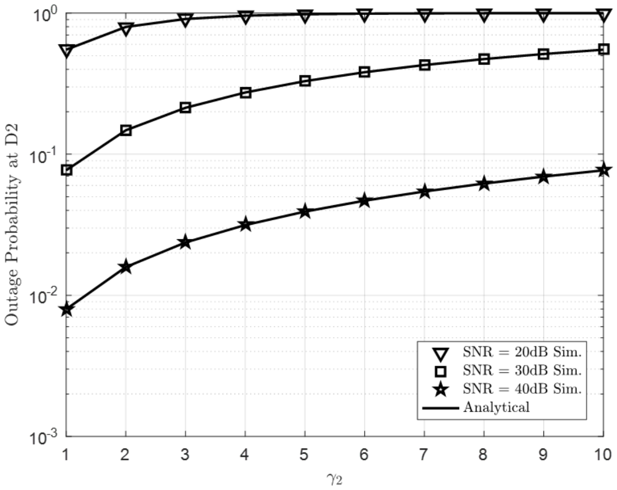

Figure 5. Outage probability of D2 versus γ_2 as varying SNR

5. Conclusion

In this work, we studied the downlink NOMA problem for NOMA-based cognitive radio network. The secondary network performs the resource allocation of power with acceptable outage performance. The transmit SNR, the threshold data rates are main impacts on outage performance. Simulation results demonstrated that the proposed system improve the spectrum efficiency significantly.

References

[1] Z Ding, Z Yang, P Fan, HV Poor. On the performance of non-orthogonal multiple access in 5G systems with randomly deployed users. *IEEE Signal Process. Lett*. 2014; 21(12): 1501–1505.

[2] Dinh-Thuan Do, Chi-Bao Le. Application of NOMA in Wireless System with Wireless Power Transfer Scheme: Outage and Ergodic Capacity Performance Analysis. *Sensors.* 2018; 18(10): 3501.

[3] Dinh-Thuan Do, H-S Nguyen, M Voznak, T-S. Nguyen. Wireless powered relaying networks under imperfect channel state information: system performance and optimal policy for instantaneous rate. *Radioengineering.* 2017; 26(3): 869-877.

[4] X-X Nguyen, Dinh-Thuan Do. Maximum Harvested Energy Policy in Full-Duplex Relaying Networks with SWIPT. *International Journal of Communication Systems (Wiley).* 2017; 30(17) 2017.

[5] X-X Nguyen, Dinh-Thuan Do. Optimal power allocation and throughput performance of full-duplex DF relaying networks with wireless power transfer-aware channel. *EURASIP Journal on Wireless Communications and Networking.* 2017; 152: 1-16.

[6] KT Nguyen, Dinh-Thuan Do, XX Nguyen, NT Nguyen, DH Ha. *Wireless information and power transfer for full duplex relaying networks: performance analysis.* in Proc. of Recent Advances in Electrical Engineering and Related Sciences (AETA 2015), HCMC, Vietnam. 2015; 53-62.

[7] T-L Nguyen, Dinh-Thuan Do. Exploiting Impacts of Intercell Interference on SWIPT-assisted Non-orthogonal Multiple Access. *Wireless Communications and Mobile Computing*. 2018; 2018: 1-12.

[8] T-L Nguyen, Dinh-Thuan Do. Power allocation schemes for wireless powered NOMA systems with imperfect CSI: An application in multiple antenna–based relay. *International Journal of Communication Systems.* 2018; 31(15).

[9] K Tourki, H-C Yang, M-S Alouini. 'Accurate outage analysis of incremental decode-and-forward opportunistic relaying. *IEEE Trans. Wireless Commun*. 2011; 10(4): 1021–1025.

[10] Z Wei, DK Ng, J Yuan, H-M Wang. 'Optimal resource allocation for power-efficient MC-NOMA with imperfect channel state information. *IEEE Trans. Commun*. 2017; 65(9): 3944–3961.

[11] Z Yang, Z Ding, P Fan, N Al-Dhahir. The impact of power allocation on cooperative non-orthogonal multiple access networks with SWIPT. *IEEE Trans. Wireless Commun*. 2017; 16(7): 4332–4343.

[12] Z Ding, F Adachi, HV Poor. The application of MIMO to nonorthogonal multiple access. *IEEE Trans. Wireless Commun*. 2016; 15(1): 537–552.

[13] J Wang, Q Peng, Y Huang, H-M Wang, X You. Convexity of weighted sum rate maximization in NOMA systems. *IEEE Commun. Lett*. 2017; 24(9): 1323–1326.

[14] Q Yang, H-M Wang, DWK Ng, MH Lee. 'NOMA in downlink SDMA with limited feedback: Performance analysis and optimization. *IEEE J. Sel. Areas Commun*. 2017; 35(10): 2281–2294.

[15] R Zhang, Y-C Liang. Exploiting multi-antennas for opportunistic spectrum sharing in cognitive radio networks. *IEEE J. Sel. Topics Signal Process*. 2008; 2(1): 88–102.

[16] KT Phan, SA Vorobyov, ND Sidiropoulos, C Tellambura. 'Spectrum sharing in wireless networks via QoS-aware secondary multicast beamforming. *IEEE Trans. Signal Process*. 2009; 57(6): 2323–2335.

[17] R Zhang, Y-C. Liang, S Cui. Dynamic resource allocation in cognitive radio networks. *IEEE Signal Process. Mag*. 2010; 27(3): 102–114.

[18] L Lv et al. Design of cooperative non-orthogonal multicast cognitive multiple access for 5G systems: user scheduling and performance analysis. *IEEE Trans. Commun*. 2017; 65(6): 2641–2656.

[19] Y Chen, L Wang, B Jiao. Cooperative multicast non-orthogonal multiple access in cognitive radio. *IEEE Int. Conf. Commun*. 2016; 20(10): 1-1.

[20] S Arzykulov, TA Tsiftsis, G Nauryzbayev, M Abdallah. Outage Performance of Cooperative Underlay CR-NOMA with Imperfect CSI. *EEE Communications Letters.* 2019; 23(1): 176–179.

[21] Al-Arkawazi, Shamil Ahmed Flamarz. Measuring the Influences and Impacts of Signalized Intersection Delay Reduction on the Fuel Consumption, Operation Cost and Exhaust Emissions. *Civil Engineering Journal.* 2018; 4(3): 552–571.

[22] T-T Nguyen, T-P Hoac, Dinh-Thuan Do, V-H Phan, T-L Dao. *Android application for WiFi based indoor position: System design and performance analysis.* in Proc. of 2016 International Conference on Information Networking (ICOIN) 1 (1), 1-4, 2016.

[23] H-S Nguyen, Dinh-Thuan Do, T-S. Nguyen, M Voznak. Exploiting hybrid time switching-based and power splitting-based relaying protocol in wireless powered communication networks with outdated channel state information. *Automatika*. 2017; 58(2017): 111-118.

[24] Ettefagh Massoud Hemmasian, José De Doná, Mahyar Naraghi, Farzad Towhidkhah. Control of Constrained Linear-Time Varying Systems via Kautz Parametrization of Model Predictive Control Scheme. 2017; 1(2): 65–74.

[25] M-N Pham, Dinh-Thuan Do, T-T Nguyen, T-T Phu. Energy harvesting assisted cognitive radio: random location-based transceivers scheme and performance analysis. *Telecommunication Systems*. 2017; 67(1): 123-132.