Indonesian Journal of Electrical Engineering and Computer Science
Vol. 26, No. 1, April 2022, pp. 267∼277
ISSN: 2502-4752, DOI: 10.11591/ijeecs.v26.i1.pp267-277

Impacts of relay and direct links at destinations in full-duplex non-orthogonal multiple access system

Dinh-Thuan Do, Tu-Trinh Thi Nguyen
Faculty of Electronics Technology, Industrial University of Ho Chi Minh City (IUH), Ho Chi Minh City, Vietnam

Article Info

Article history:

Received Sep 13, 2021
Revised Jan 31, 2022
Accepted Feb 7, 2022

Keywords:

Outage probability
Nakagami-m fading
Non-orthogonal multiple access

ABSTRACT

In this study, one of effective methods of multiple access, namely non-orthogonal multiple access (NOMA), is investigated. Such NOMA scheme can be worked with signal processing at downlink side. As such, the base station sends mixed signals of two signals to destinations. A near user could be a relay to forward the signal to the distant user by leveraging benefits of full-duplex mode which allows relay to transmit and receive signals in the same time. For simple analysis, the two-user approach and fixed power allocation factors are implemented. We also derive formulas of the outage probability of two users (near-user and far-user) to indicate fairness and emphasize the role of the near user as a relay. This considered NOMA system adopts transmission with Nakagami-m fading channel. As a further metric, throughput is considered under the impacts of key system parameters. The transmit signal-to-noise ratio (SNR) at the base station make influences the performance of two users significantly as observation indicated in our simulation results. These results are confirmed by matching Monte-Carlo with the theoretical simulations.

Corresponding Author:

Dinh-Thuan Do
Faculty of Electronics Technology, Industrial University of Ho Chi Minh City
Ho Chi Minh City, Vietnam
Email: dodinhthuan@iuh.edu.vn

1. INTRODUCTION

In recent years, non-orthogonal multiple access (NOMA) has been the leading applications to develop services with high demand of bandwidth efficiency [1]-[3]. More benefits from NOMA are better fairness and improved energy efficiency [4], [5]. The multiple users are multiplexed in the context of NOMA at the same time and frequency. Compared with conventional orthogonal multiple access (OMA), more users are provided with the superimposing signals processed at the transmitter while successive interference cancellation (SIC) is employed at the receiver [6], [7]. By exploiting the distances from users to the base station (BS) in the NOMA system, the two kinds of users are classified such as the near user and the far user. Unfortunately, the existence of the worse performance of the far user since long-distance transmission as results reported in [8]. To guarantee fairness among many users employing NOMA scheme, the far users should be allocated more power while less power is assigned to near users. In particular, the fixed power allocation approach was adopted to guarantee the performance of the fairness and processing load. This scheme will provide acceptable quality-of-service (QoS) requirements regardless of feedback/header information [8]. It is in high demand to implement higher coverage for wireless systems and a cooperative transmission approach is recommended to employ NOMA to improve the performance of two users [9]-[13].

The previous studies regarding the wireless system employing half-duplex (HD) transmission show lower bandwidth efficiency since these approaches cannot transmit and receive simultaneously. At HD, less bandwidth efficiency is required by two time slots are used to tramsit signal from the base station to destination via a relay. Recently, to overcome this problem, full-duplex (FD) based NOMA-assisted systems are studied [14]-[23]. The downlink cooperative NOMA systems employ compress-and-forward (CF)-based FD relay to improve transmissions [14]. To specify the quality, the achievable rate region is examined in the proposed technique. In the scenario of [15], to allow BS to communicate with destinations, an FD-NOMA architecture was considered for a downlink cellular network and a dedicated FD relay benefits to cell-edge users. A network-coded cooperative NOMA (NC-CNOMA) strategy is studied, in which users implement physical-layer network coding (PNC) to demodulate signals [16]. Considering the main simulation results in terms of outage probability, the NC-CNOMA scheme shows high advantages compared with the conventional cooperative NOMA system [16].

Zhang *et al.* [17], a cell-center user operates as an FD relay to forward signal to a distant user as the work presented in [16]. As the main result, [17] explored the optimal power allocation and optimal outage probability satisfies at proper applications related to NOMA scheme. The authors proved the closed-form formulas of outage probability and ergodic sum-rate [17]. The authors in [18] examined the performance of downlink NOMA by exploiting the average block error rate (BLER) and such a system is suitable for short-packet communication networks. Since stochastic geometry is deployed in a system relying on Nakagami-m fading channels, which corresponds to the locations of NOMA users and these users obey uniform distribution in a disc [19]. The authors studied theoretically the analytical formulas for average BLER in [19]. By treating Nakagami-m fading channels. a spectrum-efficient scheme is proposed for the NOMA system. The BS sends signals directly to a cell-center user (CCU). By achieving a relay and the CCU, they derived a formula for performance analysis of a cell-edge user (CEU) [20]. Motivated recent studies [20]-[23], we exploit main system performance metric for FD-NOMA.

2. SYSTEM MODEL

As illustration in Figure 1, a downlink NOMA needs a robust transmission by allowing one base station (BS) and two NOMA users (D_1 and D_2) to work together. One of possible case is the far user is able to connect directly with BS, i.e. the far user D_2 needs support from the near user D_1. $|g_1|^2$, $|g_2|^2$, $|g_3|^2$, $|g_f|^2$ are considered to follow exponential distribution, i.e. $\lambda_{g_i}, i \in \{1,2,3,f\}$. The received signal at D_1 can be given by [24]:

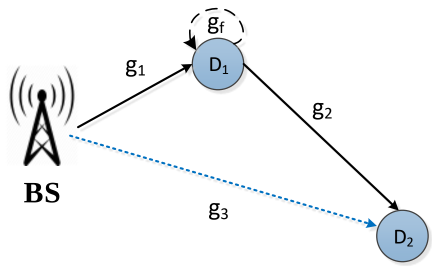

Figure 1. System model

$$y_{\mathrm{D}_1} = g_1\left(\sqrt{\alpha_1 \mathrm{P_S}}x_1 + \sqrt{\alpha_2 \mathrm{P_S}}x_2\right) + g_f\sqrt{\mathrm{P}_{\mathrm{D}_1}}x_f + \eta_{\mathrm{D}_1}, \tag{1}$$

where $\mathrm{P_S}$,$\mathrm{P}_{\mathrm{D}_1}$ is denoted as the normalized transmission powers at the BS, D_1 and D_2. x_1, x_2 are the signals for D_1, D_2. α_1, α_2 are the corresponding power allocation coefficients, we assume that $\alpha_1 < \alpha_2$ with $\alpha_1 + \alpha_2 = 1$. The received signal to interference plus noise ratio (SINR) at D_1 to detect x_2 is written as:

$$\gamma_{\mathrm{D}_2 \to \mathrm{D}_1} = \frac{\alpha_2 \rho_S |g_1|^2}{\alpha_1 \rho_S |g_1|^2 + \rho_1 |g_f|^2 + 1} \tag{2}$$

where $\rho = \rho_S = \rho_1 = \frac{\mathrm{P_S}}{N_0}$ is transmit SNR.

By exploiting SIC, a noise term is eliminated to examine new form of the received SINR at D_1 (corresponding to detect x_1) is written as:

$$\gamma_{\mathrm{D}_1} = \frac{\alpha_1 \rho_S |g_1|^2}{\rho_1 |g_f|^2 + 1} \tag{3}$$

the received signal at D_2 can be written as [24]:

$$y_{\mathrm{D}_2} = g_3 \left(\sqrt{\alpha_1 \mathrm{P_S}} x_1 + \sqrt{\alpha_2 \mathrm{P_S}} x_2 \right) + g_2 \sqrt{\mathrm{P}_1} x_2 + \eta_{\mathrm{D}_2} \tag{4}$$

considering other link D_2 (direct link) the received signal can be computed as [24]:

$$y_{\mathrm{D}_2} = g_3 \left(\sqrt{\alpha_1 \mathrm{P_S}} x_1 + \sqrt{\alpha_2 \mathrm{P_S}} x_2 \right) + \eta_{\mathrm{D}_2} \tag{5}$$

by computing SINR at D_2, x_2 could be detected and SINR is formulated by:

$$\gamma_{\mathrm{D}_2,1} = \frac{\alpha_2 \rho_S |g_3|^2}{\alpha_1 \rho_S |g_3|^2 + 1} \tag{6}$$

at user D_2, x_2 could be detected after signal x_1 as following SINR:

$$\gamma_{\mathrm{D}_2,2} = \rho_1 |g_2|^2 \tag{7}$$

by considering direct and relay links D_1 to D_2 have more chances to communicate with the BS. Allowing maximal ratio combining deployed at D_2. Obtaining MRC, the received SINR at D_2 are described respectively as:

$$\gamma_{\mathrm{D}_2}^{\mathrm{MRC}} = \rho_1 |g_2|^2 + \frac{\alpha_2 \rho_S |g_3|^2}{\alpha_1 \rho_S |g_3|^2 + 1} \tag{8}$$

the PDF and CDF of Nakagami-m fading distribution are given by:

$$f_{|g_i|^2}(x) = \frac{x^{m_{g_i}-1} \mathrm{e}^{-\frac{x}{\beta_{g_i}}}}{\Gamma(m_{g_i}) \beta_{g_i}^{m_{g_i}}} \tag{9}$$

and:

$$F_{|g_i|^2}(x) = 1 - \mathrm{e}^{-\frac{x}{\beta_{g_i}}} \sum_{n=0}^{m_{g_i}-1} \frac{x^n}{n! \beta_{g_i}^n} \tag{10}$$

where $\beta_{g_i} \triangleq \frac{\lambda_{g_i}}{m_{g_i}}$ with λ_{g_i} and $m_{g_i} = m$ represent the mean and integer fading factor.

3. OUTAGE PROBABILITIES FOR TWO NOMA USERS

3.1. Outage probability of D_1

The near user D_1 employing FD mode and it meets outage probability as (11) [24]:

$$\begin{aligned} \mathcal{OP}_{\mathrm{D}_1} &= \Pr\left(\gamma_{\mathrm{D}_2 \to \mathrm{D}_1} < \gamma_{th,2}, \gamma_{\mathrm{D}_1} < \gamma_{th,1}\right) \\ &= 1 - \Pr\left(\gamma_{\mathrm{D}_2 \to \mathrm{D}_1} > \gamma_{th,2}, \gamma_{\mathrm{D}_1} > \gamma_{th,1}\right), \end{aligned} \tag{11}$$

where $\gamma_{th,1} = 2^{R_1} - 1$, $\gamma_{th,2} = 2^{R_2} - 1$, R_1, R_2 are the needed target rates of corresponding users D_1, D_2. From 2 and 3, we have as:

$$\begin{aligned}\mathcal{OP}_{\mathrm{D}_1} &= 1 - \Pr\left(\frac{\alpha_2\rho_S|g_1|^2}{\alpha_1\rho_S|g_1|^2 + \rho_1|g_f|^2 + 1} \geq \gamma_{th,2}, \frac{\alpha_1\rho_S|g_1|^2}{\rho_1|g_f|^2 + 1} \geq \gamma_{th,1}\right) \\ &= 1 - \int_0^\infty \int_{\xi_1(\rho_1 x + 1)}^\infty f_{|g_f|^2}(x) f_{|g_1|^2}(y) dx dy \\ &= \sum_{n_1=0}^\infty \sum_{n_2=0}^{m_{g_1}+n_1} \binom{m_{g_1}+n_1}{n_2} \frac{(-1)^{n_1}\left(\frac{\rho_1\xi_1}{\beta_{g_1}}\right)^{n_2}\left(\frac{\xi_1}{\beta_{g_1}}\right)^{m_{g_1}+n_1-n_2}\Gamma\left(m_{g_f}+n_2\right)}{n_1!\left(m_{g_1}+n_1\right)\Gamma\left(m_{g_1}\right)\Gamma\left(m_{g_f}\right)}\end{aligned} \tag{12}$$

where $\xi_1 \triangleq \max\left(\frac{\gamma_{th,2}}{\alpha_2\rho_S - \alpha_1\rho_S\gamma_{th,2}}, \frac{\gamma_{th,1}}{\alpha_1\rho_S}\right)$.

3.2. Outage probability of D_2 with direct link

The complex case of the far user relies on the ability of signal detection at the near user. Then we compute the outage probability of D_2 as [24]:

$$\mathcal{OP}_{\mathrm{D}_2}^{\mathrm{DL}} = \underbrace{\Pr\left(\gamma_{\mathrm{D}_2}^{\mathrm{MRC}} < \gamma_{th,2}, \gamma_{\mathrm{D}_2\to\mathrm{D}_1} > \gamma_{th,2}\right)}_{\triangleq\Theta_1} + \underbrace{\Pr\left(\gamma_{\mathrm{D}_2\to\mathrm{D}_1} < \gamma_{th,2}, \gamma_{\mathrm{D}_2,1} < \gamma_{th,2}\right)}_{\triangleq\Theta_2} \tag{13}$$

by definition, Θ_1 can be calculated as:

$$\begin{aligned}\Theta_1 &\triangleq \Pr\left(\gamma_{\mathrm{D}_2}^{\mathrm{MRC}} < \gamma_{th,2}, \gamma_{\mathrm{D}_2\to\mathrm{D}_1} > \gamma_{th,2}\right) \\ &= \underbrace{\Pr\left(\gamma_{\mathrm{D}_2}^{\mathrm{MRC}} < \gamma_{th,2}\right)}_{\triangleq\Xi_1}\underbrace{\Pr\left(\gamma_{\mathrm{D}_2\to\mathrm{D}_1} > \gamma_{th,2}\right)}_{\triangleq\Xi_2}\end{aligned} \tag{14}$$

in which, Ξ_1 can be calculated as:

$$\begin{aligned}\Xi_1 &\triangleq \Pr\left(\gamma_{\mathrm{D}_2}^{\mathrm{MRC}} < \gamma_{th,2}\right) \\ &= \Pr\left(|g_2|^2 < \frac{\gamma_{th,2}}{\rho_1} - \frac{\alpha_2|g_3|^2}{\alpha_1\rho_S|g_3|^2 + 1}, |g_3|^2 < \underbrace{\frac{\gamma_{th,2}}{\rho_{\mathrm{D}_1}\left(\alpha_2 - \alpha_1\gamma_{th,2}\right)}}_{\triangleq\psi_1}\right) \\ &= \int_0^{\psi_1} \frac{x^{m_{g_3}-1}}{\Gamma\left(m_{g_3}\right)\beta_{g_3}^{m_{g_3}}} \mathrm{e}^{-\frac{x}{\beta_{g_3}}} dx \\ &- \frac{\mathrm{e}^{-\frac{\gamma_{th,2}}{\rho_1\beta_{g_2}}}}{\Gamma\left(m_{g_3}\right)\beta_{g_3}^{m_{g_3}}} \int_0^{\psi_1} x^{m_{g_3}-1}\mathrm{e}^{-\frac{x}{\beta_{g_3}}}\mathrm{e}^{\frac{\alpha_2 x}{\beta_{g_2}(\alpha_1\rho_S x + 1)}} \sum_{n=0}^{m_{g_2}-1} \frac{1}{n!\beta_{g_2}^n}\left(\frac{\gamma_{th,2}}{\rho_1} - \frac{\alpha_2 x}{\alpha_1\rho_S x + 1}\right)^n dx \\ &= \frac{\gamma\left(m_{g_3}, \frac{\psi_1}{\beta_{g_3}}\right)}{\Gamma\left(m_{g_3}\right)} - \sum_{n=0}^{m_{h_2}-1}\sum_{k=0}^{n}\binom{n}{k}\frac{\mathrm{e}^{-\frac{\gamma_{th,2}}{\rho_1\beta_{g_2}}}\psi_2}{n!\beta_{g_2}^n\Gamma\left(m_{g_3}\right)\beta_{g_3}^{m_{g_3}}}\left(-\frac{\alpha_2}{\alpha_1\rho_S x + 1}\right)^k\left(\frac{\gamma_{th,2}}{\rho_1}\right)^{n-k}\end{aligned} \tag{15}$$

where:

$$\begin{aligned}
\psi_2 &\triangleq \int_0^{\psi_1} x^{\mu} e^{-\frac{x}{\beta_{g3}}} e^{\frac{\alpha_2 x}{\beta_{g2}(\alpha_1 \rho_S x+1)}} dx \\
&= \alpha_1 \rho_S \left(\frac{1}{\alpha_1 \rho_S}\right)^{\mu} \int_1^{\alpha_1 \rho_S \psi_1+1} (y-1)^{\mu} e^{-\frac{y-1}{\alpha_1 \rho_S \beta_{g3}}} e^{\frac{\alpha_2 (y-1)}{\alpha_1 \rho_S \beta_{g2} y}} dy \\
&= \alpha_1 \rho_S \left(\frac{1}{\alpha_1 \rho_S}\right)^{\mu} \sum_{n_1=0}^{\mu} \binom{\mu}{n_1} (-1)^{\mu-n_1} \int_1^{\alpha_1 \rho_S \psi_1+1} y^{n_1} e^{(y-1)\left(\frac{\alpha_2}{\alpha_1 \rho_S \beta_{g2} y} - \frac{1}{\alpha_1 \rho_S \beta_{g3}}\right)} dy \\
&= \alpha_1 \rho_S \left(\frac{1}{\alpha_1 \rho_S}\right)^{\mu} \sum_{n_1=0}^{\mu} \binom{\mu}{n_1} (-1)^{\mu-n_1} e^{\frac{\alpha_2}{\alpha_1 \rho_S \beta_{g2}} + \frac{1}{\alpha_1 \rho_S \beta_{g3}}} \\
&\times \int_1^{\alpha_1 \rho_S \psi_1+1} y^{n_1+1-1} e^{-\frac{\alpha_2}{\alpha_1 \rho_S \beta_{g2} y} - \frac{y}{\alpha_1 \rho_S \beta_{g3}}} dy.
\end{aligned} \tag{16}$$

the inner integral can be solved by using result in [25, Eq. (3.381.1)] with $\mu \triangleq k + m_{g_3} - 1$ and:

$$\begin{aligned}
\Xi_2 &\triangleq \Pr\left(\gamma_{D_2 \to D_1} > \gamma_{th,2}\right) \\
&= \Pr\left(|g_1|^2 > \frac{\gamma_{th,2}\left(\rho_1 |g_f|^2 + 1\right)}{\alpha_2 \rho_S - \alpha_1 \rho_S \gamma_{th,2}}\right) \\
&= 1 - \sum_{n_1=0}^{\infty} \sum_{n_2=0}^{m_{g_1}+n_1} \binom{m_{h_1}+n_1}{n_2} \frac{(-1)^{n_1} \psi_1^{n_2} \psi_2^{m_{g_1}+n_1-n_2} \Gamma\left(m_{g_f}+n_2\right)}{n_1! \left(m_{g_1}+n_1\right) \Gamma\left(m_{g_1}\right) \Gamma\left(m_{g_f}\right)}.
\end{aligned} \tag{17}$$

next, Θ_2 can be calculated as:

$$\begin{aligned}
\Theta_2 &\triangleq \Pr\left(\gamma_{D_2 \to D_1} < \gamma_{th,2}, \gamma_{D_2,1} < \gamma_{th,2}\right) \\
&= \underbrace{\Pr\left(|g_1|^2 < \frac{\gamma_{th,2}\left(\rho_{D_1} |h_f|^2 + 1\right)}{\alpha_2 \rho_S - \alpha_1 \rho_S \gamma_{th,2}}\right)}_{\triangleq \Xi_3} \times \underbrace{\Pr\left(|g_3|^2 < \frac{\gamma_{th,2}}{\alpha_2 \rho_S - \alpha_1 \rho_S \gamma_{th,2}}\right)}_{\triangleq \Xi_4},
\end{aligned} \tag{18}$$

in which,

$$\begin{aligned}
\Xi_3 &\triangleq \Pr\left(|g_1|^2 < \frac{\gamma_{th,2}\left(\rho_1 |g_f|^2 + 1\right)}{\alpha_2 \rho_S - \alpha_1 \rho_S \gamma_{th,2}}\right) \\
&= \int_0^{\infty} \int_0^{\frac{\gamma_{th,2}(\alpha_3 \rho_1 y+1)}{\alpha_2 \rho_S - \alpha_1 \rho_S \gamma_{th,2}}} f_{|g_1|^2}(x) f_{|g_f|^2}(y) dx dy \\
&= \int_0^{\infty} \sum_{n_3=0}^{\infty} \sum_{n_4=0}^{m_{g_1}+n_3} \binom{m_{g_1}+n_3}{n_4} \frac{(-1)^{n_3} \omega_3^{n_4} \omega_4^{\mu_1} x^{n_4}}{n_3! \left(m_{g_1}+n_3\right) \Gamma\left(m_{g_1}\right)} f_{|g_f|^2}(x) dx \\
&= \sum_{n_3=0}^{\infty} \sum_{n_4=0}^{m_{g_1}+n_3} \binom{m_{g_1}+n_3}{n_4} \frac{(-1)^{n_3} \Gamma\left(m_{g_f}+n_4\right)}{n_3! \left(m_{g_1}+n_3\right) \Gamma\left(m_{g_1}\right) \Gamma\left(m_{g_f}\right)} \\
&\times \left(\frac{\gamma_{th,2}}{\alpha_2 \rho_S - \alpha_1 \rho_S \gamma_{th,2}}\right)^{n_4} \left(\frac{\gamma_{th,2}}{\rho_1}\right)^{\mu_1},
\end{aligned} \tag{19}$$

where $\mu_1 = m_{g_1} + n_3 - n_4$:

$$\begin{aligned}\Xi_4 &\triangleq \Pr\left(|g_3|^2 < \frac{\gamma_{th,2}}{\alpha_2\rho_S - \alpha_1\rho_S\gamma_{th,2}}\right)\\ &= 1 - \mathrm{e}^{-\frac{\gamma_{th,2}}{(\alpha_2\rho_S - \alpha_1\rho_S\gamma_{th,2})\beta_{g_3}}} \sum_{n_5=0}^{m_{g_3}-1} \frac{1}{n_5!}\left(\frac{\gamma_{th,2}}{(\alpha_2\rho_S - \alpha_1\rho_S\gamma_{th,2})\,\beta_{g_3}}\right)^{n_5}\end{aligned} \tag{20}$$

based on (19) and (20), we have (21).

$$\begin{aligned}\Theta_2 =& \Xi_3 \times \Xi_4\\ =& \sum_{n_3=0}^{\infty}\sum_{n_4=0}^{m_{g_1}+n_3} \binom{m_{g_1}+n_3}{n_4} \frac{(-1)^{n_3}\Gamma\left(m_{g_f}+n_4\right)}{n_3!\,(m_{g_1}+n_3)\,\Gamma\left(m_{g_1}\right)\Gamma\left(m_{g_f}\right)}\\ &\times\left(\frac{\gamma_{th,2}}{\alpha_2\rho_S - \alpha_1\rho_S\gamma_{th,2}}\right)^{n_4}\left(\frac{\gamma_{th,2}}{\rho_1}\right)^{\mu_1}\\ &\times\left(1 - \mathrm{e}^{-\frac{\gamma_{th,2}}{(\alpha_2\rho_S - \alpha_1\rho_S\gamma_{th,2})\beta_{g_3}}} \sum_{n_5=0}^{m_{g_3}-1} \frac{1}{n_5!}\left(\frac{\gamma_{th,2}}{(\alpha_2\rho_S - \alpha_1\rho_S\gamma_{th,2})\,\beta_{g_3}}\right)^{n_5}\right)\end{aligned} \tag{21}$$

3.3. Throughput

The throughput is further metric to evaluate a system can be implemented effectively or not. In fact, it depends to outage probability and target rates, so it could be examined as follow. The throughput of D_1 and D_2 are given by:

$$\mathcal{E}_{\mathrm{D}_1} = (1 - \mathcal{OP}_{\mathrm{D}_1}^{\mathrm{DL}}) \times R_1 \tag{22}$$

and,

$$\mathcal{E}_{\mathrm{D}_2} = (1 - \mathcal{OP}_{\mathrm{D}_2}^{\mathrm{DL}}) \times R_2 \tag{23}$$

the overall system throughput is given by (24).

$$\mathcal{E}_{\mathrm{system}} = \mathcal{E}_{\mathrm{D}_1} + \mathcal{E}_{\mathrm{D}_2} \tag{24}$$

4. NUMERICAL RESULTS

In this section, we perform Matlab simulations to verify derived expressions above. Some general parameters as $\lambda_{g_1} = d^{-\alpha}$, $\lambda_{g_2} = (1-d)^{-\alpha}$, $\lambda_{g_3} = 1$. Figure 2 depicts outage probability versus the transmit SNR at the BS. It can be seen that the significant improvement of outage behavior of two users is reported at high SNR region. Regarding quality of channels, $m = 5$ is known as the best case. The second user D_2 shows better outage performance compared with another user. Figure 3 shows the impact of quality of channel on outage probability. We see that the higher transmit SNR at the BS leads to improvement in term of outage probability. It can be seen that the limitation of outage performance happens as $\alpha = 5$ is known as the best case. The second user D_2 shows better outage performance compared with another user. Figure 4 shows the throughput of two users and the whole system. Since the throughput depends on outage probability, the highest throughput can be seen at high SNR region. Figure 5 indicates the impact of self-interference channel regarding on FD mode on the outage performance. Since the computation of SINR depends on such level of self-interference channel, the best performance can be reported at case of $\lambda_{g_f} = 0.001$.

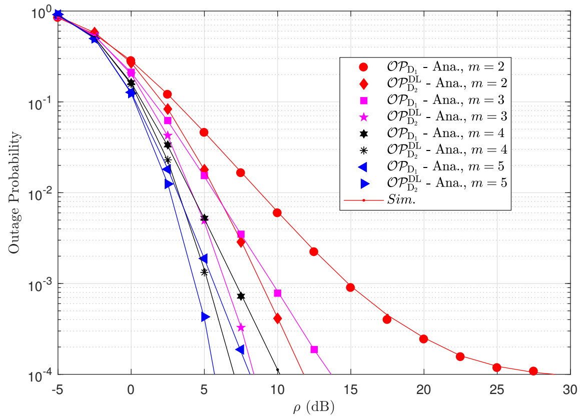

Figure 2. Outage probability transmit SNR with $\alpha = 2$, $\alpha_1 = 0.4$, $d = 0.5$, $\lambda_{g_f} = 0.01$, $R_1 = 2$, $R_2 = 0.75$

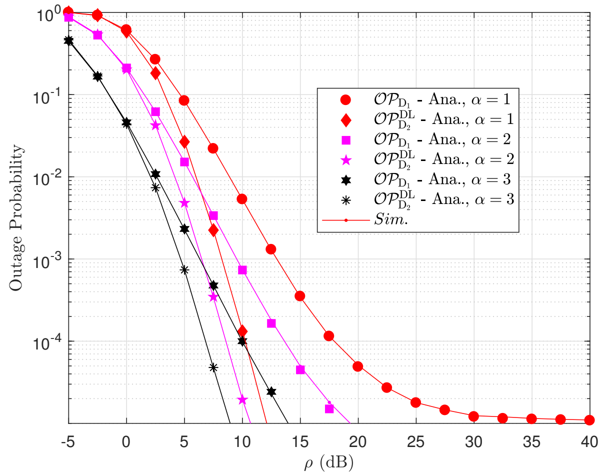

Figure 3. Outage probability with $R_1 = 2$, $R_2 = 0.75$, $\alpha_1 = 0.4$, $d = 0.5$, $\lambda_{g_f} = 0.01$, $m = 3$

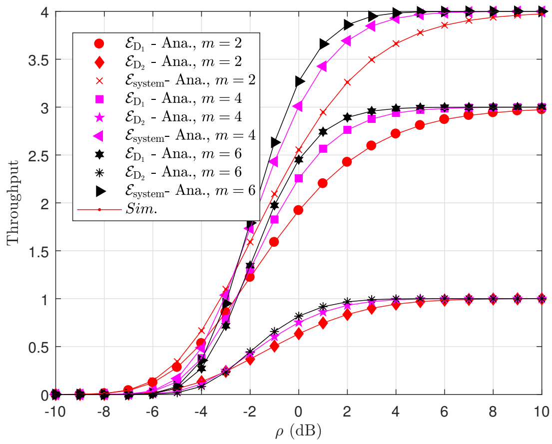

Figure 4. Throughput of two users and system throughput with $R_1 = 3$, $R_2 = 1$, $\alpha = 2$, $\alpha_1 = 0.3$, $d = 0.5$, $\lambda_{g_f} = 0.01$

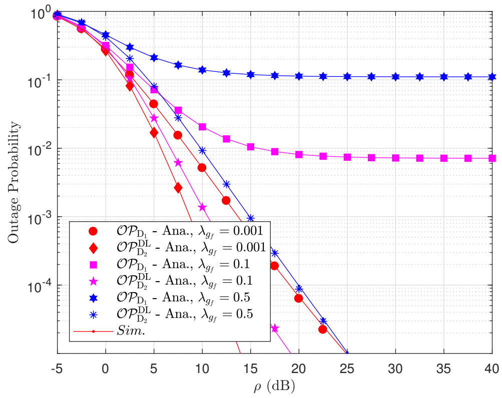

Figure 5. The system performance with different channel gains $R_1 = 1$, $R_2 = 0.75$, $\alpha = 3$, $\alpha_1 = 0.4$, $d = 0.5$, $\lambda_{g_f} = 0.01$, $m = 2$

5. CONCLUSION

In this paper, we have considered a downlink FD based NOMA systems to exploit outage performance. In particular, the system metric is improved by employing better channel parameters along with low level of self-interference channel condition due to FD mode. We derived exact expressions of outage probability and then the thoughput is also presented. We presented simple model of FD for the BS serve two NOMA users. We extend to multiple antennas designed at the BS to improve performance in the future work.

REFERENCES

[1] S. M. R. Islam, N. Avazov, O. A. Dobre, and K. Kwak, "Power-domain non-orthogonal multiple access (NOMA) in 5G systems: potentials and challenges," *IEEE Communications Surveys & Tutorials*, vol. 19, no. 2, pp. 721-742, 2017, doi: 10.1109/COMST.2016.2621116.

[2] F. Zhou, Y. Wu, Y. -C. Liang, Z. Li, Y. Wang, and K. -K. Wong, "State of the art, taxonomy, and open issues on cognitive radio networks with NOMA," *IEEE Wireless Communications*, vol. 25, no. 2, pp. 100-108, Apr. 2018, doi: 10.1109/MWC.2018.1700113.

[3] X. Li, J. Li, and L. Li, "Performance analysis of impaired SWIPT NOMA relaying networks over imperfect weibull channels," *IEEE Systems Journal*, vol. 14, no. 1, pp. 669-672, Mar. 2020, doi: 10.1109/JSYST.2019.2919654.

[4] W. Hao, M. Zeng, Z. Chu, and S. Yang, "Energy-efficient power allocation in millimeter wave massive MIMO with non-orthogonal multiple access," *IEEE Wireless Communications Letters*, vol. 6, no. 6, pp. 782-785, Dec. 2017, doi: 10.1109/LWC.2017.2741493.

[5] F. Zhou, Y. Wu, R. Q. Hu, Y. Wang, and K. K. Wong, "Energy-efficient NOMA enabled heterogeneous cloud radio access networks," *IEEE Network*, vol. 32, no. 2, pp. 152-160, 2018, doi: 10.1109/MNET.2017.1700208.

[6] S. Chen, B. Ren, Q. Gao, S. Kang, S. Sun, and K. Niu, "Pattern division multiple access—a novel nonorthogonal multiple access for fifth-generation radio networks," *IEEE Transactions on Vehicular Technology*, vol. 66, no. 4, pp. 3185-3196, Apr. 2017, doi: 10.1109/TVT.2016.2596438.

[7] B. Zheng, M. Wen, F. Chen, J. Tang, and F. Ji, "Secure NOMA based full-duplex two-way relay networks with artificial noise against eavesdropping," *2018 IEEE International Conference on Communications (ICC)*, 2018, pp. 1-6, doi: 10.1109/ICC.2018.8422946.

[8] Z. Ding, Y. Liu, J. Choi, Q. Sun, M. Elkashlan, I. Chih-Lin, and H. V. Poor, "Application of non-orthogonal multiple access in LTE and 5G networks," *IEEE Communications Magazine*, vol. 55, no. 2, pp. 185-191, Feb. 2017, doi: 10.1109/MCOM.2017.1500657CM.

[9] D.-T. Do, and T.-T.T. Nguyen, "Exact outage performance analysis of amplify-and-forward-aware cooperative NOMA," *Telecommunication, Computing, Electronics and Control (Telkomnika)*, vol. 16, no. 5, pp. 1966-1973, 2020, doi: 10.12928/telkomnika.v16i5.9823.

[10] X. Li, J. Li, Y. Liu, Z. Ding, and A. Nallanathan, "Residual transceiver hardware impairments on cooperative NOMA networks," *IEEE Transactions on Wireless Communications*, vol. 19, no. 1, pp. 680-695, Jan. 2020, doi: 10.1109/TWC.2019.2947670.

[11] D.-T Do, T.-L. Nguyen, K. M. Rabie, X. Li, and B. M. Lee, "Throughput analysis of multipair two-way replaying networks with NOMA and imperfect CSI," *IEEE Access*, vol. 8, pp. 128942-128953, 2020, doi: 10.1109/ACCESS.2020.3008674.

[12] M.-S. Van Nguyen, D.-T. Do, S. Al-Rubaye, S. Mumtaz, A. Al-Dulaimi, and O. Dobre, "Exploiting impacts of antenna selection and energy harvesting for massive network connectivity," *IEEE Transactions on Communications*, vol. 69, no. 11, pp. 7587-7602, Nov. 2021, doi: 10.1109/TCOMM.2021.3106099.

[13] D. -T. Do, A. -T. Le, Y. Liu, and A. Jamalipour, "User grouping and energy harvesting in UAV-NOMA system with AF/DF relaying," *IEEE Transactions on Vehicular Technology*, vol. 70, no. 11, pp. 11855-11868, Nov. 2021, doi: 10.1109/TVT.2021.3116101.

[14] J. So and Y. Sung, "Improving non-orthogonal multiple access by forming relaying broadcast channels," *IEEE Communications Letters*, vol. 20, no. 9, pp. 1816-1819, Sep. 2016, doi: 10.1109/LCOMM.2016.2592901.

[15] C. Zhong and Z. Zhang, "Non-orthogonal multiple access with cooperative full-duplex relaying," *IEEE Communications Letters*, vol. 20, no. 12, pp. 2478-2481, Dec. 2016, doi: 10.1109/LCOMM.2016.2611500.

[16] B. Xu, Z. Xiang, P. Ren, and X. Guo, "Outage performance of downlink full-duplex network-coded cooperative NOMA," *IEEE Wireless Communications Letters*, vol. 10, no. 1, pp. 26-29, Jan. 2021, doi: 10.1109/LWC.2020.3019570.
[17] L. Zhang, J. Liu, M. Xiao, G. Wu, Y. Liang, and S. Li, "Performance analysis and optimization in downlink NOMA systems with cooperative full-duplex relaying," *IEEE Journal on Selected Areas in Communications*, vol. 35, no. 10, pp. 2398-2412, Oct. 2017, doi: 10.1109/JSAC.2017.2724678.
[18] B. Zheng, X. Wang, M. Wen and F. Chen, "NOMA-based multi-pair two-way relay networks with rate splitting and group decoding," *IEEE Journal on Selected Areas in Communications*, vol. 35, no. 10, pp. 2328-2341, Oct. 2017, doi: 10.1109/JSAC.2017.2726008.
[19] J. Zheng, Q. Zhang and J. Qin, "Average block error rate of downlink NOMA short-packet communication systems in nakagami- m fading channels," in *IEEE Communications Letters*, vol. 23, no. 10, pp. 1712-1716, Oct. 2019, doi: 10.1109/LCOMM.2019.2930999.
[20] Y. Xu, B. Li, N. Zhao, Y. Chen, G. Wang, Z. Ding, and X. Wang, "Coordinated direct and relay transmission with NOMA and network coding in nakagami-m fading channels," *IEEE Transactions on Communications*, vol. 69, no. 1, pp. 207-222, Jan. 2021, doi: 10.1109/TCOMM.2020.3025555.
[21] Y. Alsaba, C. Y. Leow, and S. K. Abdul Rahim, "Full-duplex cooperative non-orthogonal multiple access with beamforming and energy harvesting," *IEEE Access*, vol. 6, pp. 19726-19738, 2018, doi: 10.1109/ACCESS.2018.2823723.
[22] L. Lei, E. Lagunas, S. Chatzinotas, and B. Ottersten, "NOMA aided interference management for full-duplex self-backhauling HetNets," in *IEEE Communications Letters*, vol. 22, no. 8, pp. 1696-1699, Aug. 2018, doi: 10.1109/LCOMM.2018.2847672.
[23] M. Mohammadi, X. Shi, B. K. Chalise, Z. Ding, H. A. Suraweera, C. Zhong, and J. S. Thompson, "Full-duplex non-orthogonal multiple access for next generation wireless systems," *IEEE Communications Magazine*, vol. 57, no. 5, pp. 110-116, May 2019, doi: 10.1109/MCOM.2019.1800578.
[24] X. Yue, Y. Liu, S. Kang, A. Nallanathan, and Z. Ding, "Exploiting full/half-duplex user relaying in NOMA systems," *IEEE Transactions on Communications*, vol. 66, no. 2, pp. 560-575, Feb. 2018, doi: 10.1109/TCOMM.2017.2749400.
[25] I. S. Gradshteyn and I. M. Ryzhik, *Table of Integrals, Series and Products*, 6th ed. New York, NY, USA: Academic Press, 2000.

BIOGRAPHIES OF AUTHORS

Dinh-Thuan Do (Senior Member, IEEE) received the B. S., M. Eng., and Ph. D. degrees in communications engineering from Vietnam National University (VNU-HCM), in 2003, 2007, and 2013, respectively. His research interests include signal processing in wireless communications networks, cooperative communications, non-orthogonal multiple access, full-duplex transmission, and energy harvesting. He was a recipient of the Golden Globe Award from the Vietnam Ministry of Science and Technology, in 2015 (Top ten excellent young scientists nationwide). He has served as a guest editor for eight prominent SCIE journals. He is currently serving as an associate editor for five journals, including EURASIP Journal on Wireless Communications and Networking, Computer Communications (Elsevier), ICT Express, Electronics and KSII Transactions on Internet and Information Systems. He can be contacted at email: dodinhthuan@iuh.edu.vn.

Tu-Trinh Thi Nguyen received the B. Sc. degree in computer science from the University of Hartford, USA, the M. Sc. degree in computing from the University of Bradford, U.K., and the Ph. D. degree in soft computing from The University of Sheffield, U.K. She used to hold several administrative posts with the School of Computing, Universiti Teknologi Malaysia (UTM), Johor, from 2007 to 2018, including the Head of Department, the Deputy Dean of Postgraduate Studies, and the Deputy Dean of Academic. She was also the Director of the Big Data Centre (Centre of Excellence), UTM, from 2019 to February 2020. She is currently a Professor with the Department of Data Science and the Dean of Undergraduates, Universiti Malaysia Kelantan (UMK). She has supervised and co-supervised more than 20 masters and 20 Ph. D. students. She has authored or coauthored more than 150 publications: 80 proceedings and 57 journals, with 19 H-index and more than 1000 citations. Her research interests include soft computing, machine learning, and intelligent systems. She can be contacted at email: nguyenthitutrinh@iuh.edu.vn.