TELKOMNIKA Telecommunication, Computing, Electronics and Control
Vol. 19, No. 6, December 2021, pp. 1795~1802
ISSN: 1693-6930, accredited First Grade by Kemenristekdikti, Decree No: 21/E/KPT/2018
DOI: 10.12928/TELKOMNIKA.v19i6.19034

Performance gap of two users in downlink full-duplex cooperative NOMA

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Article Info

Article history:

Received Dec 16, 2020
Revised Apr 9, 2021
Accepted Apr 21, 2021

Keywords:

Non-orthogonal multiple access
Outage probability
Power beacon
Throughput

ABSTRACT

A full-duplex non-orthogonal multiple access (FD-NOMA) systems are expected to play a significant role in fifth generation (5G) networks, addressing spectrum efficiency and massive connections. In this regard, the feasibility of FD communications to improve spectrum utilization is main consideration in term of outage performance. Specifically, we derive exact formulas of outage probability for FD-NOMA, over Nakagami-m fading channels. Extensive analysis revealed that higher quality of channel leads to better performance. We verify expressions throughout Monte-Carlo simulations.

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1. INTRODUCTION

In recent years, fifth generation (5G) networks has drawn wide attention on the application of massive connections scheme, namely non-orthogonal multiple access (NOMA). NOMA shows its potential in terms of spectral efficiency improvement [1]-[3] and higher spectrum efficiency [4], [5]. As one of differences with traditional orthogonal multiple access (OMA), by superimposing multiple users in the power domain at the transmitter, NOMA allows multiple users to be shared at the same time and frequency while the receivers employ successive interference cancellation (SIC) [6]-[8]. In NOMA system, the near user and the far user are decided based on their channel conditions. However, to ensure user fairness among near users and far users, more power is required to allocate for far user with poorer channel condition which is different with the near user with good channel condition. Recently, one can deploy cooperative techniques to improve performance of far user in the group of two users [9]-[13]. Reference [9] studied error performance of cooperative-NOMA, and they also proved the exact end-to-end bit error probability. A successive user relaying (SR) was studied in [10] to enhance the spectral efficiency of cooperative NOMA system. In the proposed SR scheme, signals from the base station are dedicated to process in a pair of half duplex (HD) users. Such signals are decoded and forward the decoded signal successively to enhance the spectral efficiency. The authors in [10] further considered a novel algorithm regarding optimize power split factor in order to improve fairness of outage performance among these users. The authors in [11] proved the superiority of NOMA with the assistance of a dedicated relay and then studied expressions of outage performance. In other system model, [12] explored the remarkable outage performance gains of the NOMA system compared to the existing OMA schemes with benefit of the relay to In the context of the cooperative NOMA scheme. The authors in [13] explored downlink cooperative NOMA system with multiple out-band relays along with two schemes in term of optimal relay selection. In term of HD deployment in system models reported in the above works [11]-[13] which results in low spectral efficiency due to the consumption of additional time resources.

To permit the relay to transmit and receive signals on the same time and frequency channel, relay is able to employ full-duplex (FD) scheme [14], [15]. However, inter-user interference and self-interference (SI) at the FD relay might occur and such worse situation results in significantly influence the system performance. To take the advantage of FD operation, antenna isolation and analog SI cancellation can be applied for SI cancellation reported in [16] and [17]. Motivated by this, recent studies have presented the combination of NOMA and FD relay [18]-[24]. Reference [24] proposed FD-NOMA system, in which near NOMA user is able to communicate with a base station (BS) directly. The far NOMA user needs to resort to a full-duplex (FD) relay. They applied wireless power transfer by allowing the FD relay integrated with power splitting architecture which can be powered wirelessly using the ambient radio signals. Motivated by recent studies [20]-[25], we study performance of FD-NOMA using Nakagami-m fading.

2. SYSTEM MODEL

In Figure 1, system consists of a BS that intends to communicate with far user U_2 via the assistance of near user U_1. U_1 is regarded as user relaying and decode and forward (DF) protocol is employed to decode and forward the information to U_2. U_1 can switch operation between FD and HD mode. $|\square_1|^2, |\square_2|^2, |\square_0|^2, |\square_f|^2$ are assumed to be exponentially distributed random variables with the parameters $\lambda_i, i \in \{1,2,0,f\}$. During the k-th time slot, The received signal at U_1 is given by (1).

$$y_{U_1}[k] = \square_1\left(\sqrt{\alpha_1 P_S}x_1[k] + \sqrt{\alpha_2 P_S}x_2[k]\right) + \square_f\sqrt{\alpha_3 P_{U_1}}x_f[k-\tau] + \eta_{U_1}[k]. \quad (1)$$

Where $\alpha_3 = 0$ denotes working in HD mode and $\alpha_3 = 1$ denotes U_1 working in FD mode. $x_f[k-\tau]$ denotes loop interference signal and τ denotes the processing delay at U_1 with an integer $\tau \geq 1$. We assume that the time k satisfies the relationship $k \geq \tau$. P_S, P_{U_1}, P_{U_2} are the normalized transmission powers at the BS and $U_1, U_2, \eta_{U_1}[k]$ is the additive white Gaussian noise with mean zero and variance σ^2 . x_1, x_2 are the signals for U_1, U_2 and $E\{x_1^2\} = E\{x_2^2\} = 1$. α_1, α_2 are the corresponding power allocation coefficients, we assume that $\alpha_2 > \alpha_1$ with $\alpha_1 + \alpha_2 = 1$. The received signal to interference plus noise ratio (SINR) at U_1 to detect x_2 is given by (2),

$$\gamma_{U_2 \to U_1}^{\mathrm{FD}} = \frac{\alpha_2 \rho_S |\square_1|^2}{\alpha_1 \rho_S |\square_1|^2 + \alpha_3 \rho_{U_1} |\square_f|^2 + 1}, \quad (2)$$

and (3),

$$\gamma_{U_2 \to U_1}^{\mathrm{HD}} = \frac{\alpha_2 \rho_S |\square_1|^2}{\alpha_1 \rho_S |\square_1|^2 + 1}. \quad (3)$$

where $\rho_S = \rho_{U_1} = \rho = \frac{P_S}{N_0}$ is transmit signal-to-noise ratio (SNR). After successive interference cancellation (SIC), the received SINR at U_1 to detect x_1 is given by (4),

$$\gamma_{U_1}^{\mathrm{FD}} = \frac{\alpha_1 \rho_S |\square_1|^2}{\alpha_3 \rho_{U_1} |\square_f|^2 + 1}, \quad (4)$$

and (5),

$$\gamma_{U_1}^{\mathrm{HD}} = \alpha_1 \rho_S |\square_1|^2.$$
(5)

The received signal at U_2 is written as (6).

$$y_{U_2}[k] = \square_0\left(\sqrt{\alpha_1 P_S}x_1[k] + \sqrt{\alpha_2 P_S}x_2[k]\right) + \square_2\sqrt{P_{U_1}}x_f[k-\tau] + \eta_{U_2}[k]. \quad (6)$$

The observation at U_2 for relaying link is written as (7).

$$y''_{U_2}[k] = \square_2\sqrt{P_{U_1}}x_2[k-\tau] + \eta_{U_2}[k]. \tag{7}$$

Where $\eta_{U_2}[k]$ is the additive white Gaussian noise (AWGN) with mean zero and variance σ^2.

The received SINR at $U_2$to detect x_2 for relaying link are given as (8).

$$\gamma_{U_2} = \rho_{U_1}|\square_2|^2. \tag{8}$$

Assuming, all channel gain undergo independence Nakagami-m fading distribution. The probability density function (PDF) and cumulative distribution function (CDF) are given by (9).

$$\begin{aligned} f_{|z|^2}(x) &= \frac{x^{m_z-1}}{\Gamma(m_z)\beta_z^{m_z}} e^{-\frac{x}{\beta_z}}, \\ F_{|z|^2}(x) &= 1 - exp\left(-\frac{x}{\beta_z}\right)\sum_{n=0}^{m_z-1}\frac{x^n}{n!\beta_z^n}, \end{aligned} \tag{9}$$

Where $\beta_z \triangleq \frac{\lambda_z}{m_z}$ with λ_z and m_z represent the mean and integer fading factor.

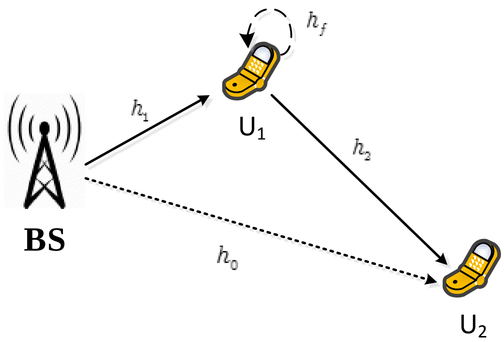

Figure 1. System model

3. SYSTEM PERFORMANCE ANALYSIS

3.1. Outage probability of U_1

According to NOMA protocol, the outage probability at U_1 in FD mode can be expresses as (10).

$$\begin{aligned} P_{\mathrm{U}_1,\mathrm{FD}} &= \Pr\left(\gamma^{\mathrm{FD}}_{\mathrm{U}_2\to\mathrm{U}_1} < \theta_2, \gamma^{\mathrm{FD}}_{\mathrm{U}_1} < \theta_1\right) \\ &= 1 - \Pr\left(\gamma^{\mathrm{FD}}_{\mathrm{U}_2\to\mathrm{U}_1} > \theta_2, \gamma^{\mathrm{FD}}_{\mathrm{U}_1} > \theta_1\right) \end{aligned} \tag{10}$$

Where the threshold SNRs are $\theta_1 = 2^{R_1} - 1, \theta_2 = 2^{R_2} - 1$, $R_1, R_2$are target rate and $\alpha_3 = 1$. Based on (2) and (4), we have (11).

$$\begin{aligned} P_{\mathrm{U}_1,\mathrm{FD}} &= 1 - \Pr\left(\frac{\alpha_2\rho_S|h_1|^2}{\alpha_1\rho_S|h_1|^2 + \alpha_3\rho_{U_1}|h_f|^2 + 1} \ge \theta_2, \frac{\alpha_1\rho_S|h_1|^2}{\alpha_3\rho_{U_1}|h_f|^2 + 1} \ge \theta_1\right) \\ &= 1 - \Pr\left(|h_1|^2 \ge \xi_1\left(\alpha_3\rho_{U_1}|h_f|^2 + 1\right)\right) \\ &= 1 - \int_0^\infty \int_{\xi_1(\alpha_3\rho_{U_1}x+1)}^\infty f_{|h_f|^2}(x) f_{|h_1|^2}(y) dxdy, \end{aligned} \tag{11}$$

We can compute the first integral as (12).

$$\begin{aligned}\psi_1 &= \int_{\xi_1\left(\alpha_3\rho_{U_1}x+1\right)}^{\infty} f_{|h_1|^2}(y)dy \\ &= \frac{1}{\Gamma\left(m_{h_1}\right)\beta_{h_1}^{m_{h_1}}}\int_{\xi_1\left(\alpha_3\rho_{U_1}x+1\right)}^{\infty}\frac{y^{m_{h_1}-1}}{\Gamma\left(m_{h_1}\right)\beta_{h_1}^{m_{h_1}}}\exp\left(-\frac{y}{\beta_{h_1}}\right)dy \\ &= 1-\sum_{n_1=0}^{\infty}\sum_{n_2=0}^{m_{h_1}+n_1}\binom{m_{h_1}+n_1}{n_2}\frac{(-1)^{n_1}}{n_1!\left(m_{h_1}+n_1\right)\Gamma\left(m_{h_1}\right)}\times\left(\frac{\alpha_3\rho_{U_1}\xi_1}{\beta_{h_1}}\right)^{n_2}\left(\frac{\xi_1}{\beta_{h_1}}\right)^{m_{h_1}+n_1-n_2}x^{n_2}.\end{aligned} \tag{12}$$

The inner integral can be further reduced using [26, Eq. (3.381.3)], Gamma function using [26, Eq. (8.354.2)] and $\xi_1 \triangleq max\left(\frac{\theta_2}{\alpha_2\rho_S-\alpha_1\rho_S\theta_2},\frac{\theta_1}{\alpha_1\rho_S}\right)$.

Replacing (12) to (11), $P_{\mathrm{U}_1,\mathrm{FD}}$ can be calculated as (13).

$$\begin{aligned}P_{\mathrm{U}_1,\mathrm{FD}} &= 1-\int_0^{\infty}\int_{\xi_1\left(\alpha_3\rho_{U_1}x+1\right)}^{\infty} f_{|h_f|^2}(x)f_{|h_1|^2}(y)dxdy \\ &= 1-\int_0^{\infty}\frac{x^{m_{h_f}-1}}{\Gamma\left(m_{h_f}\right)\beta_{h_f}^{m_{h_f}}}e^{-\frac{x}{\beta_{h_f}}}dx+\sum_{n_1=0}^{\infty}\sum_{n_2=0}^{m_{h_1}+n_1}\binom{m_{h_1}+n_1}{n_2} \\ &\quad\times\frac{(-1)^{n_1}}{n_1!\left(m_{h_1}+n_1\right)\Gamma\left(m_{h_1}\right)}\left(\frac{\alpha_3\rho_{U_1}\xi_1}{\beta_{h_1}}\right)^{n_2}\left(\frac{\xi_1}{\beta_{h_1}}\right)^{m_{h_1}+n_1-n_2}\int_0^{\infty}\frac{x^{n_2+m_{h_f}-1}}{\Gamma\left(m_{h_f}\right)\beta_{h_f}^{m_{h_f}}}e^{-\frac{x}{\beta_{h_f}}}dx \\ &= \sum_{n_1=0}^{\infty}\sum_{n_2=0}^{m_{h_1}+n_1}\binom{m_{h_1}+n_1}{n_2}\left(\frac{\alpha_3\rho_{U_1}\xi_1}{\beta_{h_1}}\right)^{n_2}\left(\frac{\xi_1}{\beta_{h_1}}\right)^{m_{h_1}+n_1-n_2}\frac{(-1)^{n_1}\beta_{h_f}^{n_2}\Gamma\left(n_2+m_{h_f}\right)}{n_1!\left(m_{h_1}+n_1\right)\Gamma\left(m_{h_f}\right)\Gamma\left(m_{h_1}\right)}.\end{aligned} \tag{13}$$

The inner integral can be further reduced using [26, Eq. (3.381.4)]. In HD mode, the outage probability of U_1 with $\alpha_3 = 0$ is given by (14).

$$\begin{aligned}P_{\mathrm{U}_1,\mathrm{HD}} &= 1-\Pr\left(\gamma_{\mathrm{U}_2\to\mathrm{U}_1}^{\mathrm{HD}} > \theta_{2,\mathrm{HD}},\gamma_{\mathrm{U}_1}^{\mathrm{HD}} > \theta_{1,\mathrm{HD}}\right) \\ &= 1-\Pr\left(\frac{\alpha_2\rho_S|h_1|^2}{\alpha_1\rho_S|h_1|^2+1}\geq\theta_{2,\mathrm{HD}},\alpha_1\rho_S|h_1|^2\geq\theta_{1,\mathrm{HD}}\right) \\ &= 1-\Pr\left(|h_1|^2\geq\xi_2\right) = 1-\left(1-F_{|h_1|^2}(\xi_2)\right) \\ &= 1-\exp\left(-\frac{\xi_2}{\beta_{h_1}}\right)\sum_{n=0}^{m_{h_1}-1}\frac{\xi_2^n}{n!\beta_{h_1}^n}.\end{aligned} \tag{14}$$

Where $\xi_2 \triangleq max\left\{\frac{\theta_{2,\mathrm{HD}}}{\alpha_2\rho_S-\alpha_1\rho_S\theta_{2,\mathrm{HD}}},\frac{\theta_{1,\mathrm{HD}}}{\alpha_1\rho_S}\right\}, \theta_{1,\mathrm{HD}} = 2^{2R_1}-1$ and $\theta_{2,\mathrm{HD}} = 2^{2R_2}-1$.

3.2. Outage probability of U_2

In FD mode, the first is that U_1 cannot detect x_2. The second is that U_2 cannot detect its own message x_2 on the conditions that U_1 can detect x_2 successfully. The outage probability of U_2 is expressed as (15).

$$\begin{aligned}P_{\mathrm{U}_2,\mathrm{FD}} &= \Pr\left(\gamma_{\mathrm{U}_2\to\mathrm{U}_1}<\theta_2\right)+\Pr\left(\gamma_{\mathrm{U}_2}<\theta_2,\gamma_{\mathrm{U}_2\to\mathrm{U}_1}>\theta_2\right) \\ &= \underbrace{\Pr\left(|h_1|^2<\frac{\theta_2\left(\alpha_3\rho_{U_1}|h_f|^2+1\right)}{\alpha_2\rho_S-\alpha_1\rho_S\theta_2}\right)}_{\triangleq\partial_2}+\underbrace{\Pr\left(|h_2|^2<\frac{\theta_2}{\rho_{U_1}}\right)}_{\triangleq\partial_3}\times\underbrace{\Pr\left(|h_1|^2>\frac{\theta_2\left(\alpha_3\rho_{U_1}|h_f|^2+1\right)}{\alpha_2\rho_S-\alpha_1\rho_S\theta_2}\right)}_{\triangleq\partial_4}.\end{aligned} \tag{15}$$

By using definition, $\partial_2,\partial_3,\partial_4$ can be calculated as (16).

$$\begin{aligned}\partial_2 &= \int_0^{\infty}\int_0^{\frac{\theta_2(\alpha_3\rho_{U_1}y+1)}{\alpha_2\rho_S-\alpha_1\rho_S\theta_2}} f_{|h_1|^2}(x)\, f_{|h_f|^2}(y)dxdy \\ &= \sum_{n_1=0}^{\infty}\sum_{n_2=0}^{m_{h_1}+n_1}\binom{m_{h_1}+n_1}{n_2}\frac{(-1)^{n_1}\Delta_1^{n_2}\Delta_2^{m_{h_1}+n_1-n_2}\Gamma\left(m_{h_f}+n_2\right)}{n_1!\left(m_{h_1}+n_1\right)\Gamma\left(m_{h_1}\right)\Gamma\left(m_{h_f}\right)}.\end{aligned} \tag{16}$$

The two integrals above can be calculated respectively as (17).

$$\begin{aligned}\Phi_1 &= \int_0^{\frac{\theta_2(\alpha_3\rho_{U_1}y+1)}{\alpha_2\rho_S-\alpha_1\rho_S\theta_2}} f_{|h_1|^2}(x)dx \\ &= \int_0^{\frac{\theta_2(\alpha_3\rho_{U_1}y+1)}{\alpha_2\rho_S-\alpha_1\rho_S\theta_2}} \frac{x^{m_{h_1}-1}}{\Gamma\left(m_{h_1}\right)\beta_{h_1}^{m_{h_1}}}\exp\left(-\frac{x}{\beta_{h_1}}\right)dx \\ &= \frac{\gamma\left(m_{h_1},\frac{\theta_2\left(\alpha_3\rho_{U_1}y+1\right)}{\beta_{h_1}(\alpha_2\rho_S-\alpha_1\rho_S\theta_2)}\right)}{\Gamma\left(m_{h_1}\right)} \\ &= \sum_{n_1=0}^{\infty}\sum_{n_2=0}^{m_{h_1}+n_1}\binom{m_{h_1}+n_1}{n_2}\frac{(-1)^{n_1}\Delta_1^{n_2}\Delta_2^{m_{h_1}+n_1-n_2}y^{n_2}}{n_1!\left(m_{h_1}+n_1\right)\Gamma\left(m_{h_1}\right)},\end{aligned} \tag{17}$$

The inner integral can be further reduced using [26, Eq. (3.381.3)] and (18).

$$\begin{aligned}\Phi_2 &= \int_0^{\infty}\sum_{n_1=0}^{\infty}\sum_{n_2=0}^{m_{h_1}+n_1}\binom{m_{h_1}+n_1}{n_2}\frac{(-1)^{n_1}\Delta_1^{n_2}\Delta_2^{m_{h_1}+n_1-n_2}y^{n_2}}{n_1!\left(m_{h_1}+n_1\right)\Gamma\left(m_{h_1}\right)}f_{|h_f|^2}(y)dy \\ &= \sum_{n_1=0}^{\infty}\sum_{n_2=0}^{m_{h_1}+n_1}\binom{m_{h_1}+n_1}{n_2}\frac{(-1)^{n_1}\Delta_1^{n_2}\Delta_2^{m_{h_1}+n_1-n_2}}{n_1!\left(m_{h_1}+n_1\right)\Gamma\left(m_{h_1}\right)}\int_0^{\infty}y^{n_2}f_{|h_f|^2}(y)dy \\ &= \sum_{n_1=0}^{\infty}\sum_{n_2=0}^{m_{h_1}+n_1}\binom{m_{h_1}+n_1}{n_2}\frac{(-1)^{n_1}\Delta_1^{n_2}\Delta_2^{m_{h_1}+n_1-n_2}\Gamma\left(m_{h_f}+n_2\right)}{n_1!\left(m_{h_1}+n_1\right)\Gamma\left(m_{h_1}\right)\Gamma\left(m_{h_f}\right)},\end{aligned} \tag{18}$$

γ is the upper and lower incomplete gamma function. By using [26, Eq. (8.354.1)], we have (19).

$$\begin{aligned}\Phi_3 &\triangleq \gamma\left(m_{h_1},\frac{\theta_2\left(\alpha_3\rho_{U_1}y+1\right)}{\beta_{h_1}(\alpha_2\rho_S-\alpha_1\rho_S\theta_2)}\right) \\ &= \sum_{n_1=0}^{\infty}\frac{(-1)^{n_1}}{n_1!\left(m_{h_1}+n_1\right)}\left(\Delta_1 y+\Delta_2\right)^{m_{h_1}+n_1} \\ &= \sum_{n_1=0}^{\infty}\sum_{n_2=0}^{m_{h_1}+n_1}\binom{m_{h_1}+n_1}{n_2}\frac{(-1)^{n_1}\Delta_1^{n_2}\Delta_2^{m_{h_1}+n_1-n_2}y^{n_2}}{n_1!\left(m_{h_1}+n_1\right)},\end{aligned} \tag{19}$$

where $\Delta_1 \triangleq \frac{\alpha_3\rho_{U_1}\theta_2}{\beta_{\square_1}(\alpha_2\rho_S-\alpha_1\rho_S\theta_2)}, \Delta_2 \triangleq \frac{\theta_2}{\beta_{\square_1}(\alpha_2\rho_S-\alpha_1\rho_S\theta_2)}$.$\partial_3$ and ∂_4 are given by (20).

$$\partial_3 \triangleq \Pr\left(|h_2|^2 < \frac{\theta_2}{\rho_{U_1}}\right) = 1 - \Pr\left(|h_2|^2 \geq \frac{\theta_2}{\rho_{U_1}}\right)$$
$$= 1 - \exp\left(-\frac{\theta_2}{\rho_{U_1}\beta_{h_2}}\right)\sum_{n=0}^{m_{h_2}-1}\frac{1}{n!\beta_{h_2}^n}\left(\frac{\theta_2}{\rho_{U_1}}\right)^n, \tag{20}$$

and (21)

$$\partial_4 \triangleq \Pr\left(|h_1|^2 > \frac{\theta_2\left(\alpha_3\rho_{U_1}|h_f|^2+1\right)}{\alpha_2\rho_S - \alpha_1\rho_S\theta_2}\right)$$
$$= 1 - \sum_{n_1=0}^{\infty}\sum_{n_2=0}^{m_{h_1}+n_1}\binom{m_{h_1}+n_1}{n_2}\frac{(-1)^{n_1}\Delta_1^{n_2}\Delta_2^{m_{h_1}+n_1-n_2}\Gamma\left(m_{h_f}+n_2\right)}{n_1!\left(m_{h_1}+n_1\right)\Gamma\left(m_{h_1}\right)\Gamma\left(m_{h_f}\right)}. \tag{21}$$

The closed-form expression for the outage probability of U_2 is given by (22).

$$P_{\mathrm{U}_2,\mathrm{FD}} = \partial_2 + \partial_3\partial_4$$
$$= 1 - \mathrm{e}^{-\frac{\theta_2}{\rho_{U_1}\beta_{h_2}}}\sum_{n=0}^{m_{h_2}-1}\frac{1}{n!\beta_{h_2}^n}\left(\frac{\theta_2}{\rho_{U_1}}\right)^n$$
$$\times\left(1 - \sum_{n_1=0}^{\infty}\sum_{n_2=0}^{m_{h_1}+n_1}\binom{m_{h_1}+n_1}{n_2}\frac{(-1)^{n_1}\Delta_1^{n_2}\Delta_2^{m_{h_1}+n_1-n_2}\Gamma\left(m_{h_f}+n_2\right)}{n_1!\left(m_{h_1}+n_1\right)\Gamma\left(m_{h_1}\right)\Gamma\left(m_{h_f}\right)}\right). \tag{22}$$

In HD mode, the outage probability of U_2 with $\alpha_3 = 0$ is given by (23).

$$P_{\mathrm{U}_2,\mathrm{HD}} = \Pr\left(\gamma_{\mathrm{U}_2\to\mathrm{U}_1}^{\mathrm{HD}} < \theta_{2,\mathrm{HD}}\right) + \Pr\left(\gamma_2^{\mathrm{U}_2} < \theta_{2,\mathrm{HD}}, \gamma_{\mathrm{U}_2\to\mathrm{U}_1}^{\mathrm{HD}} > \theta_{2,\mathrm{HD}}\right)$$
$$= \Pr\left(|h_1|^2 < \frac{\theta_{2,\mathrm{HD}}}{\alpha_2\rho_S - \alpha_1\rho_S\theta_{2,\mathrm{HD}}}\right) + \Pr\left(|h_2|^2 < \frac{\theta_{2,\mathrm{HD}}}{\rho_{U_1}}, |h_1|^2 > \frac{\theta_{2,\mathrm{HD}}}{\alpha_2\rho_S - \alpha_1\rho_S\theta_{2,\mathrm{HD}}}\right)$$
$$= 1 - \sum_{n=0}^{m_{h_1}-1}\sum_{n_1=0}^{m_{h_4}-1}\frac{\Delta_3^n\Delta_4^{n_1}\mathrm{e}^{-\frac{\Delta_3}{\beta_{h_1}}-\frac{\Delta_4}{\beta_{h_1}}}}{n!n_1!\beta_{h_1}^n\beta_{h_4}^{n_1}}. \tag{23}$$

Where $\Delta_3 \triangleq \frac{\theta_{2,\mathrm{HD}}}{\alpha_2\rho_S - \alpha_1\rho_S\theta_{2,\mathrm{HD}}}, \Delta_4 \triangleq \frac{\theta_{2,\mathrm{HD}}}{\rho_{U_1}}$.

3.3. Throughput analysis

In this section, the throughput in delay-tolerant transmission for FD/HD NOMA are presented, respectively (24),

$$J_{\mathrm{FD}} = (1 - P_{U_1,\mathrm{FD}})R_1 + (1 - P_{U_2,\mathrm{FD}})R_2, \tag{24}$$

and (25)

$$J_{\mathrm{HD}} = (1 - P_{U_1,\mathrm{HD}})R_1 + (1 - P_{U_2,\mathrm{HD}})R_2. \tag{25}$$

4. NUMERICAL RESULTS

In this section, we numerically simulate some theoretical results from some figures to show the outage performance. The main system parameters are set as $\alpha_1 = 0.2, \alpha_2 = 0.8$ and $\alpha = 2$. Figure 2 demonstrates outage performance versus transmitting SNR ρ. It is intuitively that FD-NOMA gives better performance compared with HD-NOMA. The first user shows its superior performance compared with another user. Better channel $m = 3$ case brings better performance for the considered system. Due to such outage performance, we have the corresponding throughput shown in Figure 3. It can be seen the highest performance occurs in the high SNR region. Further, under varying value of target rates, outage performance can be changed as Figure 4 and Figure 5.

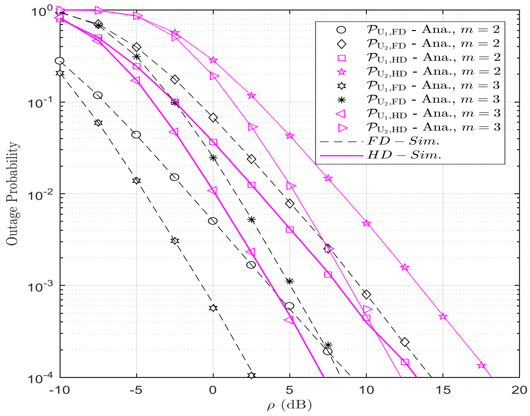

Figure 2. Outage probability transmit SNR with $d = 0.3, R_1 = 3$ bit/s/Hz, $R_2 = 0.5$ bit/s/Hz.

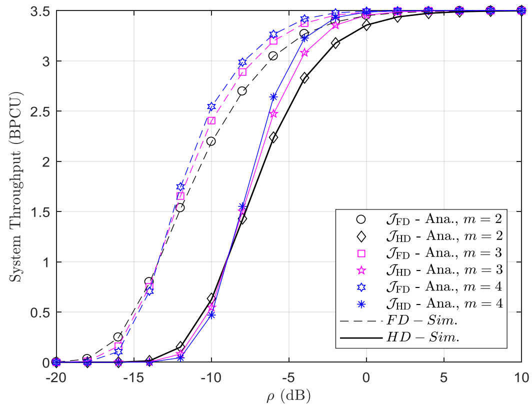

Figure 3. System throughput performance of two users with $d = 0.3$, $R_1 = 3$ bit/s/Hz, $R_2 = 0.5$ bit/s/Hz.

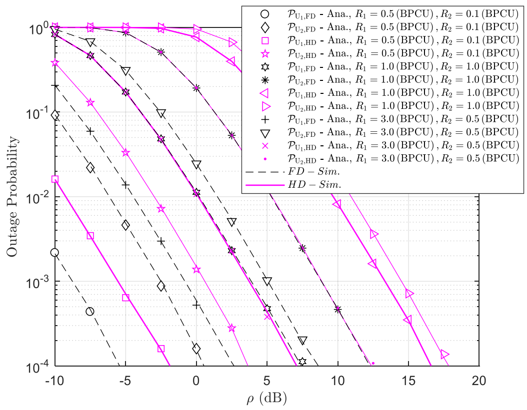

Figure 4. Outage performance of two users with $m = 2$, $d = 0.3$.

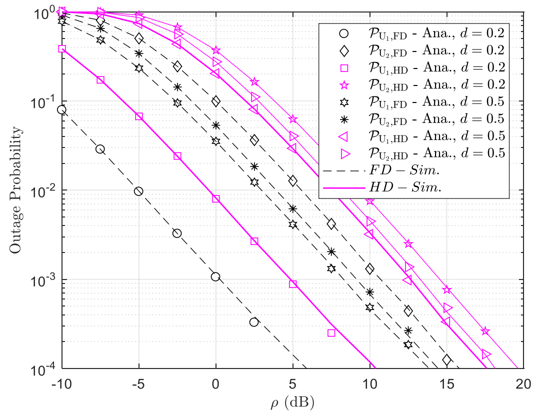

Figure 5. Outage performance of two users with $m = 2, R_1 = 3$ bit/s/Hz, $R_2 = 0.5$ bit/s/Hz.

5. CONCLUSION

In this paper, we have studied downlink non-orthogonal multiple access (NOMA) transmission with the enabler of the full-duplex scheme. By exploiting the fixed power allocation scheme, we exhibit performance differences for two users to enable NOMA for such downlink. Such NOMA can improve the transmission opportunities of the far user while reducing the impact of self-interference due to full-duplex (FD) mode. Moreover, we compare many cases of deployment of FD and NOMA, for example, we found that how channel gains can improve system quality, target rates limit performance system. The adopted mathematical derivation is checked in simulations by matching Monte-Carlo and analytical results. The system performance can be controlled by the quality of the channel and power allocation factors.

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