

Novel multiple access for cooperative networks with nakagami-m fading: system model and performance analysis

Tu-Trinh Thi Nguyen¹, Dinh-Thuan Do²

¹Faculty of Electronics Technology, Industrial University of Ho Chi Minh City, Vietnam

²Wireless Communications Research Group, Ton Duc Thang University, Vietnam

²Faculty of Electrical & Electronics Engineering, Ton Duc Thang University, Vietnam

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ABSTRACT

This study considers the performances of a downlink non-orthogonal multiple access (NOMA) network over Nakagami-m fading channels. This scheme employs two hop transmission. We first examine the analytical outage probability expression for each user and then these results are verified by Monte Carlo simulations. Based upon the outage probability, the maximal throughput are obtained and analyzed under different parameters. Furthermore, the effects of Nakagami-m channel fading on the probability and throughput are investigated. The results indicate that the performance of the NOMA system is excellent as appropriate selection of simulated parameters. This analysis can be recommended for designing the NOMA systems in the future fifth-generation wireless communication.

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Corresponding Author:

Dinh-Thuan Do,

Faculty of Electrical & Electronics Engineering, Ton Duc Thang University,

Ho Chi Minh City, Vietnam.

Email: dodinhthuan@tdtu.edu.vn

1. INTRODUCTION

As one of the bright networks, the non-orthogonal multiple access (NOMA) technique has been proposed to improved spectral efficiency for the fifth generation (5G) wireless communication system [1, 2]. Unlike the conventional orthogonal multiple access (MA) technique, NOMA can divide the power domain to multiple users to access to networks [3]. At the base station (BS) side, superposition coding is employed to support the signals of multiple users multiplexed before transmitting. At the users' side, the inter-user interference can be eliminated by employing successive interference cancellation (SIC). In addition to power domain based multiplexing, an another distinctive feature of NOMA is user fairness [4]. In these NOMA schemes, more power is allocated to users who possess worse channel conditions while users with higher channel gains require less power. As a result, NOMA communication system can be able realized to improve trade-off between user fairness and the performance. By providing significant advantages over the conventional orthogonal multiple access protocols, several studies have shown promising deployment of NOMA to achieve higher throughput and faster traffic. Recently, energy harvesting and relaying scheme are proposed to provide extended coverage and improved outage performance in many scenarios such as [5-16].

Full-duplex scheme is proposed to provide bandwidth efficiency for such relaying networks [5, 6]. Using relaying scheme, the relay assists to far users achieve more chances to remain their operations. For example, these systems can be able to eliminate interference such as co-channel interference (CCI) [8]. This paper first examine relaying network together with employing PDMA under impact of CCI on its performance analysis. In order to further enhance the reliability of NOMA, this technique has been extended to cooperative transmission scenarios [5-8]. In cooperative NOMA (C-NOMA) networks, users and relays cooperate to combat channel fading and improve the performances.

Furthermore, improved system performance as combining relaying networks with NOMA as in [17-24]. The authors in [17] considered relay selection to improve performance of far users in such NOMA. Interestingly, secure performance can be satisfied in NOMA based on relay selection [17]. Wireless powered networks are employed to support NOMA prolong life-time as power constraint-assisted device [18, 19]. The authors in [18] investigated imperfection in channel state information (CSI) on system performance of C-NOMA. However, these systems are considered performance in term of Rayleigh fading channel. The bad situation of imperfect CSI can be shown in degradation performance as in [19, 21]. To consider Nakagami-m fading, Men et al. [24] have investigated of the C-NOMA system with respect to the outage probability, but the diversity technique was not considered. Actually, the performance is further enhanced by diversity reception. Unfortunately, the closed-forms of the performance metrics are hard to derive in such a case. Thus, it is very challenging to provide an accurate analysis of the C-NOMA system with relaying scheme and Nakagami-m fading. Motivated by this requirement, we consider a relaying transmission for downlink in NOMA network with respect to Nakagami-m fading in this study.

2. SYSTEM MODEL AND OUTAGE PERFORMANCE ANALYSIS

2.1. System model

Consider a downlink for this NOMA network in this system model. This system model consists of one single-antenna base station (BS), one single-antenna relay (R) and two single-antenna users (D_1, D_2), as shown in Figure 1. In this scenario, the BS serves the two users in the same time. Two far NOMA users can be activated thanks to the help of a decode-and-forward (DF) relay. It is assumed that the channel gain of the BS-relay link experiences Nakagami-m distribution with fading parameters m . Each of the channel gains is assumed to be independent.

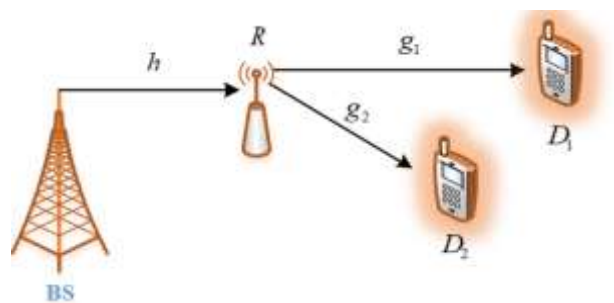


Figure 1. System model of NOMA over Nakagami-m fading channel

Based on the aforementioned assumptions, the received signals at D_k , $k=1,2$ can be written as follows:

$$y_k^d = \sqrt{P} g_k \sum_{i=1}^2 \sqrt{a_i} x_i + w_k^d \quad (1)$$

where g_k is channel coefficient from relay to D_k , P denotes the transmission power at relay and w_k^d denotes the AWGN at D_k , i.e., $w_k^d \sim \mathcal{CN}(0, \sigma^2)$, x_1, x_2 are the normalized signal for D_1, D_2 , respectively. It is assumed that $E\{x_1^2\} = E\{x_2^2\} = 1$, a_1, a_2 are power allocation factors. To stipulate better fairness between the users, we assume that $a_1 > a_2$ satisfying $a_1 + a_2 = 1$. The SINR at destination 1 in order to decode its own data can be written by:

$$\gamma_{d_1} = \frac{a_1 \rho_r |g_1|^2}{a_2 \rho_r |g_1|^2 + 1}, \quad (2)$$

Additionally, user 2 only recovers its data after successfully decomposing user 1 data and applying SIC. Then, the SINR and SNR at second user D_2 to detect the first user symbol for SIC purpose and to discover its own data are respectively given by:

$$\gamma_{d_2 \leftarrow 1} = \frac{a_1 \rho_r |g_2|^2}{a_2 \rho_r |g_2|^2 + 1}, \tag{3}$$

We denote $\rho_r = \frac{P}{\sigma^2}$ as signal to noise ratio (SNR) at relay. Then the received SINR at D_2 to detect its own information is given by:

$$\gamma_{d_2}^{pSIC} = a_2 \rho_r |g_2|^2, \tag{4}$$

and,

$$\gamma_{d_2}^{ipSIC} = \frac{a_2 \rho_r |g_2|^2}{\nu \rho_r |k_{d_1}|^2 + 1}. \tag{5}$$

3. PERFORMANCE ANALYSIS

We first call channel assumption: Assuming, all channel gain undergo independence Nakagami-m fading distribution. The PDF and CDF are given by

$$f_{|z|^2}(x) = \frac{x^{m_z-1}}{\Gamma(m_z) \beta_z^{m_z}} \exp\left(-\frac{x}{\beta_z}\right), \tag{6}$$

$$F_{|z|^2}(x) = 1 - \frac{1}{\Gamma(m_z)} \Gamma\left(m_z, \frac{x}{\beta_z}\right) = 1 - \exp\left(-\frac{x}{\beta_z}\right) \sum_{n=0}^{m_z-1} \frac{x^n}{n! \beta_z^n}, \tag{7}$$

where $\beta_z = \lambda_z / m_z$ with λ_z and m_z represent the mean and integer fading factor, $m = m_h = m_{g_1} = m_2 = m_{k_1}$, $\lambda_h = d_{1r}^\alpha$, $\lambda_{g_1} = d_{r1}^{-\alpha}$, $\lambda_{g_2} = d_{r2}^{-\alpha}$, $\lambda_{k_1} = \kappa \lambda_h$, d_{1r}, d_{r1}, d_{r2} are distances related to these nodes, α is path-loss exponent.

3.1. The outage probability for detecting x_1 at D_1

We first consider the outage probability for detecting x_1 at D_1 can be expressed as:

$$OP_1 = 1 - \Pr(\gamma_{d_1} \geq \delta_1^{th}). \tag{8}$$

where $\delta_1^{th} = 2^{2R_1} - 1$. After simple manipulations, we have following equation as

$$\begin{aligned} OP_1 &= 1 - \Pr\left(\frac{a_1 \rho_r |g_1|^2}{a_2 \rho_r |g_1|^2 + 1} \geq \delta_1^{th}\right) \\ &= F_{|g_1|^2}\left(\frac{\delta_1^{th}}{a_1 \rho_r - \delta_1^{th} a_2 \rho_r}\right) \end{aligned} \tag{10}$$

3.2. The outage probability for detecting x_2 at D_2

We call $\delta_2^{th} = 2^{2R_2} - 1$ as threshold SNR. Next, we continue to determine outage performance of D_2 to detect x_2 and it is defined by:

$$OP_2^{pSIC} = 1 - \Pr(\gamma_{d_2 \leftarrow 1} \geq \delta_1^{th}, \gamma_{d_2}^{pSIC} \geq \delta_2^{th}) \quad (11)$$

Plugging above values of (3) and (4) into (11), we have:

$$\begin{aligned} OP_2^{pSIC} &= 1 - \Pr\left(\frac{a_1 \rho_r |g_2|^2}{a_2 \rho_r |g_2|^2 + 1} \geq \delta_1^{th}, a_2 \rho_r |g_2|^2 \geq \delta_2^{th}\right) \\ &= F_{|g_2|^2}(\mathcal{Q}_1) \end{aligned} \quad (12)$$

After the implementation of the calculation, we have the outage probability for detecting x_2 at D_2 can be formulated in closed-form as:

$$OP_2^{pSIC} = 1 - \exp\left(-\frac{\mathcal{Q}_1}{\beta_{g_2}}\right) \sum_{n_1=0}^{m_{g_2}-1} \frac{\mathcal{Q}_1^{n_1}}{n_1! \beta_{g_2}^{n_1}} \quad (13)$$

$$\text{where } \mathcal{Q}_1 = \max\left(\frac{\delta_1^{th}}{a_1 \rho_r - \delta_1^{th} a_2 \rho_r}, \frac{\delta_2^{th}}{a_2 \rho_r}\right)$$

3.3. The outage probability for detecting x_2 at D_2 with imperfect SIC

The outage probability for detecting x_2 at D_2 in special case of imperfect SIC

$$OP_2^{ipSIC} = 1 - \Pr(\gamma_{d_2 \leftarrow 1} \geq \delta_1^{th}, \gamma_{d_2}^{ipSIC} \geq \delta_2^{th}) \quad (14)$$

Plugging above values of (3) and (5) into (14), we have

$$\begin{aligned} OP_2^{ipSIC} &= 1 - \Pr\left(\frac{a_1 \rho_r |g_2|^2}{a_2 \rho_r |g_2|^2 + 1} \geq \delta_1^{th}, \frac{a_2 \rho_r |g_2|^2}{\nu \rho_r |k_{d_1}|^2 + 1} \geq \delta_2^{th}\right) \\ &= 1 - \Pr\left(\underbrace{|g_2|^2 \geq \frac{\delta_1^{th}}{a_1 \rho_r - a_2 \rho_r \delta_1^{th}}, |k_{d_1}|^2 < \max\left(0, \frac{1}{\nu \rho_r} \left(\frac{a_2 \delta_1^{th}}{(a_1 - a_2 \delta_1^{th}) \delta_2^{th}} - 1\right)\right)}_{\triangleq \varphi_1}\right) \\ &\quad - \Pr\left(\underbrace{|g_2|^2 \geq \frac{\nu \delta_2^{th}}{a_2} |k_{d_1}|^2 + \frac{\delta_2^{th}}{a_2 \rho_r}, |k_{d_1}|^2 > \max\left(0, \frac{1}{\nu \rho_r} \left(\frac{a_2 \delta_1^{th}}{(a_1 - a_2 \delta_1^{th}) \delta_2^{th}} - 1\right)\right)}_{\triangleq \varphi_2}\right) \end{aligned} \quad (15)$$

From (15), we can calculate φ_1 and φ_2 as follow:

$$\begin{aligned}
 \varphi_1 &= \Pr \left(|g_2|^2 \geq \frac{\delta_1^{th}}{a_1 \rho_r - a_2 \rho_r \delta_1^{th}}, |k_{d_1}|^2 < \max \left(0, \frac{1}{\nu \rho_r} \left(\frac{a_2 \delta_1^{th}}{(a_1 - a_2 \delta_1^{th}) \delta_2^{th}} - 1 \right) \right) \right) \\
 &= \left(1 - F_{|g_2|^2} \left(\frac{\delta_1^{th}}{a_1 \rho_r - a_2 \rho_r \delta_1^{th}} \right) \right) F_{|k_{d_1}|^2} \left(\underbrace{\max \left(0, \frac{1}{\nu \rho_r} \left(\frac{a_2 \delta_1^{th}}{(a_1 - a_2 \delta_1^{th}) \delta_2^{th}} - 1 \right) \right)}_{\triangleq \mu} \right) \\
 &= \exp \left(- \frac{\delta_1^{th}}{(a_1 \rho_r - a_2 \rho_r \delta_1^{th}) \beta_{g_2}} \right) \sum_{n=0}^{m_{g_2}-1} \frac{1}{n! \beta_{g_2}^n} \left(\frac{\delta_1^{th}}{a_1 \rho_r - a_2 \rho_r \delta_1^{th}} \right)^n \\
 &\quad - \exp \left(- \frac{\delta_1^{th}}{(a_1 \rho_r - a_2 \rho_r \delta_1^{th}) \beta_{g_2}} - \frac{\mu}{\beta_{k_{d_1}}} \right) \sum_{n=0}^{m_{g_2}-1} \sum_{n_1=0}^{m_{k_{d_1}}-1} \frac{1}{n! \beta_{g_2}^n} \left(\frac{\delta_1^{th}}{a_1 \rho_r - a_2 \rho_r \delta_1^{th}} \right)^n \frac{\mu^{n_1}}{n_1! \beta_{k_{d_1}}^{n_1}}
 \end{aligned} \tag{16}$$

and,

$$\begin{aligned}
 \varphi_2 &= \Pr \left(|g_2|^2 \geq \frac{\nu \delta_2^{th}}{a_2} |k_{d_1}|^2 + \frac{\delta_2^{th}}{a_2 \rho_r}, |k_{d_1}|^2 > \max \left(0, \frac{1}{\nu \rho_r} \left(\frac{a_2 \delta_1^{th}}{(a_1 - a_2 \delta_1^{th}) \delta_2^{th}} - 1 \right) \right) \right) \\
 &= \exp \left(- \frac{\delta_2^{th}}{a_2 \rho_r \beta_{g_2}} \right) \sum_{n_2=0}^{m_{g_2}-1} \sum_{n_3=0}^{n_2} \binom{n_2}{n_3} \frac{1}{n_2! \beta_{g_2}^{n_2} \times \Gamma(m_{k_{d_1}}) \beta_{k_{d_1}}^{m_{k_{d_1}}}} \left(\frac{\nu \delta_2^{th}}{a_2} \right)^{n_3} \left(\frac{\delta_2^{th}}{a_2 \rho_r} \right)^{n_2 - n_3} \\
 &\quad \times \left(\frac{\nu \delta_2^{th}}{a_2 \beta_{g_2}} + \frac{1}{\beta_{k_{d_1}}} \right)^{-n_3 - m_{k_{d_1}}} \Gamma \left(n_3 + m_{k_{d_1}}, \mu \left(\frac{\nu \delta_2^{th}}{a_2 \beta_{g_2}} + \frac{1}{\beta_{k_{d_1}}} \right) \right)
 \end{aligned} \tag{17}$$

Plugging above values of (16) and (17) into (15), After the implementation of the calculation, we have the outage probability for detecting x_2 at D_2 in special case of imperfect SIC can be formulated in closed-form as:

$$\begin{aligned}
 OP_2^{iSIC} &= 1 - \exp \left(- \frac{\delta_1^{th}}{(a_1 \rho_r - a_2 \rho_r \delta_1^{th}) \beta_{g_2}} \right) \sum_{n=0}^{m_{g_2}-1} \sum_{n_1=0}^{m_{k_{d_1}}-1} \frac{1}{n! \beta_{g_2}^n} \left(1 - \exp \left(- \frac{\mu}{\beta_{k_{d_1}}} \right) \frac{\mu^{n_1}}{n_1! \beta_{k_{d_1}}^{n_1}} \right) \left(\frac{\delta_1^{th}}{a_1 \rho_r - a_2 \rho_r \delta_1^{th}} \right)^n \\
 &\quad - \exp \left(- \frac{\delta_2^{th}}{a_2 \rho_r \beta_{g_2}} \right) \sum_{n_2=0}^{m_{g_2}-1} \sum_{n_3=0}^{n_2} \binom{n_2}{n_3} \frac{1}{n_2! \beta_{g_2}^{n_2} \times \Gamma(m_{k_{d_1}}) \beta_{k_{d_1}}^{m_{k_{d_1}}}} \left(\frac{\nu \delta_2^{th}}{a_2} \right)^{n_3} \left(\frac{\delta_2^{th}}{a_2 \rho_r} \right)^{n_2 - n_3} \\
 &\quad \times \left(\frac{\nu \delta_2^{th}}{a_2 \beta_{g_2}} + \frac{1}{\beta_{k_{d_1}}} \right)^{-n_3 - m_{k_{d_1}}} \Gamma \left(n_3 + m_{k_{d_1}}, \mu \left(\frac{\nu \delta_2^{th}}{a_2 \beta_{g_2}} + \frac{1}{\beta_{k_{d_1}}} \right) \right)
 \end{aligned} \tag{18}$$

3.4. The throughput on the outage probability

Other metric provides further performance of such network. The throughput mainly depends on the outage probability. In particular, throughput performance can be obtained in three cases as follows:

$$TH_1 = (1 - OP_1) \times R, \tag{19}$$

$$TH_2^{pSIC} = (1 - OP_2^{pSIC}) \times R, \tag{20}$$

$$TH_2^{ipSIC} = (1 - OP_2^{ipSIC}) \times R. \tag{21}$$

4. SIMULATION RESULTS

This section provides numerical results. It can be seen outage performance of two users versus transmit SNR at the BS as in Figure 2. At ipSIC case, user 2' performance will meet floor value at high SNR. The varying target rates contribute to outage performance and it shows that the better outage performance as lower target rates required. While Figure 3 illustrates throughput performance versus transmit SNR.

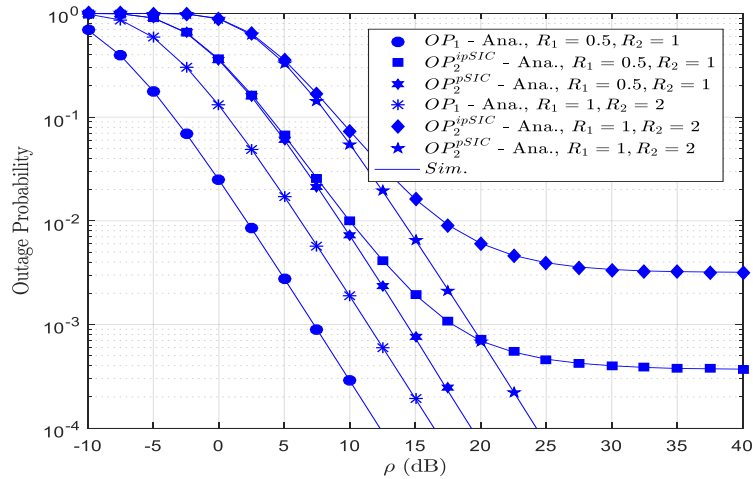


Figure 2. Outage probability vs. the transmit SNR with $a_1 = 0.9$, $a_2 = 0.1$, $m = 2$, $\alpha = 2$, $\kappa = 0.005$, $d_{1r} = 0.5, d_{r1} = 0.5, d_{r2} = 0.25$

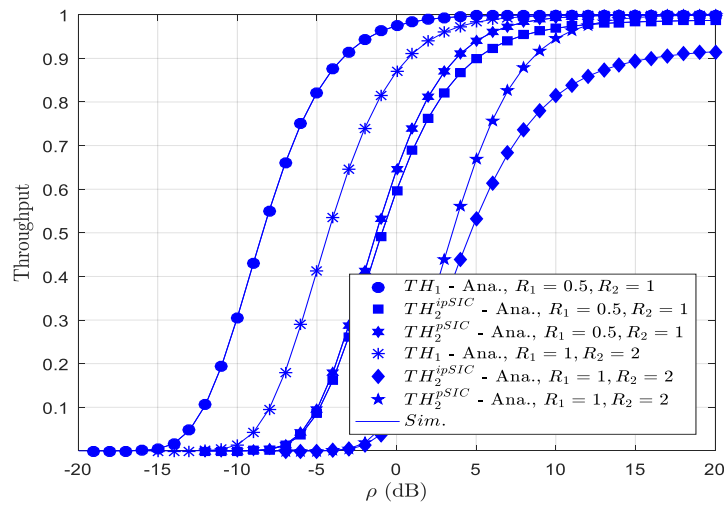


Figure 3. Throughput performance vs. the transmit SNR with $a_1 = 0.9$, $a_2 = 0.1$, $m = 2$, $\alpha = 2$, $\kappa = 0.03$, $d_{1r} = 0.5, d_{r1} = 0.5, d_{r2} = 0.25$

Figure 4 examines impact of Nakagami-m fading factors on outage performance as considering range of interference levels $\kappa = -50 \rightarrow 0(dB)$. It can be seen clearly that higher level of interference of SIC imperfection leads to outage condition.

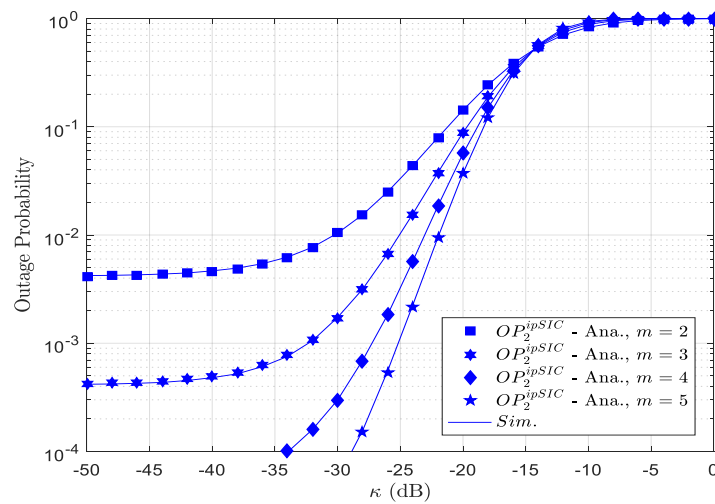


Figure 4. Outage probability under impact of κ with $a_1 = 0.9$, $a_2 = 0.1$, $R_1 = 0.5, R_2 = 1$, $\alpha = 2$, $\kappa = 0.03, d_{1r} = 0.5, d_{r1} = 0.5, d_{r2} = 0.25$.

5. CONCLUSION

In this paper, the performance of the downlink NOMA system with two hop transmission over Nakagami-m fading channels is investigated. First, we derived expressions of outage probability to provide the analytical evaluation for each user. To confirm the accuracy of the analytical results, Monte-Carlo simulations are performed. In addition, by selecting suitable target rate coefficients, Nakagami-m fading factors, it can be achieved the outage behaviors of the users. Then, we evaluated the throughput of the NOMA system based upon the outage probability of each user. By conducting numerical research on several parameters, the lowest outage performance and highest throughputs were obtained.

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