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Enabling relay selection in non-orthogonal multiple access networks: direct and relaying mode

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ABSTRACT

In this paper, we consider downlink non-orthogonal multiple access (NOMA) in which the relay selection (RS) scheme is enabled for cooperative networks. In particular, we investigate impact of the number of relays on system performance in term of outage probability. The main factors affecting on cooperative NOMA performance are fixed power allocations coefficients and the number of relay. This paper also indicate performance gap of the outage probabilities among two users the context of NOMA. To exhibit the exactness of derived formula, we match related results between simulation and analytical methods. Numerical results confirms that cooperative NOMA networks benefit from increasing the number of relay.

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1. INTRODUCTION

As an effective multiple access (MA) technique, non-orthogonal multiple access (NOMA) has been proposed to significantly improve the spectral efficiency [1]. An extra rising issue is that system performance depends on users with good channel conditions while the worse performance is affected by users associated with bad channel conditions [2]. A potential solution for hard problem is joining relaying networks with NOMA and then a cooperative NOMA (C-NOMA) transmission scheme is generated. In such system, the users with good channel conditions work as relays to reinforce the transmission consistency for users affected by bad channel circumstances [3-6]. Interestingly, recent works regarding relaying schemes [7-12] can be further deployed in considered cooperative NOMA. Outage performance [7-10] and related throughput are two main metrics to evaluate in such papers [9-12]. The question is how NOMA system remains its performance to adapt to QoS requirement.

In [13], to address energy efficiency, NOMA together with energy harvesting-enabled networks is investigated. In [14], the simultaneous information processing and energy transfer scheme applied in the downlink of NOMA is evaluated. In [14], however, the near user is higher priority to harvesting energy from the source to serve signal transmission to the far user. In addition, the authors in [15] explored the static power splitting (SPS). More specifically, they examined the outage probability and diversity gain or the downlink of cooperative NOMA with ability of near users with respect to energy harvesting. In other trends for NOMA, the authors in [16-19] introduced employing the fixed decoding order to examine the closed-form outage probability expressions for a two-user scenario. Outage performance is also considered as relay selection scheme applied in NOMA networks [20, 21]. Motivated by novel results in [20-25], in this paper, we consider a downlink NOMA network corresponding DF mode with both relay selection and direct link to forward signal to far NOMA users under Rayleigh fading channels.

The rest of the paper is structured as follows. In Section II, we introduce the system model and analytical computation related to signals. Outage probability analysis for relaying networks with NOMA are addressed in Section III. Some numerical results are shown in Section IV and conclusions are finally drawn in Section V. Through the paper, $\Pr(.)$ denotes as outage probability, $F_X(.), f_X(.)$ are represented for the cumulative distribution function (CDF) and the probability density function (PDF), in which X is random variable, $E\{.\}$ is the expectation operator.

2. SYSTEM MODEL

Suppose that the NOMA system as in Figure 1 co-operates at the signal transmitted from a BS to transmit signal to the device near the BS, and to device located at the cell boundary, also known as two NOMA users (near devices $D1$ and far device $D2$). Particularly many traditional mobile users (CUs) in the role of intermediate node for transferring to $D2$. More specifically, the BS directly transmits the signal to the user $D1$, while user $D2$ needs the help of the best relay relay. It worth noting that the weak signal occurs in the link from the BS to $D2$ due to obstacle of the high building. Because the half-duplex mode is employed, single-antenna is equipped in each node and amply-and-forward (AF) is operated in such pattern. In this model, two consecutive time slots are required in the collaborative NOMA.

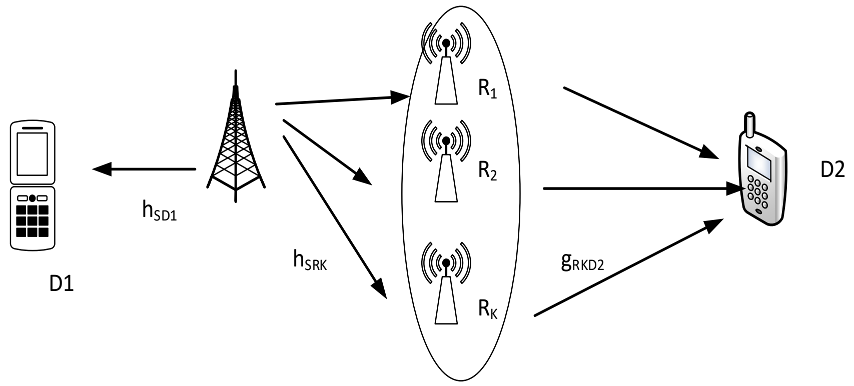

Figure 1. System model of relay selection for the far users and direct link for the near user

More specifically, the best relay in K AF relays $(R_1,...,R_K, K \geq 1)$ is selected to support a base station (BS) which is expected to forward the signal to the far user $D2$. Normally, selection criteria for determining signal which need be forwarded including max-min selection, best relay selection and partial relay selection. Such decisions are provided to select the forwarding node in the central control unit in considered network. Here, as the simplistic model can be applied in practice the partial relay selection option which is studied as in this paper. It is possible that additional gaussian white noise (AWGN) terms are applied in the model, and assuming that Rayleigh frequency blocks are chosen for any link in the network.

It can be denoted $h_{SR_k} \sim CN(0,\lambda_{SR_k})$ as the complex channel coefficient between S and R_k and the AWGN as w_{R_k}; $h_{SD1} \sim CN(0,\lambda_{SD_1})$, $g_{R_k D2} \sim CN(0,\lambda_{R_k D2})$ and w_{D1}, w_{D2} stand for the complex channel factors and the AWGN term between R_k and $D2$, $k = 1, 2, ..., K$, respectively. In this scheme, all channel links are assumed as independent and flat Rayleigh fading and it means they satisfy the same in block time but independently vary with other blocks. It is noted that w_{D_1}, w_{D_2} denote as the AWGN noise terms $w_{D_1}, w_{D_2}, w_{R_k} \sim CN(0, N_0)$.

In addition, it is assumed that in the same cell K relay nodes operate and they are placed close to each other to lead to similar distances in different links between the BS and relaying node, and thus the radio channel model is independent identically distributed (i.i.d.) applied as frequent assumption in in existing papers. It worth noting that we assume in NOMA that $D1$ is required to be served opportunistically while small packet with a lower target data rate is required at $D2$. As a further application, download a movie or carry out some high speed transmission is assigned for $D1$ while medical health sensor sent the pivotal safety information containing in a few bytes is performed at $D2$, such as blood pressure and heart rates.

Firstly, the BS will transfer signal in each fading block, and signal processing frame is divided into two time epochs. In particular, the BS transmits the composed signal x_S and it is dedicated for all relays in the first phase, as:

$$x_S = \sqrt{a_1 P_S} x_1 + \sqrt{a_2 P_S} x_2, \tag{1}$$

Where $D1$ and $D2$ receives x_1 and x_2 respectively; x_1 and x_2 are the normalized signal it is assumed that $E\left\{x_1^2\right\} = E\left\{x_2^2\right\} = 1$ while a_1 and a_2 are the power allocation coefficients, and P_s denotes as transmit power at the BS. Higher power factor is assigned for strong user, i.e. $|a_1| > |a_2|$ with $a_1 + a_2 = 1$. The received signal at $D1$ in the direct link is expressed by:

$$\begin{aligned} y_{SD1}^{NOMA} &= h_{SD1} x_S^{NOMA} + w_{D_1} \\ &= h_{SD1}\left(\sqrt{a_1 P_S} x_1 + \sqrt{a_2 P_S} x_2\right) + w_{D_1}. \end{aligned} \tag{2}$$

The received signal at R_k is given by:

$$\begin{aligned} & y_{SRK}^{NOMA} = h_{SR_k} x_S^{NOMA} + w_{R_k} \\ & = h_{SR_k}\left(\sqrt{a_1 P_S} x_1 + \sqrt{a_2 P_S} x_2\right) + w_{R_k}. \end{aligned} \tag{3}$$

The signal can be received at $D2$ is:

$$y_{SRKD_2}^{NOMA} = g_{R_k D_2} \sqrt{P_R} x_2 + w_{D_2}. \tag{4}$$

We obtain SNR to detect signal x_1 at destination $D1$ as:

$$\gamma_{SD1}^{NOMA} = \frac{a_1 P_S |h_{SD1}|^2}{a_2 P_S |h_{SD1}|^2 + N_0} = \frac{a_1 \rho_S |h_{SD1}|^2}{a_2 \rho_S |h_{SD1}|^2 + 1}, \tag{5}$$

where $\rho_S = \frac{P_S}{N_0}$. We perform SNR to first detect x_1 and then deploying SIC to detect x_2 as below:

$$\gamma_{SRK,x1}^{NOMA} = \frac{a_1 \rho_S \left|h_{SR_k}\right|^2}{a_2 \rho_S \left|h_{SR_k}\right|^2 + 1}, \tag{6}$$

$$\gamma_{SRK,x2}^{NOMA} = a_2 \rho_S \left|h_{SR_k}\right|^2. \tag{7}$$

At destination $D2$, we calculate SNR to detect x_2 as it is forwarding from the relay to $D2$.

$$\gamma_{RKD2,x2}^{NOMA} = \frac{P_R \left|g_{R_k D_2}\right|^2}{N_0} = \rho_R \left|g_{R_k D_2}\right|^2, \tag{8}$$

where $\rho_R = \frac{P_R}{N_0}$, P_R denotes the transmit power of the k^{th} relay and this power is assumed same for all relay.

3. OUTAGE PERFORMANCE ANALYSIS
3.1. Outage probability at the near user $D1$

We first determine the outage probability at near device $D1$ related to detecting the signal x_1, x_2, where $\varepsilon_1 = 2^{2R_1} - 1$ as:

$$OP_{1-NOMA} = \Pr\left(\gamma_{SD1}^{NOMA} < \varepsilon_1\right) = 1 - \exp\left(-\frac{\varepsilon_1}{\left(a_1 - \varepsilon_1 a_2\right)\rho_S \lambda_{SD1}}\right), \quad (9)$$

3.2. Outage probability at $D2$ for detecting x_1

In DF mode, the relay first decode x_1 and then forward x_2 to destination $D2$. The SNR for detect signal at $D2$ can be formulated by:

$$\gamma_k^{NOMA} = \min\left(\gamma_{SRK,x1}^{NOMA}, \gamma_{SRK,x2}^{NOMA}, \gamma_{RKD2,x2}^{NOMA}\right). \quad (10)$$

it is noted that the best relay node in K relay nodes is selected by the following criterion**:**

$$\gamma_{k*}^{NOMA} = \max_{k=1\cdots K}\left(\gamma_k^{NOMA}\right). \quad (11)$$

therefore, the outage probability at $D2$ can be calculated by:

$$\begin{aligned} OP_{2-NOMA} &= \Pr\left(\gamma_{SRK*,x1}^{NOMA} < \varepsilon_1 \cup \gamma_{SRK*,x2}^{NOMA} < \varepsilon_2 \cup \gamma_{RK*D2,x2}^{NOMA} < \varepsilon_2\right) \\ &= \prod_{k=1}^{K}\left(1 - \underbrace{\Pr\left(\gamma_{SRK,x1}^{NOMA} \geq \varepsilon_1, \gamma_{SRK,x2}^{NOMA} \geq \varepsilon_2, \gamma_{RKD2,x2}^{NOMA} \geq \varepsilon_2\right)}_{A}\right). \end{aligned} \quad (12)$$

it need be further computed A as below:

$$\begin{aligned} A &= \Pr\left(\left|h_{SR1}\right|^2 \geq \frac{\varepsilon_1}{\rho_S\left(a_1 - \varepsilon_1 a_2\right)}, \left|h_{SR1}\right|^2 \geq \frac{\varepsilon_2}{a_2 \rho_S}, \left|g_{RKD2}\right|^2 \geq \frac{\varepsilon_2}{\rho_R}\right) \\ &= \Pr\left(\left|h_{SR1}\right|^2 \geq \max\left(\frac{\varepsilon_1}{\rho_S\left(a_1 - \varepsilon_1 a_2\right)}, \frac{\varepsilon_2}{a_2 \rho_S}\right), \left|g_{RKD2}\right|^2 \geq \frac{\varepsilon_2}{\rho_R}\right). \end{aligned} \quad (13)$$

it is rewritten as:

$$\begin{aligned} A &= \Pr\left(\frac{1}{\theta}\left|h_{SR1}\right|^2 \geq 1, \frac{\rho}{\varepsilon_2}\left|g_{RKD2}\right|^2 \geq 1\right) = \Pr\left(\min\left(\frac{1}{\theta}\left|h_{SR1}\right|^2, \frac{\rho_R}{\varepsilon_2}\left|g_{RKD2}\right|^2\right) \geq 1\right) \\ &= \exp\left(\frac{-\theta}{\lambda_{SR1}} - \frac{\varepsilon_2}{\rho_R \lambda_{RKD2}}\right). \end{aligned} \quad (14)$$

therefore, we obtain final expression for $D2$'s outage event:

$$OP_{2-NOMA} = \prod_{k=1}^{K}\left(1 - \exp\left(\frac{-\theta}{\lambda_{SR1}} - \frac{\varepsilon_2}{\rho_R \lambda_{RKD2}}\right)\right), \quad (15)$$

where $\theta = \max\left(\frac{\varepsilon_1}{\rho_S\left(a_1 - \varepsilon_1 a_2\right)}, \frac{\varepsilon_2}{a_2 \rho_S}\right)$, $\varepsilon_2 = 2^{2R_2} - 1$. In addition, we also evaluate overall outage event of overall NOMA system as:

$$
\begin{aligned}
OP_{NOMA} &= \Pr\left(\gamma_{SD1}^{NOMA} < \varepsilon_1 \cup \gamma_{SRK^*,x1}^{NOMA} < \varepsilon_1 \cup \gamma_{SRK^*,x2}^{NOMA} < \varepsilon_2 \cup \gamma_{RK^*D2,x2}^{NOMA} < \varepsilon_2\right) \\
&= 1 - \Pr\left(\gamma_{SD1}^{NOMA} \ge \varepsilon_1\right)\Pr\left(\gamma_{SRK^*,x1}^{NOMA} \ge \varepsilon_1 \cup \gamma_{SRK^*,x2}^{NOMA} \ge \varepsilon_2 \cup \gamma_{RK^*D2,x2}^{NOMA} \ge \varepsilon_2\right) \\
&= 1 - \left(1 - OP_{1-NOMA}\right)\left(1 - OP_{2-NOMA}\right).
\end{aligned}
\tag{16}
$$

3.3. Outage probability in OMA scenario

As benchmark of NOMA, we computed signal at $D1$ in OMA mode as:

$$y_{SD1}^{OMA} = h_{SD1}\sqrt{P_S}x_1 + w_{D1}. \tag{17}$$

The received signal at relay is given by:

$$y_{SRK}^{OMA} = h_{SR1}\sqrt{P_S}x_2 + w_{RK}. \tag{18}$$

The signal can be computed at $D2$ as:

$$y_{RKD_2}^{OMA} = g_{RKD2}\sqrt{P_R}x_2 + w_{RKD_2}. \tag{19}$$

We continue compute SNR to detect signal x_1 which is transmitted from BS to $D1$:

$$\gamma_{SD1}^{OMA} = \rho_S \left|h_{SD1}\right|^2. \tag{20}$$

To consider SNR to detect x_2 at the relay K, we compute following equation:

$$\gamma_{SRK,x2}^{OMA} = \rho_S \left|h_{SR1}\right|^2. \tag{21}$$

Similarly, SNR to detect x_2 from relay to $D2$ can be expressed by:

$$\gamma_{RKD2,x2}^{OMA} = \rho_R \left|g_{RKD2}\right|^2. \tag{22}$$

We continue to compute outage event for $D1$ in case of OMA:

$$OP_{1-OMA} = \Pr\left(\gamma_{SD1}^{OMA} < \xi_1\right) = 1 - \exp\left(-\frac{\xi_1}{\rho_S \lambda_{SD1}}\right), \tag{23}$$

where $\xi_1 = 2^{2R_1} - 1$.

In OMA mode, the best relay node is selected by the following criterion:

$$
\begin{aligned}
\gamma_k^{OMA} &= \min\left(\gamma_{SRK,x2}^{OMA}, \gamma_{RKD2,x2}^{OMA}\right), \\
\gamma_{k^*}^{OMA} &= \max_{k=1\cdots K}\left(\gamma_k^{OMA}\right).
\end{aligned}
\tag{24}
$$

The outage probability at $D2$ in OMA case is examined by:

$$
\begin{aligned}
OP_{2-OMA} &= \Pr\left(\gamma_{k^*}^{OMA} < \xi_2\right) = \prod_{k=1}^{K}\left(1 - \Pr\left(\gamma_k^{OMA} \ge \xi_2\right)\right) \\
&= \prod_{k=1}^{K}\left(1 - \Pr\left(\left|h_{SR1}\right|^2 \ge \frac{\xi_2}{\rho_S}, \left|g_{RKD2}\right|^2 \ge \frac{\xi_2}{\rho_R}\right)\right) \\
&= \prod_{k=1}^{K}\left(1 - \exp\left(-\frac{\vartheta}{\lambda_{SR1}} - \frac{\chi}{\lambda_{RKD2}}\right)\right),
\end{aligned}
\tag{25}
$$

where $\xi_2 = 2^{4R_2} - 1$, $\vartheta = \frac{\xi_2}{\rho_S}$, $\chi = \frac{\xi_2}{\rho_R}$.

final, overall outage event in OMA case is given by:

$$\begin{aligned} OP_{OMA} &= \Pr\left(\gamma_{SD1}^{OMA} < \varepsilon_1 \cup \min\left(\gamma_{SRK^*,x2}^{OMA}, \gamma_{RK^*D2,x2}^{OMA}\right) < \xi_2\right) \\ &= 1 - \Pr\left(\gamma_{SD1}^{OMA} \geq \varepsilon_1\right) \Pr\left(\min\left(\gamma_{SRK^*,x2}^{OMA}, \gamma_{RK^*D2,x2}^{OMA}\right) \geq \xi_2\right) \\ &= 1 - \left(1 - OP_{1-OMA}\right)\left(1 - OP_{2-OMA}\right). \end{aligned} \tag{26}$$

4. NUMERICAL RESULT

In these simulation results, the proposed relay selection strategy for NOMA transmission is performed to determine the outage performance, and several corresponding parameters are conducted. In Figure 2, the performance of proposed scheme is illustrated as comparing the outage performance versus the transmit SNR in case of varying number of relay node. The relay is befitted by selection mode for the far user while near device do not need any relay. From Figure 2, high number of relay node contribute to increase performance significantly. More specifically, the performance gap can be seen clearly at high SNR regime. Unfortunately, the proposed relay selection scheme has the similar performance at some specific values, i.e. the number of relay is 5 or 10, and this situation confirmed that the limited number of relay can be performed to approach performance floor.

As can be seen from Figure 3, the outage performance for detecting signal of x_2 versus the transmit SNR. Similarly as in Figure 2, the performance gap provides the enhanced performance as reasonable selection of number of relay. To improve the reliability of the cooperative networks, the higher diversity gains is required and such model satisfies basic requirement. It is noted that the downward trend is seen in the considered NOMA for outage behavior.

It can be shown outage performance of detecting signal of x_1 as changing power allocation fractions as in Figure 4 and varying the threshold SNR as in Figure 5. It is preciously seen that as the analysis lines of match tightly with the simulation curves. The other aspect is that more allocated power assigned to user leads to better performance. In other hand, the higher threshold SNR requires higher data rate, and hence declining outage performance seen in Figure 5. Similar trend can be seen in Figure 6 for corresponding signal x_2. Next, Figure 6 compares outage performance for detecting both signals. The different power allocation factors and different transmission links are main reason to show different outage performance. Another observation is that the performance of NOMA is better OMA at several points of transmit SNR to highlight improvement of considered NOMA.

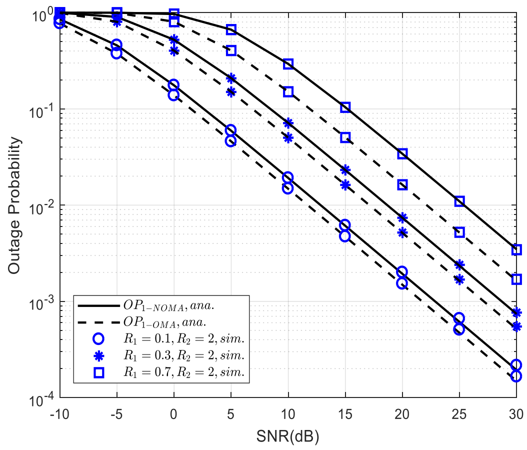

Figure 2. Outage probability for x_1 OP1 ($a_1 = 0.8$, $\lambda_{SD1} = 1$)

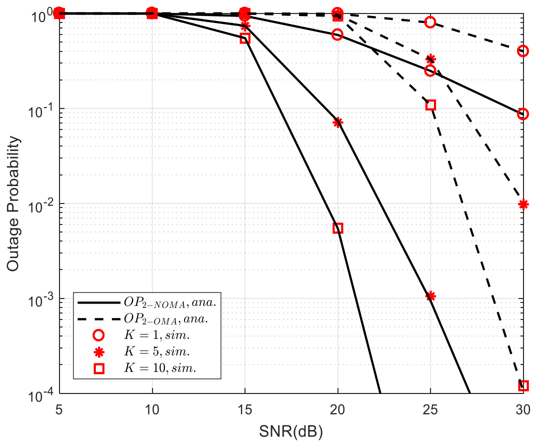

Figure 3. Outage probability for detecting x_2 ($a_1 = 0.8$, $\lambda_{SR1} = \lambda_{RKD2} = 1$, $R_1 = 0.5$, $R_2 = 2$)

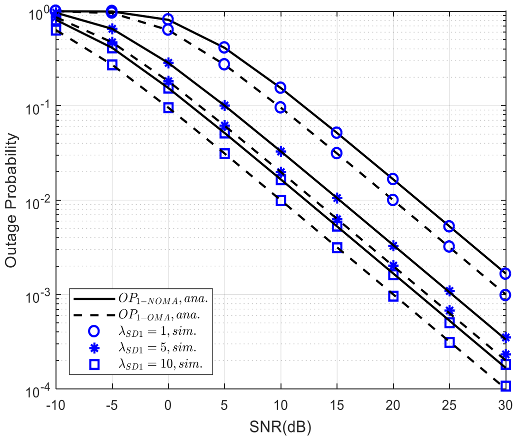

Figure 4. Outage probability of x_1 as varying channel gains ($a_1 = 0.8$, $R_1 = 0.5$)

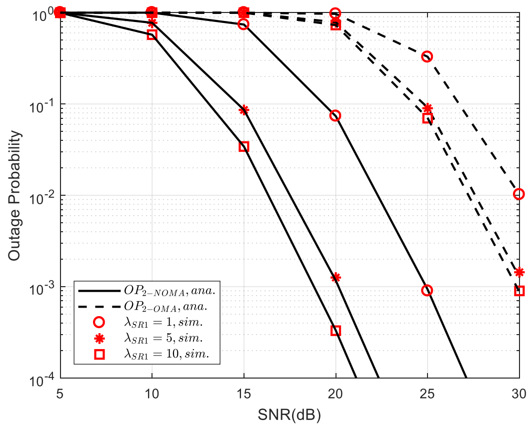

Figure 5. Outage probability of x_2 as varying channel gains ($a_1 = 0.8$, $\lambda_{RKD2} = 1$, $R_1 = 0.5$, $R_2 = 2$)

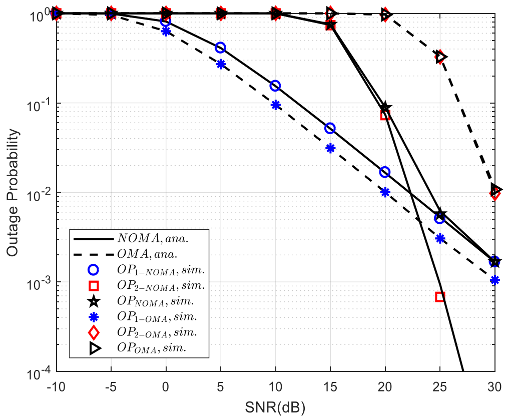

Figure 6. Outage probability comparison for x_1 and x_2 ($a_1 = 0.8$, $\lambda_{SR1} = \lambda_{SD1} = \lambda_{RKD2} = 1$, $R_1 = 0.5$, $R_2 = 2$, $K = 5$)

5. CONCLUSION

In this study, the outage probability of NOMA networks together with optimal selection scheme was presented to enhance system performance in two real scenarios at near and far distance between user and the BS. In such model, the selected criteria is with joint location of user and relay selection. In particular, the closed-form analytical expressions is provided to system performance. It can be determine how number of relays and the target data rate have effects on system performance. The second reason to choose such model that the number of users is reasonable chosen to improve the transmission quality in NOMA.

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