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Comparison study on secrecy probability of AF-NOMA and AF-OMA networks

Dinh-Thuan Do*[1], Minh-Sang Van Nguyen[2], Thi-Anh Hoang[3]
[1]Wireless Communications Research Group, Ton Duc Thang University, Ho Chi Minh City, Vietnam
[1]Faculty of Electrical & 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), Vietnam
*Corresponding author, e-mail: dodinhthuan@tdtu.edu.vn[1], nguyenvanminhsang@iuh.edu.vn[2],
hoangthianh@iuh.edu.vn[3]

Abstract

The strictly positive secrecy capacity (SPSC) performance is examined in a new design of non-orthogonal multiple access (NOMA) considered in this study. This system model employs Amplify-and-Forward (AF) relaying scheme to serve far users. In this scheme, a transmitter sends confidential signal to far users. It can be raised falling performance in the presence of an external eavesdropper in such NOMA system. With regard to orthogonal multiple access (OMA), performance of NOMA system model is compared. In particular, tradeoff the SPSC performance and transmit SNR is examined. In this study, the SPSC is evaluated as the secrecy metric to limit impacts of the practical passive eavesdropper in real scenario. It is confirmed that the secrecy performance of NOMA is significantly lower than OMA due to related parameters characterization in NOMA, and it should be controlled by varying related coefficients. As main results, both of NOMA and OMA against to impact of eavesdropper is studied in terms of analytically result and numerically result.

Keywords: *non-orthogonal multiple access, physical layer security, secrecy outage probability*

1. Introduction

In order to satisfy the continuous progress of mobile users and fast development of Internet of things (IoT), new techniques should be addressed. In this circumstance, the fifth generation (5G) wireless communication networks have challenges on an explosive demand on low latency and massive connection while they are under limited radio resources. Non-orthogonal multiple access (NOMA) has shown the potential, and it is considered as a promising technology in 5G networks [1–3]. Main advantages including improved spectral efficiency, enlarge connections, and low access latency. Compared with the traditional orthogonal multiple access (OMA), NOMA simultaneously serves a many user with the same radio resource by using superposition coding, at transmitter. At receiver side, by implementing the successive interference cancellation (SIC), different users with different power levels can be detected after eliminating the multiuser interference.

In NOMA, user fairness is also a important feature of NOMA. In comparison with conventional waterfilling power allocation, NOMA intends to distribute less power to users with better channel conditions and more power to users with worse channel conditions, and hence an improved trade-off between system throughput and user fairness is resolved. Therefore, multiple users are operated at the same time, frequency and spreading codes but different power level, which leads to an increase in spectral efficiency and user fairness is guaranteed as well.

In [4-8], the reliability of wireless network will be improved as relay is employed. The outage and throughput performance of such relaying scheme provide large coverage and high-speed data rates for next generation wireless networks. Deploying relaying scheme to NOMA, the authors in [9] investigated for cooperative NOMA (C-NOMA) networks in term of the achievable average rate. In [10], multiple-antenna cooperative network is applied to NOMA to improve the system performance, and the system outage probability was then analyzed.

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The multiple-input-multipleoutput (MIMO) assisted NOMA networks are examined in term of ergodic capacity maximization problem and they presented an optimal power allocation scheme [11]. In [12], a cellular downlink NOMA networks were studied in two metrics such as the outage behavior and the ergodic sum rate. Generally, improved system capacity and enhanced reliability are main characterization in C-NOMA networks which continous attracted some attentions. In [13], NOMA was applied to improve the spectral efficiency as coordinated directed and relay transmission are joint deployed. In [14], the authors proposed a new detection scheme to perform applications in the C-NOMA network. They presented a suboptimal and practical power allocation strategy [14].

Additionally, as a reliable additional layer of network, physical layer security (PLS) has been proposed to protect against wiretapping. PLS has many advantages in comparison with conventional cryptographic methodologies. We can enhance network security by deploying the main characterization of wireless channels as they are in random manner. Recently, a lot of paper from the research community to show the performance of PLS, e.g., in relay networks [15] and cognitive relay networks [16]. Interestingly, it can be incooperate emerging techniques [17-21] with NOMA to form reliable NOMA. The recent works reported in [22-25] exhibits benefits as implementation of NOMA, and they need be considered secure performance as existence of eavesdropper. Motivated by above analysis and interesting results presented in [15], this paper first introduces analytical expressions of SPSC performance to compare with OMA scheme by controlling related coefficients consisting of SNR, power allocation factor.

2. System model

This paper introduces in Figure 1 new model including a base station (S), two users with strong user D1, and weak user D2, a helping relay, and unwanted eavesdropper (E) in a NOMA-aware cellular network. Regarding wireless channel, all the channels follow independent Rayleigh distribution fading. It worth noting that in non-secure circumstance, signal obtained the messages from relay to users can be overhear by user E, including the forwarding signal at relays, and corresponding decoding procedure. All links at each node pair of S-R, R-D1, R-D2, R-E have channel gains are represented by $|h_{SR}|^2, |g_{D1}|^2, |g_{D2}|^2$, and $|g_E|^2$, respectively. Then, λ_{SR}, λ_{D1}, λ_{D2} and λ_E are called as the Rayleigh channel coefficients corresponding to channel $|h_{SR}|^2$, $|g_{D1}|^2, |g_{D2}|^2$, and $|g_E|^2$, respectively. Next, P, P_R are transmit power at node S and R and noise power terms denoting as N_0 at normal nodes are the same, and node E is N_E. In considered situation, node S is located in the center of the cell, and user D1 located cell-center while user D2 and user E are very close to the cell-edge. In this scenario no direct links are existed between S and the users, as well as E. We further assume that single antennas equipped at all nodes in the network.

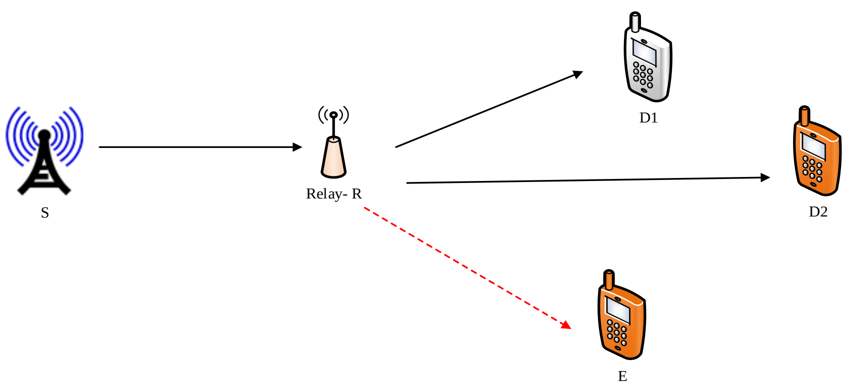

Figure 1. System model of secure NOMA as existence of eavesdropper

To perform NOMA transmission, the received signal at the relay R is given by

$$y_{SR}^{NOMA} = h_{SR}\left(\sqrt{\gamma_1 P}s_1 + \sqrt{\gamma_2 P}s_2\right) + n_{SR}, \tag{1}$$

where s_1, s_2 are the normalized signal dedicated for D1, D2, respectively, n_{SR} is AWGN noise It is assumed that $E\left\{s_1^2\right\} = E\left\{s_2^2\right\} = 1$. In NOMA, γ_1, γ_2 are denoted as power allocation factors and we assume that $\gamma_1 > \gamma_2$ to stipulate better fairness between the users. It is further required $\gamma_1 + \gamma_2 = 1$.

In the second time slot, the relay amplifies and forwards its received signals by using AF schem to the two NOMA users. Then, the received signal at the user D_i is

$$y_{RD}^{NOMA} = \psi g_{Di} y_{SR}^{NOMA} + n_{RD},\ i = \{1, 2\}, \tag{2}$$

where ψ is the amplifying factor given by $\psi = \sqrt{\frac{P_R}{P\left|h_{SR}\right|^2 + N_0}}$, n_{RD} is AWGN noise. Based received signal at destination, we obtain the following instantaneous signal-to-interference-plus-noise ratio (SINR) as

$$\varphi_1^{NOMA} = \frac{\rho\rho\gamma_1^2\left|h_{SR}\right|^2\left|g_{D1}\right|^2}{\rho\rho\gamma_2^2\left|h_{SR}\right|^2\left|g_{D1}\right|^2 + \rho\left|g_{D1}\right|^2 + \rho\left|h_{SR}\right|^2 + 1}, \tag{3}$$

$$\varphi_2^{NOMA} = \frac{\rho\rho\gamma_2^2\left|h_{SR}\right|^2\left|g_{D2}\right|^2}{\rho\left|g_{D2}\right|^2 + \rho\left|h_{SR}\right|^2 + 1}. \tag{4}$$

then, the instantaneous rates are computed at Di

$$R_{Di}^{NOMA} = 0.5\log_2\left(1 + \varphi_i^{NOMA}\right), \tag{5}$$

where $\rho = P/N_0 = P_R/N_0$ stands for transmit SNR at node S. In trusted relay-based NOMA, the parallel interference cancellation (PIC) is used at E to distinguish the superimposed mixture. Then, we can express the channel capacity from the relay to E as

$$R_{Ei}^{NOMA} = 0.5\log_2\left(1 + \varphi_{Ei}^{NOMA}\right), \tag{6}$$

where $\varphi_{Ei}^{NOMA} = \frac{\rho\rho_E\left|h_{SR}\right|^2\left|g_E\right|^2\gamma_i^2}{\rho_E\left|g_E\right|^2 + \rho\left|h_{SR}\right|^2 + 1}$ is the received SINR at E, while $\rho_E = P_R/N_E$ is the average SNR of the illegal link between the relay and E.

It is denoted R_{Ei}^{NOMA} as channel capacity at $D_i, i = 1, 2$, the AF-based NOMA systems obtain secrecy rate of the for user $D_i, i = 1, 2$ is given by

$$\chi_i^{NOMA} = \left[R_{Di}^{NOMA} - R_{Ei}^{NOMA}\right]^+, \tag{7}$$

where $[x]^+ = \max\{x, 0\}$.

3. SPSC in NOMA

In NOMA systems, SPSC is important metric to examine performance in situation that using the helping relay to forward two signals from the S to far users consisting of D1 and D2. In principle, SPSC is defined as probability to its related instantaneous rates is positive umber. In particular, we calculate SPSC as

$$\begin{aligned} SPSC_{AF}^{NOMA} &= \Pr\left(\chi_1^{NOMA} > 0\, or\, \chi_2^{NOMA} > 0\right) \\ &= \Pr\left(\varphi_1^{NOMA} > \varphi_{E1}^{NOMA}, \varphi_2^{NOMA} > \varphi_{E2}^{NOMA}\right). \end{aligned} \tag{8}$$

In such case $\varphi_1^{NOMA}, \varphi_2^{NOMA}, \varphi_{E1}^{NOMA}$ and φ_{E2}^{NOMA} are correlated and these factors results in untractable exact computation. Fortunately, it can be achieved the following upper bounds as

$$\varphi_1^{NOMA} < \frac{\gamma_1^2}{\gamma_2^2}\ ,\ \varphi_2^{NOMA} < \frac{\rho\rho\gamma_2^2 |h_{SR}|^2 |g_E|^2}{\rho|g_E|^2 + \rho|h_{SR}|^2}\ \text{and}\ \varphi_{Ei}^{NOMA} < \frac{\rho\rho_E |h_{SR}|^2 |g_E|^2 \gamma_i^2}{\rho_E|g_E|^2 + \rho|h_{SR}|^2}, i = 1, 2$$

then, approximate expression of $SPSC_{AF}^{NOMA}$ can be obtained as

$$SPSC_{AF}^{NOMA} \approx \Pr\left(\frac{\gamma_1^2}{\gamma_2^2} > \frac{\rho\rho_E |h_{SR}|^2 |g_E|^2 \gamma_1^2}{\rho_E|g_E|^2 + \rho|h_{SR}|^2}, \frac{\rho\rho\gamma_2^2 |h_{SR}|^2 |g_E|^2}{\rho|g_E|^2 + \rho|h_{SR}|^2} > \frac{\rho\rho_E |h_{SR}|^2 |g_E|^2 \gamma_2^2}{\rho_E|g_E|^2 + \rho|h_{SR}|^2}\right). \tag{9}$$

it is noted that using inequality $xy/(x+y) \le \min\{x, y\}$, we further compute SPSC as

$$SPSC_{AF}^{NOMA} \approx \Pr\left(\begin{aligned} &\frac{\gamma_1^2}{\gamma_2^2} > \gamma_1^2 \min\left(\rho|h_{SR}|^2, \rho_E|g_E|^2\right), \\ &\min\left(\rho|h_{SR}|^2, \rho|g_{D2}|^2\right) > \min\left(\rho|h_{SR}|^2, \rho_E|g_E|^2\right) \end{aligned}\right). \tag{10}$$

to address this, we use the fact $\Pr(e_1, e_2) = \Pr(e_1) - \Pr(e_1, \overline{e_2})$, where $\overline{e_2}$ denotes the complementary event of e_2. Then, we have

$$e_1 = \min\left(\rho|h_{SR}|^2, \rho|g_{D2}|^2\right) > \min\left(\rho|h_{SR}|^2, \rho_E|g_E|^2\right), \tag{11}$$

$$e_2 = \gamma_1^2 \min\left(\rho|h_{SR}|^2, \rho_E|g_E|^2\right) < \frac{\gamma_1^2}{\gamma_2^2}. \tag{12}$$

therefore, $SPSC_{AF}^{NOMA}$ can be further computed as

$$SPSC_{AF}^{NOMA} = \Pr(e_1) - \Pr(e_1, \overline{e_2}). \tag{13}$$

applying some manipulations, $\Pr(e_1)$ is given by

$$\Pr\left(e_1\right) = \Pr\left(\min\left(\rho\left|h_{SR}\right|^2, \rho\left|g_{D2}\right|^2\right) > \rho_E\left|g_E\right|^2\right)$$
$$= \int_0^\infty \exp\left(-\frac{\left(\lambda_{SR}+\lambda_{D2}\right)\rho_E}{\rho}x\right)\lambda_E \exp\left(-\lambda_E x\right)dx \tag{14}$$
$$= \frac{\rho\lambda_E}{\left(\lambda_{SR}+\lambda_{D2}\right)\rho_E+\rho\lambda_E}.$$

therefore, $\Pr\left(e_1, \overline{e_2}\right)$ can be computed as

$$\Pr\left(e_1,\overline{e_2}\right) = \int_{\frac{1}{\rho_E\gamma_2^2}}^\infty \exp\left(-\frac{\left(\lambda_{SR}+\lambda_{D2}\right)\rho_E}{\rho}x\right)\lambda_E \exp\left(-\lambda_E x\right)dx$$
$$= \frac{\rho\lambda_E}{\left(\lambda_{SR}+\lambda_{D2}\right)\rho_E+\rho\lambda_E}\exp\left(-\left(\frac{\left(\lambda_{SR}+\lambda_{D2}\right)\rho_E}{\rho}+\lambda_E\right)\frac{1}{\rho_E\gamma_2^2}\right). \tag{15}$$

finally, AF based NOMA systems is evaluated in term of SPSC metric as

$$SPSC_{AF}^{NOMA} = \frac{\rho\lambda_E}{\left(\lambda_{SR}+\lambda_{2D2}\right)\rho_E+\rho\lambda_E}\left(1-\exp\left(-\left(\frac{\left(\lambda_{SR}+\lambda_{D2}\right)\rho_E}{\rho}+\lambda_E\right)\frac{1}{\rho_E\gamma_2^2}\right)\right). \tag{16}$$

4. SPSC in Benchmark of OMA

In OMA mode, the received signal at the relay can be written as

$$y_{SR}^{OMA} = h_{SR}s_i\sqrt{P}+n_{SR}. \tag{17}$$

then, the received signal at the user Di is

$$y_{RD}^{OMA} = \psi g_{Di} y_{SR}^{OMA} + n_{RD}. \tag{18}$$

then, it can be formulated the SINR to evaluate performance of D1 by

$$\varphi_1^{OMA} = \frac{\rho\rho\left|g_{D1}\right|^2\left|h_{SR}\right|^2}{\rho\left|g_{D1}\right|^2+\rho\left|h_{SR}\right|^2+1}. \tag{19}$$

similarly, we can be expressed the SINR to examine performance of D2 by

$$\varphi_2^{OMA} = \frac{\rho\rho\left|g_{D2}\right|^2\left|h_{SR}\right|^2}{\rho\left|g_{D2}\right|^2+\rho\left|h_{SR}\right|^2+1}. \tag{20}$$

next, as existence of eavesdropper at E, SINR is given by

$$\varphi_{Ei}^{OMA} = \frac{\rho\rho_E\left|h_{SR}\right|^2\left|g_E\right|^2\gamma_i^2}{\rho_E\left|g_E\right|^2+\rho\left|h_{SR}\right|^2+1}. \tag{21}$$

then, SPSC in OMA mode can be written as

$$\begin{aligned} SPSC_{AF}^{OMA} &= \Pr\left(\chi_1^{OMA} > 0\, or\, \chi_2^{OMA} > 0\right) \\ &= \Pr\left(\varphi_1^{OMA} > \varphi_{E1}^{OMA}, \varphi_2^{OMA} > \varphi_{E2}^{OMA}\right) \\ &\approx \Pr\left(|g_{D1}|^2 > \frac{\rho_E}{\rho}|g_E|^2, |g_{D2}|^2 > \frac{\rho_E}{\rho}|g_E|^2\right) \\ &\approx \int_0^\infty \exp\left(-\left(\lambda_{D1}+\lambda_{D2}\right)\frac{\rho_E}{\rho}x\right)\lambda_E \exp\left(-\lambda_E x\right)dx. \end{aligned} \quad (22)$$

interestingly, in similar way with previous section, it can be following result

$$SPSC_{AF}^{OMA} \approx \frac{\lambda_E}{\left(\left(\lambda_{D1}+\lambda_{D2}\right)\frac{\rho_E}{\rho}+\lambda_E\right)} \quad (23)$$

5. Numerical Results

In this section, the SPSC performance of the downlink AF-NOMA network under Rayleigh fading channel is evaluated. These numerical examples are performed to validate derived formula. Moreover, in order to further evaluation in NOMA, the fixed power allocation is applied. In the following simulations, we set the fixed power allocation factors for NOMA users as $\gamma_1 = 0.85$. Without loss of generality, we assume the distance in each link of two-hop relaying NOMA is normalized to unity. The NOMA result will be compared with OMA counterpart.

Figure 2 plots the SPSC probability of considered NOMA scheme versus transmit SNR at S for a simulation as setting of varying ρ_E. It can be seen that the exact analytical results and simulation results are matched very well. In particular, at low SNR of ρ_E, the SPSC will be improved. Another important observation is that the SPSC remains constant at high SNR regime.

In Figure 3, the SPSC versus power allocation factor of γ_1^2 is presented in different impact of parameters related to the eavesdropper. In this case, our parameter is $\rho = 30$ (dB). Obviously in this case, the SPSC curves match exactly with the Monte Carlo simulation results. It is worth noting that the setting of reasonable power allocation factor to achieve optimal secure performance.

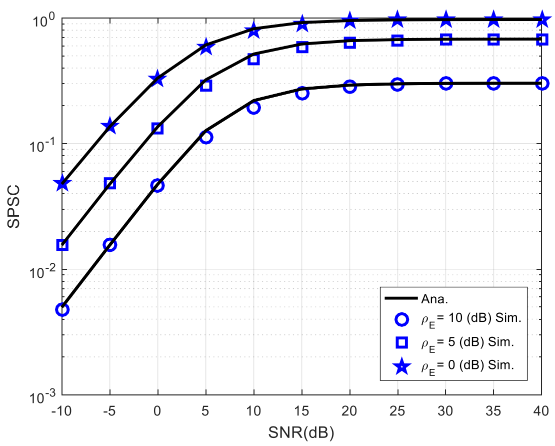

Figure 2. NOMA mode: SPSC vs the transmit SNR

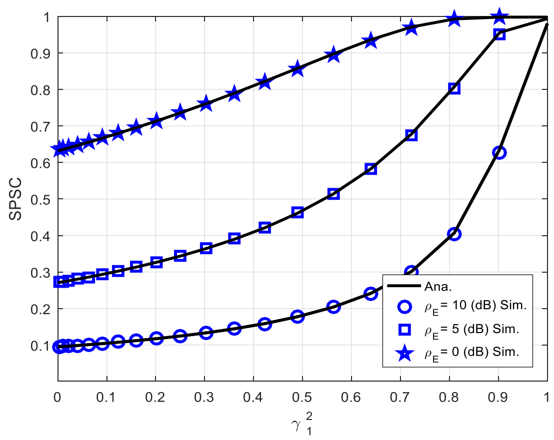

Figure 3. NOMA mode: SPSC vs the transmit SNR with different impacts of eavesdropper

Figure 4 illustrates SPSC probability versus ρ_E as we change ρ. It can be observed that the analytical results meet with that in low range of target rate. One can observe that adjusting the target rates of NOMA users will affect the outage behaviors of considered scheme. As the value of target rates increases, the outage performance will become worse. This illustration indicates that our derived expressions are tight result for evaluation in related NOMA networks.

Figure 5 plots SPSC performance between OMA and NOMA system versus SNR. Here, we set several cases of SNR of eavesdropper to show its impacts. Furthermore, the AF-based NOMA scheme is significantly better than OMA scheme in terms of SPSC performance. This phenomenon indicates that it is of significance to consider the impact of ρ_E for such NOMA scheme when designing practical cooperative NOMA systems.

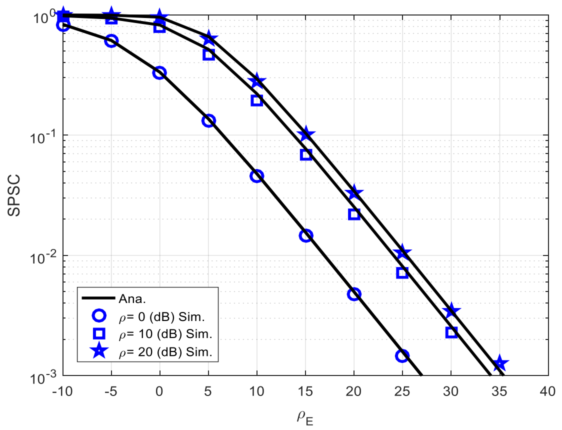

Figure 4. NOMA mode: SPSC theo ρ_E as varying ρ

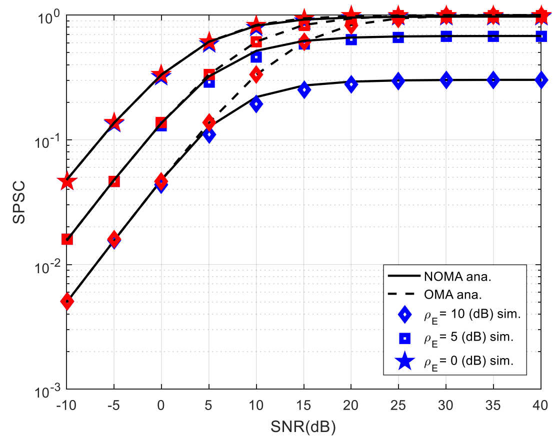

Figure 5. Comparison on SPSC between OMA and NOMA

6. Conclusion

This paper studied a novel downlink cooperative communication system that compare NOMA and OMA scenarios in analytical model for SPSC analysis with respect to AF relaying technique. The impacts of related various parameters in these systems are considered in term of SPSC performance. Additionally, influence of the SNR of eavesdropper on SPSC performance in both NOMA and OMA. Especially, the SPSC is achieved at high level as high transmit SNR can be selected to guarantee quality of secured system. The performance comparison of the suggested schemes was verified by the numerical results. More importantly, reducing impact of eavesdropper on strong and weak users of both NOMA and OMA in the system to approach reasonable performance requirements.

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