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Exact Outage Performance Analysis of Amplify-and-Forward-Aware Cooperative NOMA

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Abstract

In this paper, new radio access scheme that combines Amplify-and-Forward (AF) relaying protocol and non-orthogonal multiple access (NOMA) system is introduced. In particular, different scenarios for fixed power allocation scheme is investigated. In addition, the outage probability of both weak and strong user is derived and provided in closed-form expressions. Such outage is investigated in high SNR scenario and comparison performance between these NOMA scenarios is introduced. Numerical simulations are offered to clarify the outage performance of the considered scheme if varying several parameters in the existing schemes to verify the derived formulas.

Keywords: *Cooperative non-orthogonal multiple access, amplify-and-forward (AF), outage probability.*

1. Introduction

As one favorable technology in future fifth-generation (5G) wireless networks, non-orthogonal multiple access (NOMA) has been proposed to increase spectral efficiency [1]. By permitting multiple users served in the same time, frequency or code domain, spectral efficiency and user fairness are improved in NOMA compared with orthogonal multiple access (OMA). In NOMA, the transmitter superposes multiple users' messages and the receivers deploys successive interference cancellation (SIC) to distinct the mixture signals in the power domain [2]. In [3], the system performance regarding outage probability (OP) and ergodic sum rate (ESR) was studied in typical single-hop NOMA transmission. The power allocation with max-min fairness criterion is investigate in [4]. Recently, large-scale underlay cognitive radio (CR) networks is deployed in NOMA [5].

The fixed relaying and adaptive relaying schemes have been suggested to implement cooperative communication. In relaying networks, two well- known cooperative relaying protocols are studied, namely amplify forward (AF) and decode forward (DF) [6], [7]. By AF protocols, received signal from the source is amplified to forward to the destination, while the received signal in DF protocols need be first decoded, then re-encoded to forward to the destination. The author in [8] presented hardware impairment as important impact on system performance of such relaying scheme.

Formerly, superposition coding is proposed in wireless network and currently it is named as NOMA. Such scheme improves the throughput of a broadcast/multicast system and efficient broadcasting is achieved. Additionally, the influence of user coupling on the performance in NOMA is investigated [9], in which both the fixed power distribution assisted NOMA (F-NOMA) and cognitive radio assisted NOMA (CR-NOMA) systems were considered in term of the outage performance. Furthermore, the outage balancing among users was investigated by deploying user grouping and decoding order selection [10]. In particular, the optimal decoding order and power distribution in closed-form formula for downlink NOMA were performed. In [11], only feed back one bit of its channel state information (CSI) to a base station (BS) is considered in term of outage behavior of each NOMA user in downlink NOMA. As advantage of such model as providing higher fairness for multiple users, it lead to NOMA with better performance as comparison with conventional opportunistic one-bit feedback. In order to increase the specific data rate, the

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wireless powered communication networks (WPCN) scheme is deployed with NOMA uplink system in [12]. By using the harvested energy [13], [14] in the first time slot, the strong users in NOMA can be forward signal to the weak users' messages in the second time slot in case of using half-duplex (HD) scheme and other relaying networks [15-19] can be depoyed in NOMA.

Motivated by above analysis and especially in [9], this paper presents a fixed power allocation scheme to show outage performance of separated users in the NOMA scheme in case of AF scheme is deployed.

2. System Model and Outage performance analysis
2.1. System model

We consider a downlink cooperative NOMA scenario consisting of one base station denoted as BS, *one* relay R and twi users (i.e., the nearby user *D2* and far user *D1*. The Amplify-and –Forward (AF) protocol is employed at each relay and only one relay is selected to assist BS conveying the information to the NOMAusers in each time slot. All wireless channels in the considered scenario are assumed to be independent non-selective block Rayleigh fading and are disturbed by additive white Gaussian noise with mean power σ^2. The wireless channel h, g_1, g_2 following distribution CN (0,1) corresponding with channel coefficient of link BS-R, R-D1, R-D2, respectively, as shown in Figure 1. In principle of NOMA, two users are classified into the nearby user and far user by their quality of service (QoS) not sorted by their channel conditions. In this case, we assume transmit power at relay and the BS is the same.

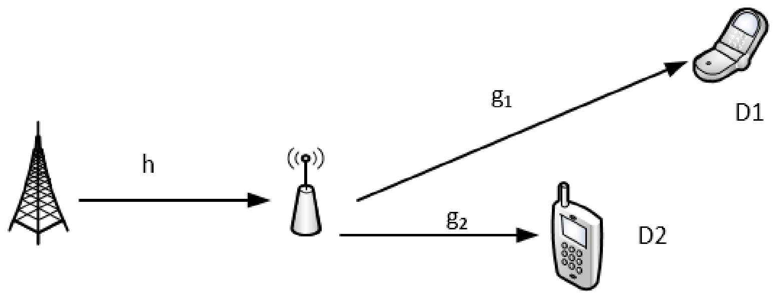

Figure 1. System model of AF-NOMA

Based on the aforementioned assumptions, the observation at the relay *R is* given by:

$$y_R = h\left(\sqrt{a_1 P}x_1 + \sqrt{a_2 P}x_2\right) + w_r \tag{1}$$

where w_r, w_d are additive white Gaussian noise terms with variance σ^2, x_1, x_2 are the normalized signal for $D1$, $D2$, respectively. It is assumed that $E\left\{x_1^2\right\} = E\left\{x_2^2\right\} = 1$, a_1, a_2 are power allocation factors. To stipulate better fairness between the users, we assume that $a_1 > a_2$ satisfying $a_1 + a_2 = 1$.

Using AF scheme, the amplify gain is defined by:

$$\beta = \frac{1}{\sqrt{P|h|^2 + \sigma^2}}. \tag{2}$$

In the second phase, the received signal at user $D1$ is:

$$y_{D1} = \beta\sqrt{P}g_1\left[h\left(\sqrt{a_1 P}x_1 + \sqrt{a_2 P}x_2\right) + w_r\right] + w_d, \tag{3}$$

Similarly, the received signal at user $D2$ is given by:

$$y_{D2} = \beta\sqrt{P}g_2\left(\sqrt{a_1 P}x_1 + \sqrt{a_2 P}x_2\right)h + \beta\sqrt{P}g_2 w_r + w_d\,. \quad (4)$$

To evaluate system performance, we first consider the received signal to interference and noise ratio (SINR) at $D1$ to detect $x1$ is given by:

$$\gamma_1 = \frac{a_1\rho^2|h|^2|g_1|^2}{\rho^2|h|^2|g_1|^2 a_2 + \rho|h|^2 + \rho|g_1|^2 + 1}\,. \quad (5)$$

In which, we denote $\rho = \frac{P}{\sigma^2}$ as signal to noise ratio (SNR) at the BS.

By considering in SIC is also invoked by $D2$ and the received SINR at $D2$ to detect $x1$ is given by:

$$\gamma_{2,x1} = \frac{a_1\rho^2|h|^2|g_2|^2}{\rho^2|h|^2|g_2|^2 a_2 + \rho|h|^2 + \rho|g_2|^2 + 1}\,. \quad (6)$$

Then the received SINR at S $D2$ to detect its own information is given by:

$$\gamma_{2,x2} = \frac{a_2\rho^2|h|^2|g_2|^2}{\rho|h|^2 + \rho|g_2|^2 + 1}. \quad (7)$$

2.2. Outage performance analysis

In this section, we perform analysis on the performance of AF-NOMA scheme in terms of outage probability for several signal processing cases. To make its convenient in analysis, this paper presents exact expressions for the outage probability. In order to reduce the computation complexity, a tight lower bound for the outage probability is provided in the high-SNR regime to better understand the behavior of the network.

In general, an outage event occurs at the strong or the weak user when the user fails to decode its own signal. In this section, we denote the threshold SNR as $\varepsilon_i, i = 1,2$. Based on the rate requirements of the users, we can choose different values for R1 and R2, and we will demonstrate how the R1 and R2 affect the outage performance in the numerical result section. For sake of brevity, we denote $e_1 = 2^{2R_1} - 1, e_2 = 2^{2R_2} - 1$.

2.2.1 The outage probability for detecting $x1$ at $D1$

We first consider the outage probability for detecting $x1$ at $D1$ can be expressed as:

$$OP_{D1,x1} = 1 - \Pr\left(\gamma_1 > \varepsilon_1\right). \quad (8)$$

Next, it can be calculated each component of outage event as:

$$OP_{D1,x1} = 1 - \Pr\left(\rho|g_1|^2\left(\rho|h|^2\left(a_1 - a_2\varepsilon_1\right) - \varepsilon_1\right) > \varepsilon_1\left(\rho|h|^2 + 1\right)\right). \quad (9)$$

In the event of $\rho|h|^2\left(a_1 - a_2\varepsilon_1\right) - \varepsilon_1 < 0$, i.e. $|h|^2 < \frac{\varepsilon_1}{\rho\left(a_1 - a_2\varepsilon_1\right)}$, we have $OP_{D1,x1} = 1$, else

$$OP_{D1,x1}=1-\frac{1}{\rho\left(a_1-a_2\varepsilon_1\right)}\int_0^\infty \exp\left(-\frac{\varepsilon_1\left(\rho\left(\frac{t+\varepsilon_1}{\rho\left(a_1-a_2\varepsilon_1\right)}\right)+1\right)}{\rho t}-\left(\frac{t+\varepsilon_1}{\rho\left(a_1-a_2\varepsilon_1\right)}\right)\right)dt\ . \tag{10}$$

It is obtained (10) by putting new variable as $t=\rho z\left(a_1-a_2\varepsilon_1\right)-\varepsilon_1 \to z=\frac{t+\varepsilon_1}{\rho\left(a_1-a_2\varepsilon_1\right)}$

It can be further manipulated as:

$$OP_{D1,x1}=1-\frac{1}{\rho\left(a_1-a_2\varepsilon_1\right)}\exp\left(-\frac{2\varepsilon_1}{\rho\left(a_1-a_2\varepsilon_1\right)}\right)\int_0^\infty \exp\left(-\frac{\varepsilon_1^{\ 2}+\varepsilon_1\left(a_1-a_2\varepsilon_1\right)}{\rho t\left(a_1-a_2\varepsilon_1\right)}-\left(\frac{t}{\rho\left(a_1-a_2\varepsilon_1\right)}\right)\right)dt\ .$$

In final step, it can be expressed the outage event as:

$$OP_{D1,x1}=1-e^{-\frac{2\varepsilon_1}{\rho\left(a_1-a_2\varepsilon_1\right)}}2\sqrt{\frac{\varepsilon_1\left(\varepsilon_1+\left(a_1-a_2\varepsilon_1\right)\right)}{\rho^2\left(a_1-a_2\varepsilon_1\right)^2}}\mathrm{K}_1\left(2\sqrt{\frac{\varepsilon_1\left(\varepsilon_1+\left(a_1-a_2\varepsilon_1\right)\right)}{\rho^2\left(a_1-a_2\varepsilon_1\right)^2}}\right). \tag{11}$$

where $K_1\left(.\right)$ is Bessel function.

2.2.2 The outage probability for detecting $x2$ at $D2$

Secondly, the outage probability for detecting $x2$ at $D2$ can be expressed as:

$$OP_{D2,x2}=1-\Pr\left(\gamma_{2,x1}>\varepsilon_1,\gamma_{2,x2}>\varepsilon_2\right) \tag{12}$$

Based on (6) and (7) and (12) we can find that:

$$OP_{D2,x2}=1-\Pr\left(\frac{a_1\rho^2\left|h\right|^2\left|g_2\right|^2}{\rho^2\left|h\right|^2\left|g\right|^2a_2+\rho\left|h\right|^2+\rho\left|g_2\right|^2+1}>\varepsilon_1,\frac{a_2\rho^2\left|h\right|^2\left|g_2\right|^2}{\rho\left|h\right|^2+\rho\left|g_2\right|^2+1}>\varepsilon_2\right). \tag{13}$$

In this paper, we approximate the $\gamma_{2,x1}=\frac{a_1\rho^2\left|h\right|^2\left|g_2\right|^2}{\rho^2\left|h\right|^2\left|g\right|^2a_2+\rho\left|h\right|^2+\rho\left|g_2\right|^2+1}\le\frac{a_1}{a_2}$ in high SNR regime when $\rho^2>>\rho>>1$.

Therefore, it can be reduced as:

$$OP_{D2,x2}=1-\Pr\left(\frac{a_1}{a_2}>\varepsilon_1\right)\Pr\left(\frac{a_2\rho^2\left|h\right|^2\left|g_2\right|^2}{\rho\left|h\right|^2+\rho\left|g_2\right|^2+1}>\varepsilon_2\right). \tag{14}$$

Firstly, we consider the first item, if $\frac{a_1}{a_2}<\varepsilon_1$ we obtain $OP_{D2,x2}=1$, else $\frac{a_1}{a_2}>\varepsilon_1$ we have,

$$OP_{D2,x2}=1-\Pr\left(\left|g_2\right|^2>\frac{\varepsilon_2\left(\rho\left|h\right|^2+1\right)}{\rho\left(a_2\rho\left|h\right|^2-\varepsilon_2\right)}\right). \tag{15}$$

Similarly, in the first case of $a_2\rho|h|^2-\varepsilon_2<0$, it leads to following equation $|h|^2<\frac{\varepsilon_2}{\rho a_2}$, outage probability in this case calculated as $OP_{D2,x2}=1$. In the second case, as $a_2\rho|h|^2-\varepsilon_2>0$.

$$OP_{D2,x2}=1-\int_{\frac{\varepsilon_2}{\rho a_2}}^{\infty}\exp\left(-\frac{\varepsilon_2(\rho z+1)}{\rho(a_2\rho z-\varepsilon_2)}-z\right)dz. \tag{16}$$

Similarly, it can be found outage probability in such as as:

$$OP_{D2,x2}=1-\exp\left(-\frac{2\varepsilon_2}{\rho a_2}\right)2\sqrt{\frac{\varepsilon_2}{\rho^2 a_2}\left(\frac{\varepsilon_2}{a_2}+1\right)}\mathrm{K}_1\left(2\sqrt{\frac{\varepsilon_2}{\rho^2 a_2}\left(\frac{\varepsilon_2}{a_2}+1\right)}\right). \tag{17}$$

2.3 Outage performance at high SNR and The throughput on the outage probability

And the lower bounds of the outage probability in (11) and (17) are shown to be tight bounds in the medium-and high-SNR regimes.

At high SNR, the outage probability at $D1$ will become:

$$OP_{D1,x1}=1-e^{-\frac{2\varepsilon_1}{\rho(a_1-\varepsilon_1 a_2)}}. \tag{18}$$

At high SNR, the outage probability at $D2$ will become:

$$OP_{D2,x2}=1-e^{-\frac{2\varepsilon_2}{\rho a_2}}. \tag{19}$$

The throughput mainly depends on the outage probability.

The throughput at $D1$ will become:

$$\begin{aligned}C_1&=\left(1-OP_{D1,x1}\right)\times R\\&=\left(1-\left(1-e^{-\frac{2\varepsilon_1}{\rho(a_1-a_2\varepsilon_1)}}2\sqrt{\frac{\varepsilon_1\left(\varepsilon_1+(a_1-a_2\varepsilon_1)\right)}{\rho^2(a_1-a_2\varepsilon_1)^2}}\mathrm{K}_1\left(2\sqrt{\frac{\varepsilon_1\left(\varepsilon_1+(a_1-a_2\varepsilon_1)\right)}{\rho^2(a_1-a_2\varepsilon_1)^2}}\right)\right)\right)\times R\end{aligned} \tag{20}$$

Similarly, the throughput at $D2$ will become:

$$\begin{aligned}C_2&=\left(1-OP_{D2,x2}\right)\times R\\&=\left(1-\left(1-\exp\left(-\frac{2\varepsilon_2}{\rho a_2}\right)2\sqrt{\frac{\varepsilon_2}{\rho^2 a_2}\left(\frac{\varepsilon_2}{a_2}+1\right)}\mathrm{K}_1\left(2\sqrt{\frac{\varepsilon_2}{\rho^2 a_2}\left(\frac{\varepsilon_2}{a_2}+1\right)}\right)\right)\right)\times R\end{aligned} \tag{21}$$

3. Simulation Results

In this section, the outage performance of the downlink AF-NOMA network under Rayleigh fading channel is evaluated via numerical examples to validate derived formula. Moreover, the fixed power allocation is applied in order to further evaluation of such NOMA. Without loss of generality, we assume the distance in each link of two-hop relaying NOMA is normalized to unity. In the following simulations, we set $a_1=0.9, a_2=0.1$. We denote “ana” as analysis and “sim” as Monte-Carlo simulation results.

Figure 2 plots the outage probability of considered scheme versus SNR for a simulation setting $R_1 = 1$ (bits/s/Hz), $R_2 = 1$ (bits/s/Hz). It can be seen that the exact analytical results and simulation results are matched very well. In particular, it shown that as the system SNR increases, the outage probability decreases. Another important observation is that the outage probability for User D1 of NOMA outperforms for User $D2$. Note that the results related to such outage performance resulted from power allocation for each user in NOMA.

In Figure 3, the outage probability versus system SNR is presented in different threshold SNR parameters. Three cases of target rates are set as $\{R_1, R_2\} = \{1, 2\}$ bits/s/Hz, $\{R_1, R_2\} = \{0.5, 1.5\}$ (bits/s/Hz). Obviously in this case, the outage probability curves match exactly with the Monte Carlo simulation results. 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 becomes worse. It is worth noting that the setting of reasonable threshold SNR or target rate for NOMA users is prerequisite based on the specific application requirements of different scenarios.

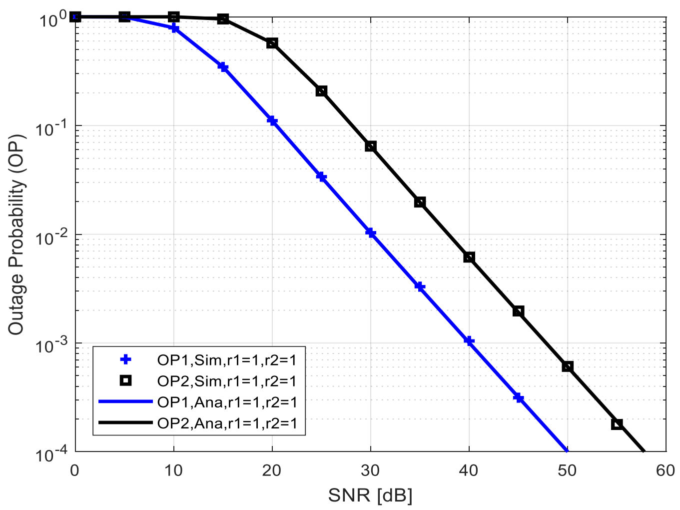

Figure 2. Outage probability vs. the transmit SNR

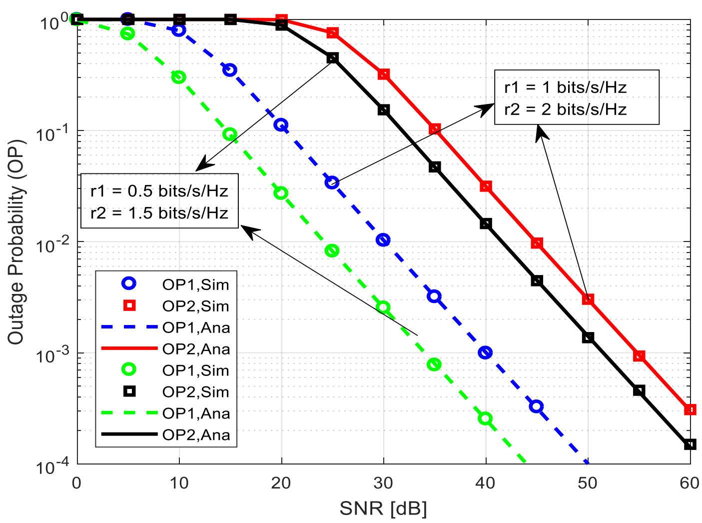

Figure 3. Outage probability vs. the transmit SNR with different threshold SNR

Figure 4 plots system outage probability versus SNR in high SNR mode. It can be observed that the analytical results meet with that in high SNR case. In Figure 4, the outage performance comparison in high SNR regime, where $R_1 = 1$ (bits/s/Hz), $R_2 = 1$ (bits/s/Hz). This illustration indicates that our derived expressions are tight result for evaluation in related NOMA networks.

Figure 5 plots system throughput versus SNR in delay-limited transmission mode. Furthermore, the AF-based NOMA scheme for $D1$ outperform $D2$ in terms of system throughput. Our setup is $R_1 = 1$ (bits/s/Hz), $R_2 = 2$ (bits/s/Hz). This phenomenon indicates that it is of significance to consider the impact of power allocation for such scheme when designing practical cooperative NOMA systems.

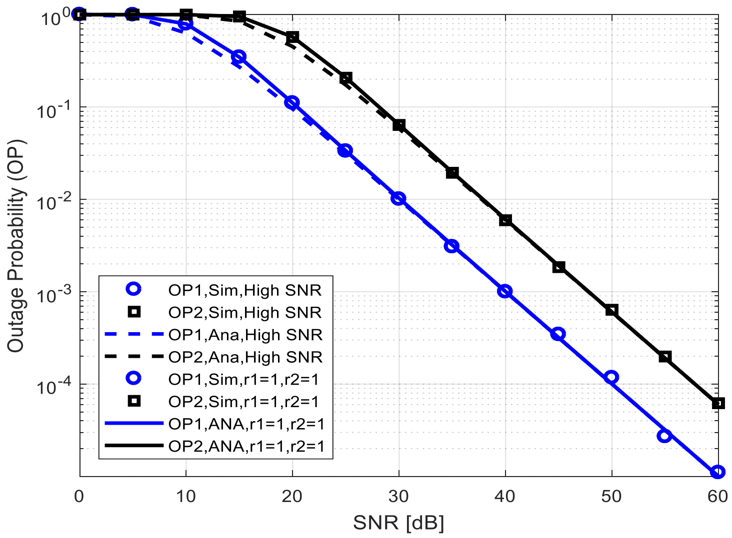

Figure 4. Outage performance comparison in high SNR

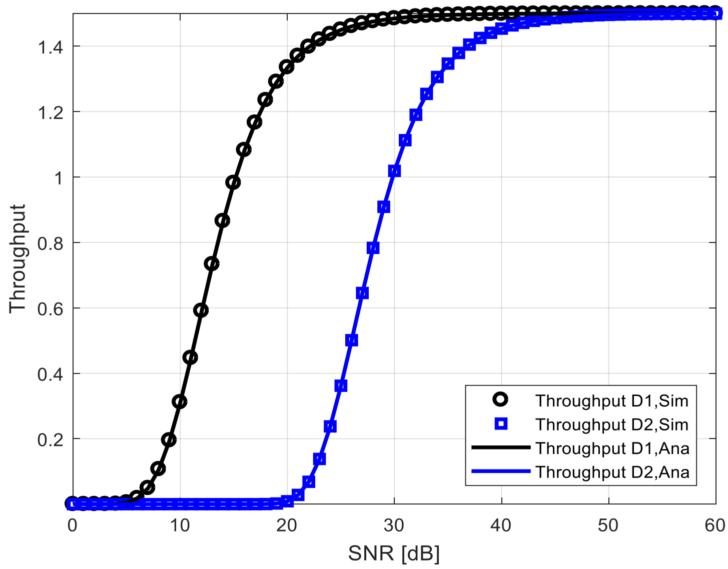

Figure 5. Throughput performance vs. the transmit SNR

4. Conclusion

This paper presented a novel downlink cooperative communication system that combines NOMA with AF relaying techniques in analytical model for outage analysis. The proposed scheme achieves outage performance comparision under impacts of various parameters in cooperative NOMA systems. Furthermore, impact of the transmit SNR of the source node in cooperative relaying NOMA on the throughput is performed via simulation and acceptable threshold can be shown to the system evaluation. The superior performance of the proposed schemes was demonstrated by the numerical results. As a future work, it will be interesting to investigate the user fairness problem only with relative locations of the users as in group. More importantly, the outage probability of both strong and weak users in the system is derived and verified by comparing numerical simulations and analytical simulation.

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