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Exact Outage Performance of NOMA Networks Under Impact of Interference Among Users

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Abstract

To increase the spectrum efficiency and system throughput with comparison on the conventional orthogonal multiple access (OMA), non-orthogonal multiple access (NOMA) is proposed as a favorable technique for the 5th generation (5G) wireless communication network. In this paper, considering on Rayleigh fading channels, the conventional NOMA based relaying networks including the base station and NOMA users, in which base station connects with multiple mobile users concurrently by employing a Decode-and-Forward (DnF) relay. Firstly, the system outage behavior is studied, and close-form expressions for the exact outage probability is performed, respectively. The analytical results are further evaluated in the high SNR regime to evaluation of the network. Finally, numerical examples are conducted to confirm the validity of our analysis and show a comparison of NOMA with different target rates.

Keywords: Non-orthogonal multiple access (NOMA); successive interference canceller (SIC); relaying networks; outage behavior.

INTRODUCTION

The higher spectral efficiency and system capacity are main requirements to achieve progress on the field research of next generation mobile networks, so-called as the fifth generation (5G) networks, is now receiving considerable attention [1]-[3]. Nominated as a promising candidate for 5G multiple access, Non-orthogonal multiple access (NOMA) is widely deployed. The main principle of NOMA is deviding power for each user, i.e power-domain NOMA signal processing [4]. In [5], authors studied a random arrangement of destinations and analyzed the overall outage probability and ergodic sum rate under a downlink NOMA scheme. [6] enhanced the sum rate of cellular devices in terms of communicating over an uplink NOMA scheme. [7] explored the influence of user pairing on the achievable rate in optimized-power allocation NOMA scheme and a cognitive radio interested NOMA scheme. [8] improved effective power allocation designs to ensure the value of service in either downlink or uplink NOMA scheme. [9] examined concurrent/average CSI (channel state information) at the source and proposed power allocation designs to optimize the lowest achievable rate in the NOMA scheme. Additionally, [10], [11], [12], [13] relaying networks are studied to support the communication between pair of transceivers and evaluated the outage probability/throughput performance. The authors in [14], [15], [16] combined the multiple-input multiple-output (MIMO) model into the NOMA scheme and demonstrated the performance evaluation.

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. The authors in [17] presented a two-step relaying scheme based on NOMA as wireless relaying system for improving the rates. Additionally, the influence of user coupling on the performance in NOMA is investigated [18], 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 [19]. In particular, the optimal decoding order and power distribution in closed-form formula for downlink NOMA were performed. In [20], 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 wireless powered communication networks (WPCN) scheme is deployed with NOMA uplink system in [21]. By using the harvested energy 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 [22]. The maximising the data rate in the strong user with guaranteeing the QoS of the weak user is considered as in [23] to solve tackle of SWIPT NOMA system related to half-duplex case.

Motivated by these analysis, few papers focus on interference between NOMA users, this paper fills this gap to clarify the advantages of NOMA.

Throughout this paper, $\Pr(.)$ represents probability; $g_X(.)$ denote the probability density function (PDF) of a random variable X, respectively.

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SYSTEM MODEL

We design a cooperative NOMA scheme including one source (i.e the base station (BS)) transmit to relay with aims to send message with the far user D2 and the near user D1. It is assumed that no direct link scenario between the BS and D2 is considered. The relay is assigned as user relaying and such device utilities DF protocol to decode and forward the composed information to two NOMA users. To enable real scenario where interference exists among NOMA users. For simplicity, D1 is furnished with single antenna and the BS and D2 are also assigned single-antenna devices. All wireless links in the NOMA network are supposed to be independent non-selective block Rayleigh fading channels and are disturbed by additive white Gaussian noise with mean power N_0. h_0, h_1, h_2 are denoted as the complex channel coefficient of the link BS-relay, relay-D1, relay-D2 respectively. We denote f_1, f_2 are the interference from the nearby user to D1, D2 respectively.

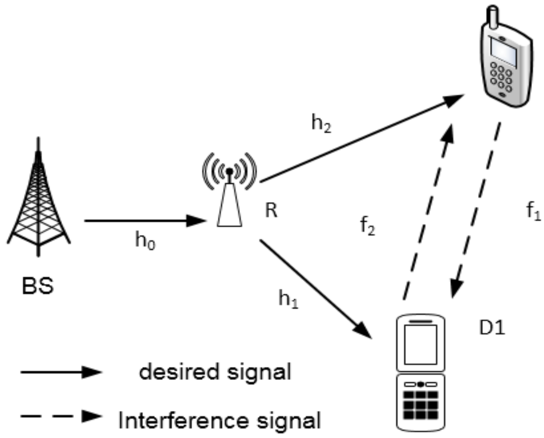

Figure 1. System model of NOMA

We denote P_S as transmit power at the BS, a_1, a_2 are power allocation factors for NOMA users, with intended signal as x_1, x_2. In the first phase, the BS transmit the composed signal to the relay R. The received signal can be obtained at the relay R and at D1 respectively as

$$y_R[k] = h_0(\sqrt{a_1 P_s} x_1[k] + \sqrt{a_2 P_s} x_2[k]) + n_R[k], \quad (1)$$

and

$$y_{D1}[k] = h_1(\sqrt{a_1 P_s} x_1[k] + \sqrt{a_2 P_s} x_2[k]) + f_1\sqrt{P_{D2}} x_{D2}[k-\tau] + n_{D1}[k], \quad (2)$$

From the received signal, we can compute the SNR as below. Firstly, the SNR at relay can be expressed by

$$\gamma_R = \rho |h_0|^2 \quad (3)$$

where $\rho = \frac{P_s}{N_0}$ is SNR at the BS. In NOMA, we assume that $a_2 > a_1$ with the constraint $a_1 + a_2 = 1$. After first phase, the signal is decoded at relay to forward signal to two destination, D1 and D2. The destination device D1 decodes signal interference from D2'signal of both links, i.e. link relay-D1 and D2-D2. As a result, the signal to interference and noise ratio (SINR) at D1 can be shown as

$$\gamma_{D2\to D1} = \frac{a_2 \rho |h_1|^2}{|h_1|^2 a_1\rho + |f_1|^2 \rho + 1} \quad (4)$$

It is noted that x_1, x_2 transmitted from the BS is unitary signal, i.e. $E\{x_1^2\} = E\{x_2^2\} = 1$. After using SIC at D1, it can be extracted its own signal at D1 as

$$\gamma_{D1} = \frac{a_1 \rho |h_1|^2}{|f_1|^2 \rho + 1} \quad (5)$$

PERFORMANCE SYSTEM EVALUATION

When the target rate of NOMA users are determined to obtains required quality of service (QoS), and hence the outage probability is an important parameter for performance evaluation.

A. Outage Probability of D1:

According to the NOMA protocol, the complementary events of outage at *D*1 can be explained as: *D*1 can detect *x*2 as well as its own message *x*1. From the above description, the outage probability of *D*1 can be expressed as below:

$$P_{D1} = 1 - \Pr(\gamma_R > \gamma_{th0}) \Pr(\gamma_{D2\to D1} > \gamma_{th2}, \gamma_{D1} > \gamma_{th1}) \quad (6)$$

where $\gamma_{th0} = 2^{2R_0} - 1, \gamma_{th1} = 2^{2R_1} - 1, \gamma_{th2} = 2^{2R_2} - 1$, and R_0, R_1, R_2 are the target rates at relay, D1 and D2, respectively. For simplicity, the channel gain of interference between D1 and D2 is the same due to symmetry. We denote $\Omega_0, \Omega_1, \Omega_2, \Omega_f$ are the channel gain of channel h_0, h_1, h_2, f. In the first phase, the outage event occur in relay as

$$\Pr(\gamma_R < \gamma_{th0}) = 1 - \exp\left(-\gamma_{th0} / (\Omega_0 \rho)\right) \quad (7)$$

Proposition 1. *The closed-form expression to compute the outage probability at D1* is *given by*

$$OP_{D1} = 1 - \frac{\Omega_1}{\Omega_1 + \rho \Omega_f \varphi} e^{-\frac{\varphi_1}{\Omega_1}} \exp\left(-\gamma_{th0} / (\Omega_0 \rho)\right) \quad (8)$$

where $\varphi_1 = \max(C_1, \beta_1)$, $C_1 = \frac{\gamma_{th2}}{\rho(a_2 - a_1\gamma_{th2})}, \beta_1 = \frac{\gamma_{th1}}{a_1 \rho}$, and $a_2 > a_1\gamma_{th2}$

Proof:

By definition, we first compute the complementary outage event and can be calculated as follows:

$$OP_1 = \Pr\left(|h_1|^2 \ge \left(|f|^2 \rho + 1\right)\varphi\right)$$
$$= \int_0^\infty \int_{(x\rho+1)\varphi}^\infty g_{|f|^2}(x) g_{|h_1|^2}(y) dxdy \quad (9)$$
$$= \frac{\Omega_1 \exp(-\varphi/\Omega_1)}{\Omega_1 + \rho\varphi\Omega_f}$$

It can be combined (7) and (9), we obtain final results.

B. Outage Probability of D2:

The outage performance for *D1* can be clarified for two reasons. The first is that R can not decode the composed signal and *D1* cannot detect x_2. The second is that R can not decode the composed signal and *D*2 cannot detect its own message *x*2 on the conditions that *D*1 can detect *x*2 successfully.

Proposition 2. Based on this, the outage probability of *D*2 can be expressed as below

$$OP_{D2} = \Pr(\gamma_R < \gamma_{th0}) \Pr(\gamma_{D_2 \to D_1} < \gamma_{th_2}) + \Pr(\gamma_R < \gamma_{th0}) \Pr(\gamma_{2,D_2} < \gamma_{th_2}, \gamma_{D_2 \to D_1} > \gamma_{th_2}) \quad (10)$$

It can be re-written as below

$$OP_{D2} = \left[1 - \frac{\Omega_1}{\Omega_1 + p\Omega_f C_1} e^{-\left(\frac{C_1}{\Omega_1} + \frac{\gamma_{th2}}{\rho\Omega_2}\right)}\right] \times \left[1 - \exp\left(-\gamma_{th0} / (\Omega_0 \rho)\right)\right] \quad (11)$$

Proof:

By definition, it can be derived the first and second outage events, respectively. The process calculated is given by

$$\Pr(\gamma_{D_2 \to D_1} < \gamma_{th2}) = \Pr\left\{|h_1|^2 < C_1\left(|f|^2 \rho + 1\right)\right\}$$
$$= \int_0^\infty \int_0^{C1(y\rho+1)} g_{|h_1|^2}(x) g_{|f_1|^2}(y) dxdy \quad (12)$$
$$= 1 - \frac{\Omega_1 \exp(-C_1/\Omega_1)}{\Omega_1 + C_1\rho\Omega_f}$$

Next, we compute second outage event

$$\Pr(\gamma_{2,D_2} < \gamma_{th2}, \gamma_{D_2 \to D_1} > \gamma_{th2})$$
$$= 1 - \frac{\Omega_1 \exp(-C_1/\Omega_1)}{\Omega_1 + C_1\rho\Omega_f}\left(1 - \exp\left(-\gamma_{th2} / (\Omega_2 \rho)\right)\right) \quad (13)$$

Combining the results from (7), (12) and (13), the final expression is proved completely.

NUMERICAL RESULTS

In this section, MATLAB numerical results are offered to confirm the accuracy of the analysis, and more important insights for NOMA under interference among NOMA users is investigated. In the considered network, the distance between nodes are normalized for simplicity. The target rates at relays, D1 and D2 are $R_0 = 1(bpcu), R_1 = 3(bpcu), R_2 = 1(bpcu)$. Monte Carlo simulation results are marked as bend mark to verify our derivation.

Fig. 2 plots the outage probability of two NOMA users for the first scenario when the transmit *SNR at BS* is changed from 0 dB to 30 dB. In Fig. 2, the power allocation coefficients are $a_1 = 0.2, a_2 = 0.8$.The illustrated curves are obtained from the analytical results derived in previous section. Several observations can be drawn as follows: 1) Reducing the outage event at high SNR; 2) the target rate contributes to outage performance.

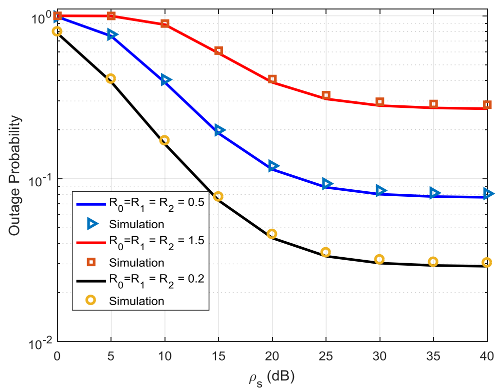

Figure 2. Outage probability for D1

In Fig. 3, the outage probability versus system SNR is presented in different target rate for D2. As can be seen, the exact analytical results and simulation results are in excellent agreement. Moreover, as the system SNR increases, the outage probability decreases. Another important observation is that the lowest outage probability for D2 of NOMA as setting lowest target rate.

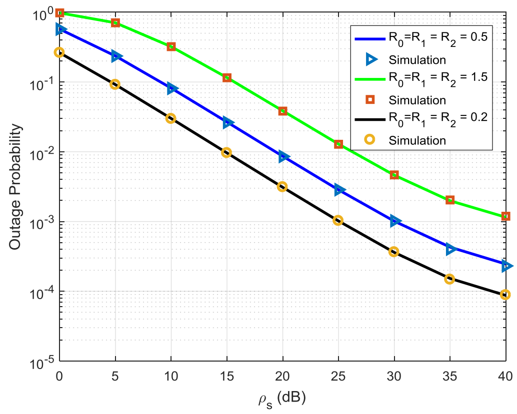

Figure 3. Outage probability for D2

CONCLUSION

In this paper, with self-interference among NOMA users taken into account, the outage performance for downlink cooperative NOMA networks over Rayleigh fading channels is examined. Expressions for the exact of the outage probability are achieved in closed-form, which is the theoretical basis to provide valuable guidelines in the actual communication system design. Simulation results demonstrate that NOMA provides significant performance for each user under chosen level of interference.

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