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Comparison on AF/DF for Device-To-Device NOMA Networks

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Abstract

A novel combination downlink cooperative non-orthogonal multiple access (NOMA) with device-to-device (D2D) network **in two schemes will be investigated in this paper**. In particular**,** D2D NOMA scheme with **Amplify-and-Forward (AF) and Decode-and-Forward (DF)** are explored **to achieve a remarkable tradeoff**s **between outage performances and** transmit **power at base station (BS). The tractable investigation on AF/DF is proposed to survey system performance for the current device-to-device (D2D)** transmission to adapt to fairness in **NOMA scheme. Specifically, it can be examined that the outage probability by** conveying **the effect of power division coefficient, transmits signal to noise ratio (SNR), broadcast power of the recommended scheme. Simulation** result **comes about not just affirm the exactness of the derived analytical results, yet in addition indicate performance gap between AF and DF accomplished by the proposed scheme over such D2D NOMA scheme.**

Keywords: Outage probability, D2D communications, NOMA.

INTRODUCTION

In recent times, relaying network and cooperative non-orthogonal multiple access (NOMA) network have attracted a lot of attention. It is considered as one of the modern technologies applied in 5th generation mobile networks for the purpose of improving spectral efficiency (SE) [1, 2], particularly keeping in mind the end goal to help the usefulness of the Internet of things (IoT) and the massive machine-type communications (mMTC) scenarios. The NOMA admits multiple users concurrently severed with the same bandwidth resources, e.g., time slots, frequency or spreading codes. By applying power-domain multiplexing at the source device and successive interference cancelation (SIC) at the destination devices, A comparison of orthogonal multiple access (OMA) and NOMA in [3,4] has shown that NOMA achieves better performance. On the other hand, the multi-antenna technique has been acquainted into NOMA systems to promote the SE further [5, 6], and the relay-aided cooperative scheme [7] has been proposed to improve the communication accuracy of the cell-edge clients under impacts of co-channel interference, in which such scheme can be deployed in scenario as the cell-center clients operate as relays to support the cell-edge user.

With the purpose of further boosting the performance of NOMA, recently cooperative NOMA (C-NOMA) schemes have pulled in a few considerations. In [8], the authors proposed energy harvesting protocol in full-duplex relaying networks, which results in the improved bandwidth efficiency, and hence the proposed model can improve the outage probability. In [9], the author proposes that a NOMA model combines energy harvesting, which is called simultaneous wireless information and power transfer (SWIPT), in which user that were near to the source, i.e., strong user will act as energy harvesting relay to support the transmission of information from the source to far user. In [10], the application of NOMA to the coordinated multiple points (CoMP) systems was proposed. In [11], a cooperative beamforming NOMA scheme was proposed, which employed intra-beam superposition coding of a many clients' signal at the transmitter and the spatial draining of inter-beam interference pursued by the intra-beam successive interference cancellation (SIC) at the ended receiver. Additionally, the performance of NOMA for relaying networks was also examined [12], [13].

With the development of modern technology such as IoT, D2D communication that can be done by direct data transmission between devices without communicating via a base station (BS) has recently risen as an empowering technology to resolve expanding demands for spectrum resources [14]. In recent time, D2D communication as an underlay to cellular networks has been proposed for better spectrum utilization [15]. Since AF/DF is widely deployed as coveragre enhancing scheme, and hence it is recommended for effective transmission in practical applications [16, 17].

To successfully deal with the interference from CU and upgrade the transmission effectiveness from the BS, optimization problems are considered at the BS to assess system performance in the downlink. With the NOMA and D2D link, the power are planned for data transmissions in a NOMA fashion to accomplish optimal outage performance. To the best of our knowledge, there few of papers concerning both AF and DF scheme. Motivated by above analysis and novel result in [16-19], this paper only focus on downlink D2D transmission with respect to consider AF/DF mode in term of outage performance as performing reasonable selection of power division fraction. Particularly, the novelty and contribution of this paper are shown as follows:

- We derived the closed-form of outage probability as function of transmit SNR. As a result, impacts of power division factions in NOMA for two users can be determined
- We introduce the tractable form to evaluate system performance as comparing between AF and DF modes.
- Next, Monte Carlo simulations are presented the outage performance to corroborate our analysis and the impact of some significant parameters on proposed protocol in D2D networks are investigated.

The rest of this article is organized as follows: Section 2 shows the system model and AF /DF protocol is investigated. In section 3, we derive the analytical expressions of outage probability in delay-limited transmission mode. Section 4 examines the simulation results. Finally, Section 5 concludes with important remarks for the paper and analyses the important results.

SYSTEM MODEL

The system model is given by Figure 1, which is a downlink cooperative NOMA (C-NOMA) system together with D2D transmission and comprises of a BS and two devices, i.e., D_1 and D_2. Here, it can be considered the two users in the system model. Furthermore, users obtain the SIC technique to eliminate the unwanted interference of the remaining user. Nevertheless, when the amount of clients raises, the delay and complexity in processing also increase significantly. So, to reduce the complexity and delay in signal processing, we just consider a system which consists of two users. In this case, the two-user system model is a choice in a practical way that will actually show the harmony of the number of clients, interference, the processing delay and complexity. Also, based on the two user system model, we can design a general D2D NOMA system which consists of user pairing schemes that include two device which can be communicated directly.

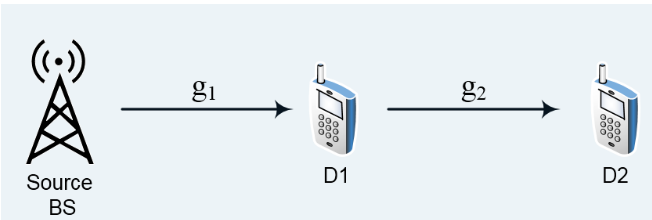

Figure 1. Downlink D2D-NOMA system model

As appeared in Fig. 1, g_1 and g_2 denote the Rayleigh fading channel coefficients of the link BS® D_1 and D_1 ® D_2, respectively, in which $g_1 : CN(0, \lambda_{SD1})$ and $g_2 : CN(0, \lambda_{RD2})$. We denote λ_{SD1} and λ_{RD2} are the average power for the links between the BS and the relaying node, between the relaying nodes, i.e., D_1 and D_2, respectively.

We assume that there does not exist a direct link from the BS to D_2. Nevertheless, to be able to carry the message from BS to D_2, D_1 will act as a relay for D_2 when receiving its own messages. The signal model and the SINR in the considered D2D NOMA system will be analyzed in the content below.

Firstly, the BS transmits a composed signal x_{S1} of D_1 and x_{S2} of D_2 with $x_{Si}\left(\mathrm{E}\left[\left|x_{Si}\right|^2\right]=1\right)$, $i=1,2$, as a downlink NOMA signal

$$x_S = \sqrt{\beta P_S}x_{S1} + \sqrt{(1-\beta)P_S}x_{S2}, \tag{1}$$

in which P_S, β and $(1-\beta)$ denote the broadcast power of the BS, the power division coefficients of x_{S1} and x_{S2}, respectively, where $(0 \le \beta \le 1)$.

After receiving the signal from the BS, D_1 will transmit the message $u = \hat{x}_{S2}$ with power P_R to D_2, where $\hat{x}_{S2}$ is the decoded version of x_{S2}. In particular, if D_1 successfully decodes x_{S2}, we acquire $\hat{x}_{S2} = x_{S2}$. Otherwise, we acquire $\hat{x}_{S2} \neq x_{S2}$. Therefore, D_1 may receive two signals at the same time. The received signal at D_1 is given by

$$y_{D1} = \underbrace{g_1\left(\sqrt{\beta P_S}x_{S1} + \sqrt{(1-\beta)P_S}x_{S2}\right)}_{\text{BS's signal}} + \underbrace{\omega_{D1}}_{\text{Noise}} \tag{2}$$

in which $w_{Di} : CN(0, s^2)$, $i = 1,2$, is the white Gaussian noise at D_i.

A. *DF Relaying*

In this case, the received signal at D_2 is given by

$$y_{RD2}^{DF} = g_2\sqrt{P_R}u + \omega_{D2} \tag{3}$$

After receiving the signal y_{D1}, D_1 firstly decodes x_{S2} and then decodes its own message x_{S1} by applying the SIC technique. Thus, the instantaneous SINR at D_1 to decode x_{S2} can be calculated as

$$\gamma_{SD1-2}^{DF} = \frac{(1-\beta)P_S|g_1|^2}{\beta P_S|g_1|^2+\sigma^2} = \frac{(1-\beta)\rho|g_1|^2}{\beta\rho|g_1|^2+1} \tag{4}$$

where $\rho = \frac{P_S}{\sigma^2}$. In addition, to get the signal x_{S1}, D_1 must firstly remove the x_{S2} in y_{D1} and detect x_{S1}. So, the instantaneous SINR to get x_{S1} at D_1 can be stated as

$$\gamma_{SD1-1}^{DF} = \frac{\beta P_S|g_1|^2}{\sigma^2} = \beta\rho|g_1|^2 \tag{5}$$

After D_1 effectively decodes x_{S2}, the SINR at D_2 to get its own data, i.e., x_{S2} is presented by

$$\gamma_{RD2-2}^{DF} = \frac{P_R |g_2|^2}{\sigma^2} = \rho_1 |g_2|^2 \quad (6)$$

where $\rho_1 = \frac{P_R}{\sigma^2}$

B. AF Relaying

In the time slot 1st, it can be got the received signal at D_1, i.e., y_{D1} as in (2). In the time slot 2nd, relay D_1 amplifies and transmits the signal y_{D1} to D_2 in AF relaying mode. Therefore, the signal which received at D_2 can be stated as follows

$$y_{RD2}^{AF} = g_2 G \sqrt{P_R} y_{D1} + \omega_{D_2} \quad (7)$$

In which G is amplify coefficient in AF mode and it can be calculated as follows

$$G^2 = \frac{1}{\sqrt{P\mathrm{E}\left\{|g_1|^2\right\} + \sigma^2}} \quad (8)$$

We denote $\mathrm{E}\{.\}$ as expectation operation. It is similar to C-NOMA with DF relaying, in AF NOMA relaying mode, it can be assumed that D_1 always decodes the signal x_{S1}. So, D_2 will firstly get the signal x_{S1}, then remove it. Therefore, the received SINR for D_2 to decode message x_{S1} is given by

$$\gamma_{SD2-1}^{AF} = \frac{(1-\beta)|g_1|^2 |g_2|^2 \rho}{\beta |g_1|^2 |g_2|^2 \rho + |g_2|^2 + \kappa} \quad (9)$$

in which $\kappa @ 1/\mathrm{G}^2$, after applying SIC technology, the receiving SINR for D_2 is given by

$$\gamma_{RD2-2}^{AF} = \frac{\beta |g_1|^2 |g_2|^2 \rho}{|g_2|^2 + \kappa} \quad (10)$$

II. PERFORMANCE ANALYSIS

A. DF Outage Probability Analysis

First of all, we assume that the C-NOMA system will be interrupted when D_1 can not successfully decode x_{S1} or D_2 can not successfully decode x_{S2}. Then, we denote $\gamma_{\mathrm{i},th} = 2^{2\mathrm{R}} - 1$, $i = 1,2$, as the target SINRs to decode D_i's message and R is the objective rate.

In this case, to successfully decode the x_{S1} signal, there are two conditions must be met: the initial condition is that D_1 successfully decodes x_{S2}, i.e., $\gamma_{SD1-2}^{DF} \geq \gamma_{2,th}$, and the second condition is that D_1 effectively decodes x_{S1}, i.e., $\gamma_{SD1-1}^{DF} \geq \gamma_{1,th}$. Similarly, to successfully decode the x_{S2} signal, two conditions must be guaranteed: the first condition is that D_1 successfully decodes x_{S2}, and the second one is that D_2 successfully decodes x_{S2}, i.e., $\gamma_{RD2-2}^{DF} \geq \gamma_{2,th}$. as a consequence, the outage probability can be presented as: [19]

$$OP_{DF} = 1 - \Pr\left\{\gamma_{SD1-2}^{DF} \geq \gamma_{2,th}, \gamma_{SD1-1}^{DF} \geq \gamma_{1,th}, \gamma_{RD2-2}^{DF} \geq \gamma_{2,th}\right\} \quad (11)$$

It can be observed from (11) that when β conforms to the following condition:

$$\beta = 0 \quad (12)$$

in this case, $OP_{DF} = 1$;

When β meets the following conditions:

$$\beta \neq 0 \text{ and } \beta \neq \frac{1}{1+\gamma_{2,th}} \quad (13)$$

the expression (11) can be rewritten as follows

$$\begin{aligned} OP_{DF} &= 1 - \\ &Pr\left\{ \begin{array}{l} |g_1|^2 \geq \max\left\{\frac{\gamma_{2,th}}{(1-\beta-\beta\gamma_{2,th})\rho}; \frac{\gamma_{1,th}}{\beta\rho}\right\}, \\ \rho_1 |g_2|^2 \geq \gamma_{2,th} \end{array} \right\} \\ &= 1 - \\ &\underbrace{Pr\left\{|g_1|^2 \geq \max\left\{\frac{\gamma_{2,th}}{(1-\beta-\beta\gamma_{2,th})\rho}; \frac{\gamma_{1,th}}{\beta\rho}\right\}\right\}}_{E1} \times \\ &\underbrace{Pr\left\{\rho_1 |g_2|^2 \geq \gamma_{2,th}\right\}}_{E2} \end{aligned} \quad (14)$$

From (14), we can easily obtain the following outage components

$$E2 = Pr\left\{\rho_1 |g_2|^2 \geq \gamma_{2,th}\right\} = e^{-\frac{\gamma_{2,th}}{\rho_1 \lambda_{RD2}}} \quad (15)$$

To compute the E1 in (14), there are two cases that can be occurred as follows

Case I:

$$E1 = Pr\left\{|g_1|^2 \geq \frac{\gamma_{1,th}}{\beta\rho}\right\} = e^{-\frac{\gamma_{1,th}}{\beta\rho\lambda_{SD1}}} \quad (16)$$

Case II:

$$\begin{aligned} E1 &= Pr\left\{|g_1|^2 \geq \frac{\gamma_{2,th}}{(1-\beta-\beta\gamma_{2,th})\rho}\right\} \\ &= e^{-\frac{\gamma_{2,th}}{(1-\beta-\beta\gamma_{2,th})\rho\lambda_{SD1}}} \end{aligned} \quad (17)$$

In case I, substituting (15) and (16) in (14), it can be obtained the outage probability of the C-NOMA scheme as follows

$$OP_{DF} = 1 - e^{-\frac{\gamma_{1,th}}{\beta\rho\lambda_{SD1}} - \frac{\gamma_{2,th}}{\rho_1\lambda_{RD2}}} \quad (18)$$

In case II, substituting (15) and (17) in (14), we have

$$OP_{DF} = 1 - e^{-\frac{\gamma_{2,th}}{(1-\beta-\beta\gamma_{2,th})\rho\lambda_{SD1}} - \frac{\gamma_{2,th}}{\rho_1\lambda_{RD2}}} \quad (19)$$

It worth noting that above result can be computed by using the probability density functions (PDFs) and the cumulative distribution functions (CDFs) of the channel X are $f_X(x) = \frac{1}{\lambda_X} e^{-\frac{x}{\lambda_X}}$ and $F_X(x) = 1 - e^{-\frac{x}{\lambda_X}}$, respectively.

It can be displayed that the outage probability OP_{DF} is dependent on the value of the β at the BS, and is controlled by the objective SINRs $\gamma_{1,th}$ and $\gamma_{2,th}$. In particular, for $\beta = 0$, the outage probability is 1. This is on account of, D_1 needs to first decode D_2's message and then decode its own message. If D_1 cannot decode D_2's message because of a huge power division parameter β or cannot decode D_1's message because of a very small power division parameter β, an outage event will happen.

B. Outage Performance in AF Scheme

In this scenario, the users consolidate with the perceptions from the BS and the relaying node by utilizing selection combining at the last slot. Thus, an outage event for D_2 can be interpreted as two reasons, i.e., it cannot recognize its own message at two slots. Based on the above explanation, the outage probability of D_2 is provided by

$$OP_{AF} = \left(\gamma_{RD2-2}^{AF} \le \gamma_{2,th}\right) \quad (20)$$

The next following proposition brings the outage probability of D_2 in this context.

Proposition 1: The closed-form expression for the outage probability of the device D_2 is stated as.

$$OP_{AF} = 1 - \exp\left(\frac{-\theta}{\lambda_{SD1}}\right) 2\sqrt{u} K_1\left(2\sqrt{u}\right) \quad (21)$$

where $\theta = \frac{\gamma_{2,th}}{\beta\rho}, u = \frac{\theta\kappa}{\lambda_{SD1}\lambda_{RD2}}$ and $K_1(.)$ is the modified Bessel function of the second kind with first order.

Proof:

See in Appendix

NUMERICAL RESULTS

In this part, the performance of the recognized NOMA scheme in term of outage performance and such performance is evaluated by Monte Carlo simulations. In this section, to confirm the validity of the derived theoretical expressions we perform the numerical results for several scenarios over Rayleigh fading channels. In such circumstances, the distance from BS to other devices is normalized to unity.

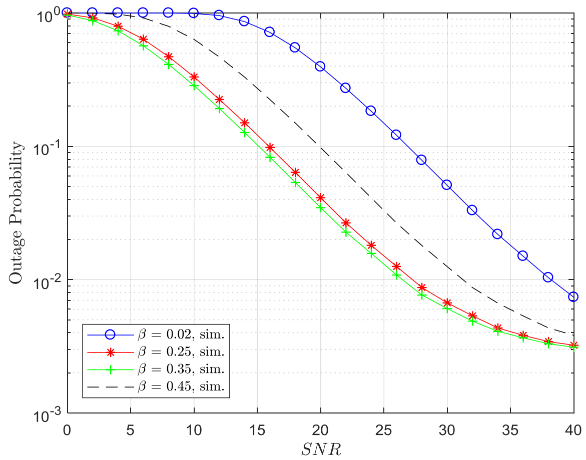

Figure 2. DF outage performance versus SNR with parameter set as $\lambda_{SD1} = 1$, $\lambda_{RD2} = 1$, $\gamma_{1,th} = \gamma_{2,th} = 1$, $\rho_1 = 25dB$

Fig. 2 plots the outage probability in DF scheme of such D2D NOMA network versus SNR with varying value of power division for each user in NOMA. It is noted that such power division is limited by 0.5 as upper bound. The exact outage probability curves of system for D2D NOMA over Rayleigh fading channels are given by numerical simulation. The results confirmed that at very low and very high of power division factors will be lead to worse outage performance.

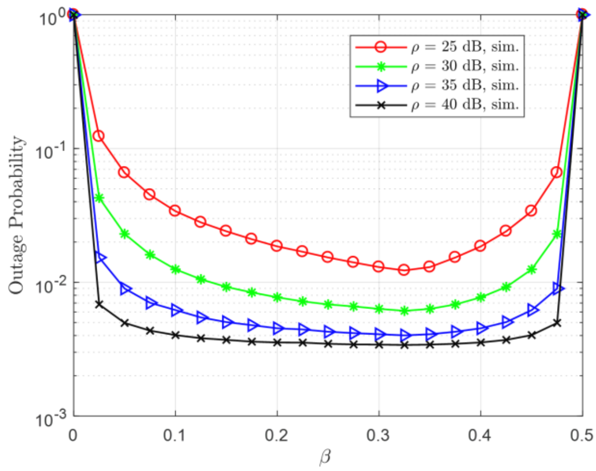

Figure 3. DF outage performance versus power division as varying SNR and $\lambda_{SD1} = \lambda_{RD2} = 1, \gamma_{1,th} = \gamma_{2,th} = 1, \rho_1 = 25dB$

To find exact optimal power division elements for each client in D2D NOMA, Fig. 3 presents that the optimal outage probability in DF scheme can be achieved as controlling power division factors corresponding to transmit SNR at source. It is shown that higher SNR contributes to lower outage performance due to more power for signal processing in such D2D downlink transmission.

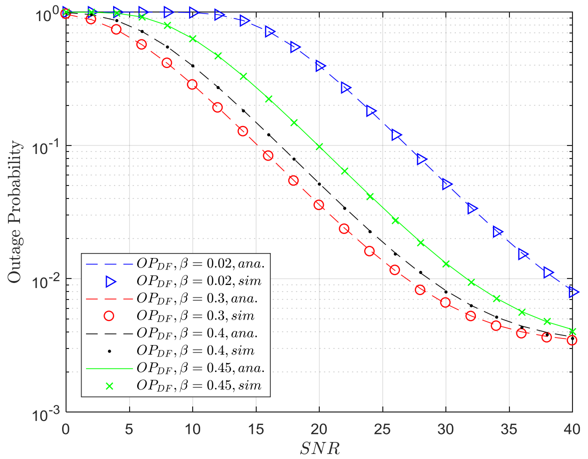

Figure 4. DF outage performance with $\lambda_{SD1} = \lambda_{RD2} = 1$, $\gamma_{1,th} = \gamma_{2,th} = 1$, $\rho_1 = 25dB$

Fig. 4 demonstrates the simulation outcomes and systematic results for the outage probability of DF NOMA scheme and our proposed D2D NOMA scheme. Besides, the outage probability depends on the power division in two users of NOMA scheme. It can be considered that our diagnostic outcomes closely coordinate with the simulation results, especially for all value of SNR regime. The reason is that AF scheme acts amplify both signal and noise and it outcomes in lower outage performance. Interestingly, DF NOMA shows that an outage floor can be occurred in high SNR regime. In high SNR, performance gap as varying power division fraction is blurred.

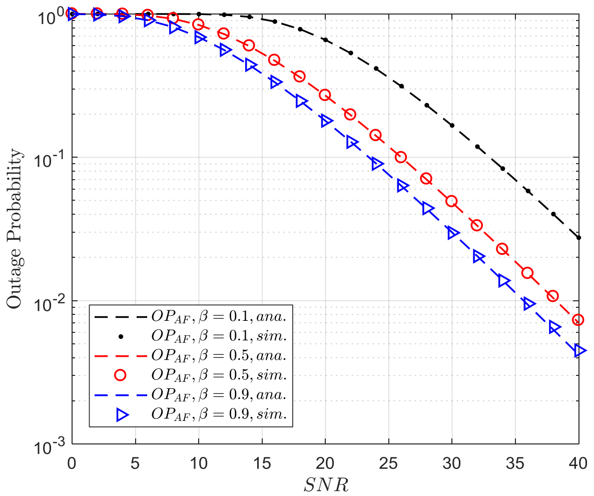

Figure 5. Outage performance of AF NOMA as $G = 0.8$, $\lambda_{SD1} = \lambda_{RD2} = 1$, $R = 1$.

Fig. 5, the analytical results in derived expression in previous section in which are the outage probabilities for system are compared in different system parameters. The lines in such figure show a perfect match between the analytical derivations and the computer simulation results, for the whole range of the SNR, which confirms the accuracy of our analytical expressions. Furthermore, one can observe from Fig. 5 that D2D NOMA can result in lower outage at very high SNR. On the other hand, there is no outage floor in AF NOMA which differ with DF NOMA

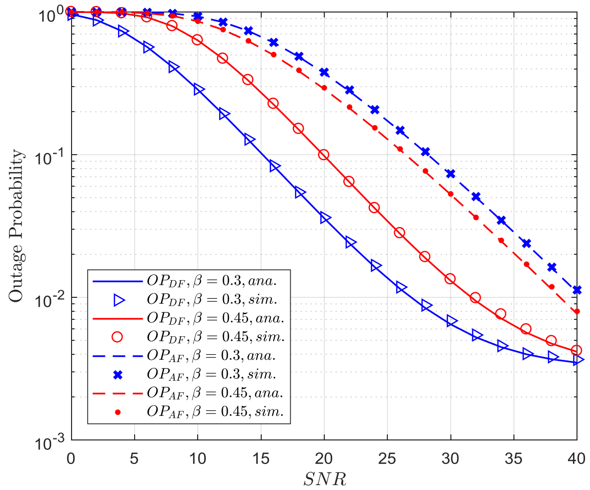

Figure 6. Comparison study between AF and DF as set $\lambda_{SD1} = \lambda_{RD2} = 1$, $\gamma_{1,th} = \gamma_{2,th} = 1$, $\rho_1 = 25dB$, $G = 0.8$, $R = 1$.

In fig. 6, the Monte Carlo simulation results for the outage performance of both users are expressed. Furthermore, one can observe that the outage probabilities for DF NOMA with better outage performance compared with AF NOMA, and the performance gap can be seen clearly as SNR changed from 15 dB to 30 dB. This is because in AF NOMA systems, noise term is amplified and hence it leads to worse performance. It is noted that the fixed amplify gain affect to system performance. However, the difficulty in circuit design of AF NOMA is easier than DF NOMA where quires more complexity in decoding algorithm.

CONCLUSION

In this paper, the cooperative transmission in the downlink of D2D was studied by comparing between AF and DF modes.The system model was proposed to outage performance gap and to accomplish better tradeoff between system performance and power division for cooperative NOMA schemes. Particularly, the cooperative transmission in downlink of D2D is examined. The performance of the proposed model is evaluated by the outage probability, the power distribution coefficients and the system outage. Our analyzes are verified by simulation. There is only a slight decrease in performance at weak device, our suggested scheme can dramatically increases the spectral efficiency of the system via a traditional cooperative relaying schemes and a right decision on AF NOMA or DF NOMA scheme where best performance is careful selected in specific application.

APPENDIX

Proof of Proposition 1

Substituting (10) into (18), the outage probability of D_2 is stated as follows

$$\begin{aligned} OP_{AF} &= \Pr\left(\frac{\beta |g_1|^2 |g_2|^2 \rho}{|g_2|^2 + \kappa} \le \gamma_{2,th} \right) \\ &= 1 - \Pr\left(|g_2|^2 \ge \frac{\theta\kappa}{|g_1|^2 - \theta}, |g_1|^2 \ge \theta \right) \\ &= 1 - \int_{\theta}^{\infty} \left(1 - F_{|g_2|^2}\left(\frac{\theta\kappa}{x - \theta} \right) \right) f_{|g_1|^2}(x)\, dx \\ &= 1 - \frac{1}{\lambda_{SD1}} \int_{\theta}^{\infty} \exp\left(\frac{-\theta\kappa}{(x-\theta)\lambda_{RD2}} \right) \exp\left(\frac{-x}{\lambda_{RD2}} \right) dx \\ &= 1 - \exp\left(\frac{-\theta}{\lambda_{SD1}} \right) 2\sqrt{\frac{\theta\kappa}{\lambda_{SD1}\lambda_{RD2}}} K_1\left(2\sqrt{\frac{\theta\kappa}{\lambda_{SD1}\lambda_{RD2}}} \right) \end{aligned} \quad \text{(A.1)}$$

The final integration in (A.1) can be obtained by applying [20, eq. (3.324)]. The proof is finished.

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