TEST Engineering & Management
May – June 2020
ISSN: 0193-4120 Page No. 5456-5460

Performance Analysis of User Assisted Relaying Based Cooperative NOMA System

P.Bachan[1], Aasheesh Shukla[1], Atul Bansal[1]

[1]Department of Electronics & Communication, G. L. A. University, Mathura, India
p.bachan, aasheesh.shukla, atul.bansal@gla.ac.in

Article Info
Volume 83
Page Number: 5456 - 5460
Publication Issue:
May - June 2020

Article History
***Article Received:** 19 November 2019*
***Revised:** 27 January 2020*
***Accepted:** 24 February 2020*
***Publication:** 17 May 2020*

Abstract

In this paper we study a two-user cooperative Non-Orthogonal Multiple Access (C-NOMA) system for downlink transmissions. In this system the user closer to the base station act as a full-duplex relay for the user which is placed away from the base station. Firstly, the performance of C-NOMA with full-duplex relay based system will be analyzed through the closed form expressions of probability of outage by considering static power assignments at base station and user assisted relay. Secondly we investigate the outage performance with variable relay power allocations. In both the analysis we also examine the impact of perfect and imperfect SIC implementation. Simulation based numerical results confirm the applicability of mathematical analysis for both fixed and variable power allocations.

***Keywords:** Cooperative NOMA, full-duplex relay, power allocations, outageprobability.*

I. Introduction

The higher data rate and massive connectivity are two key metrics of 5G and beyond 5G cellular networks. The ability to achieve higher spectral efficiency(SE) and massive connectivity makes the Non-Orthogonal multiple access(NOMA) technique a very promising and proficient candidate for the next generation networks [1-2]. Unlike orthogonal multiple access(OMA) scheme, NOMA is intended to assist multiple users simultaneously at a single base station in same time/frequency slot but with different power levels. Although, sharing the same time/frequency resource may lead to co-channel interference(CCI) between the users at the receiver. So successive interference cancellation technique is utilized to reduce CCI [3].

For successful SIC implementation in conventional NOMA systems, receiver must have the prior knowledge of information of other receivers. Ding et al. suggested a unique cooperative NOMA scheme to improve the spatial diversity gain at receivers and the signal transmission rate at the base stations [4]. In cooperative NOMA systems two most preferred relaying approaches that have been used in the previous works are half-duplex relaying and full-duplex relaying. In Half-Duplex C-NOMA scheme, the system will function in two stages, where in the first stage, the base stationtransmits the superimposed composite NOMA signals to the proximate receivers (i.e., users/relays). Then, in the second stage, the proximate receivers forward the information of distant receivers, whereas in Full-Duplex C-NOMA scheme, the user/relay node will collect and forward the signals simultaneously to their distant receivers. The limitation of full-duplex technology lies in the fact that it introduces some self-interference (SI) generated from the output of transceiver to the input activated by the signal leakage [5], which has severe impact on the performance of the full-duplex system.Moreover, full-duplex technology has been employed in C-NOMA systems by many researchers because it receives-and-forwards the information on the same frequency by exploiting the total system bandwidth.

Recently, the combination of NOMA with relay-assisted communication has picked up part of consideration due to its capability of improving user's transmission rate while enhancing the spectral efficiency of the network. In recent past only few authors have investigated User assisted relay based cooperative NOMA systems. In [6-8] authors have studied and analyzed system performance of half-duplex(HD) C-NOMA systems where reception of signal at near user and forwarding of signal from near user to far user takes place in two different stages. In addition to this [9] investigated the HD-C-NOMA system both for uplink and downlink

May – June 2020
ISSN: 0193-4120 Page No. 5456-5460

transmissions. To further enhance the system performance full-duplex(FD) C-NOMA systems were also investigated in [10-12].

In this work we analyze the user assisted relay based cooperative NOMA systems for downlink transmissions. This model considers that there is line of sight(LOS) path available between base-station(BS) and near user only and Non-LOS path is available between BS and far user due to heavy shadowing.

The body of this paper is organized as follows: In the subsequent section we start with system model for the above mentioned scenario where we analytically represent the signal model and SINR model. Then in section III we theoretically analyze the probability of outage for static power assignments at base station and relay. Simulation results for user-assisted relay based C-NOMA system will be discussed in section IV. Finally, section V summarizes the objectives and outcomes of this entire work.

II. System Model

The system model for relay based two user downlink C-NOMA system is shown in figure 1. This system consists of single base station which broadcasts the composite NOMA signal to near user(U_1) meanwhile U_1first decode this superimposed signal and forward the information to far user (U_2). As U_2 receive the signal from base station via U_1 so, U_1functions as a full duplex relay for far user U_2. The channels from base station to U_1 and from U_1 to U_2 are labelled as h_1 and h_2 respectively. Both h_1 and h_2 are modeled as complex Gaussian random variables with zero mean and variances l_1 and l_2 respectively. Now in the following sub-section we provide the signal model and SINR model from BS to $U_1$and $U_2$for user assisted C-NOMA system.

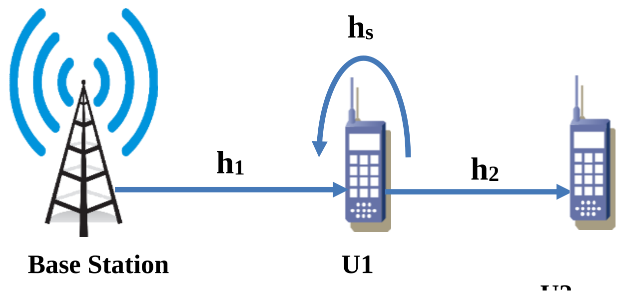

Fig.1. System model for User assisted relay based two user downlink C-NOMA system considering near user U_1 as a full-duplex relay for far user U_2.

II.1 Signal Model

Let us consider m_1 and m_2 as the messages corresponding to U_1 and U_2 respectively. The superimposed signal transmitted by the base station to U_1 for downlink NOMA system is,

$$m(t) = \sqrt{aP}m_1(t) + \sqrt{bP}m_2(t),$$

where $b = 1$ -,

P is base station transmit power, $a(0 \leq a \leq$ and $(0 \leq b \leq$, are power distribution coefficients of messages m_1 and m_2 respectively.

In full duplex mode U_1 simultaneously receives the message from base station and transmits the message($m_2'(t-t$ of U_2 with power Pu. If message of U_2 is successfully decoded by U_1then $m_2' =$. In full duplex relay based transmission U_1 will also affected by self-interference. So we consider a parameter $z(0 \leq z \leq$ to indicate self-interference cancellation factor at U_1. If z is close to 1 then, it represents absence for failure of self-interference cancellation and z close to 0 indicates perfect self-interference cancellation. The signal received at U_1 is,

$$r_1(t) = h_1(t)m(t) + h_s(t)\sqrt{zPu}m_2'^{(t-t1)} + n_1(t), \quad (2)$$

where and represents the channel of self-interference signal and noise at U_1 respectively. Both and are modeled as complex Gaussian random variables with zero mean and variances l_s and σ^2 respectively.

The received signal at U_2 is,

$$r_2(t) = h_2(t)\sqrt{Pu}m_2'(t-t1) + n_2(t),$$

$n_2$represents complex Gaussian distributed noise at U_2 with zero mean and variance σ^2.

II.2 SINR Model

Successive interference cancellation(SIC) is applied at U_1 to decode the message m_1 from composite NOMA signal. First m_2 is decoded by U_1 then it subtracts m_2 from r_1 and detect m_1. Thus SINR for detecting m_2 at U_1 is given by,

$$g_1^2 = \frac{bP|h_1|^2}{aP|h_1|^2 + zPu|h_s|^2 + \sigma^2},$$

and the SINR for detecting at U1 is given by,

$$g_1^1 = \frac{aP|h_1|^2}{zPu|h_s|^2+\sigma^2},$$

Finally after success full detection of at U₁, the SINR for decoding at U₂ is given by,

$$g_2^2 = \frac{Pu|h_2|^2}{\sigma^2},$$

(6)

III. Probability of Outage

In this section, firstly we analyze the outage probability by considering static power assignments at both base station and user assisted relay(U_1). To begin with let us denote and as the target SINR to decode the messages and respectively. There are two necessary conditions for successful detection of : a) $g_1^2 \geq$ (is successfully decoded at U_1) and b) $g_1^1 \geq$ (is successfully decoded at U_1). Then to successfully decode at U_2 $g_2^2 \geq$.

An outage happens when either of the above mentioned condition is failed. Thus the probability of outage can be calculated as,

$$Pout = 1 - Pr[\, g_1^2 \geq G_2,\ g_1^1 \geq G_1,\ g_2^2 \geq G_2],$$ (7)

The analytical expressions of outage probability for different range of ‘ ’ is given as follows:

Case1: when either is in the range,

$$\frac{1}{1+G_2} \leq a \leq \text{or} \quad a =$$

$$Pout = 1;$$

This happens because message of U_2 should be successfully decoded at U_1 then only U_1 can decode its own message. So if the power allocation parameter is too large then U_1 may fail to decode message of U_2 or if the power allocation parameter is too small then U_1 may fail to decode its own message then an outage will happen.

Case2: when is in the range,

$$0 < a \leq \frac{G_1}{G_1 + G_2 + G_1 G_2}$$

$$Pout = 1 - \frac{aPl_1}{aPl_1 + zPul_sG_1} e^{-\frac{\sigma^2 G_1}{aPl_1} - \frac{\sigma^2 G_2}{Pul_2}}$$

(9)

Case3: when is in the range,

$$\frac{G_1}{G_1 + G_2 + G_1 G_2} < a < \frac{1}{1 + G_2}$$

(5)

$$Pout = 1 - \frac{(b-aG_2)Pl_1}{(b-aG_2)Pl_1 + zPul_sG_2} e^{-\frac{\sigma^2 G_2}{(b-aG_2)Pl_1} - \frac{\sigma^2 G_2}{Pul_2}}$$ (10)

IV. Simulation Results

In this section we evaluate the performance of user assisted relay based cooperative NOMA(C-NOMA) system through numerical simulations. The numerical simulation analysis is carried out in two steps: Firstly, relay transmit power(Pu) was fixed and outage probability is calculated for range of base station powers(P). Then in the second step outage probability was also analyzed for range of relay power while keeping the base station power fixed.

In this C-NOMA system we consider power allocation coefficient $a = 0.3$, variance associated with different channels are l_1=1, l_2=0.5, l_s=0.1. The target SINR $G_1 = 1$to perfectly decode the message $m_1$and $G_2 = 1$for successful detection of m_2. We also assume nose power as unity, i.e. σ^2=1and the transmit powers at both base station and relay are considered in dB which is be equivalent to signal to noise ratio.

Fig. 2 demonstrates the probability of outage for a range of base station powers (P=0 to 40 dB) with fixed relay(U1) transmit power (Pu=15 dB).

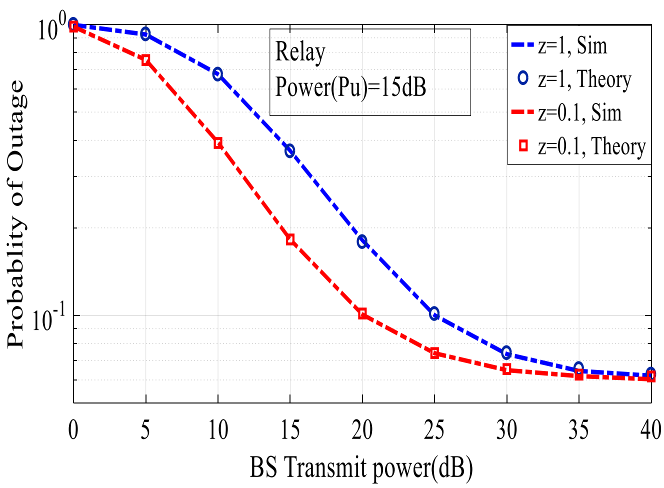

Fig.2. Probability of outage in two user full-duplex relay based C-NOMA system with and fixed Pu=15 dB.

Here we observe that the outage probability curve is a perfect match with the theoretical analysis given in section III. Secondly, with respect to increasing values of base station transmit power(P)

TEST Engineering & Management

May – June 2020
ISSN: 0193-4120 Page No. 5456-5460

the numerical values of probability of outage is decreasing and when P is significant enough it converges to a minimum value. We have also shown the impact of self-interference parameter 'z' on probability of outage.

We may observe that at P=25 dB, Pout = 0.1 with imperfect self-interference cancellation(z=1) and it reduces to 0.073 with perfect self-interference cancellation(z=0.1). So to improve the performance of relay based C-NOMA systems superior self-interference cancellation technique should be adopted.

Further Fig. 3 illustrates the probability of outage for the same setup and parameters but with increased relay transmit power(Pu=25dB). So it is clearly evident that relay transmit power increases the outage curve converges to the minimum value at higher base transmit powers(P) as compared to fig. 1 but the numerical values of probability of outage is significantly reduced at higher value of P. For P=35 dB it can be seen that Pout=0.038 and 0.01 with imperfect(z=1) and perfect (z=0.1) self-interference cancellation respectively. So the performance of C-NOMA system can be further improved by increasing the value of relay transmit power(Pu) upto certain limit.

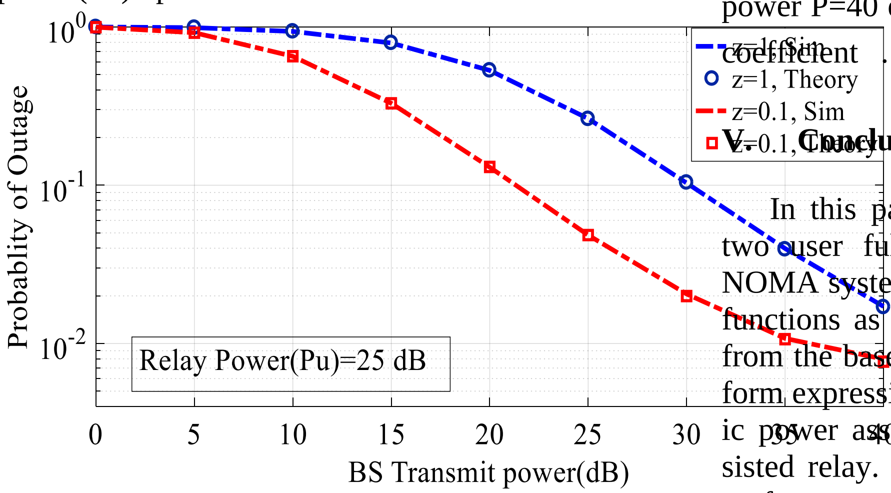

Fig.3. Probability of outage in two user full-duplex relay based C-NOMA system with $a = 0.3$ and fixed Pu=25 dB.

In Fig. 4 we have shown the probability of outage performance for a range of relay transmit power (Pu=0 to 40 dB) while keeping the base station power fixed at P=40 dB. To analyze the outage performance w.r.t Pu, three different values of power allocation coefficient (are considered. We observe that in all three cases simulation based outage probability curve matches with the theoretical curve.

Furthermore, we detect that the minimum outage probabilities are obtained with $a = 0.$ at Pu=28 dB, with $a = 0.$ at Pu=30 dB and with $a = 0.$ at Pu=26 dB. We also notice that outage performance is at its best when satisfies the upper limit of the range given in (9). So it is necessary that the power distribution coefficient should be optimized to further enhance the performance of C-NOMA systems.

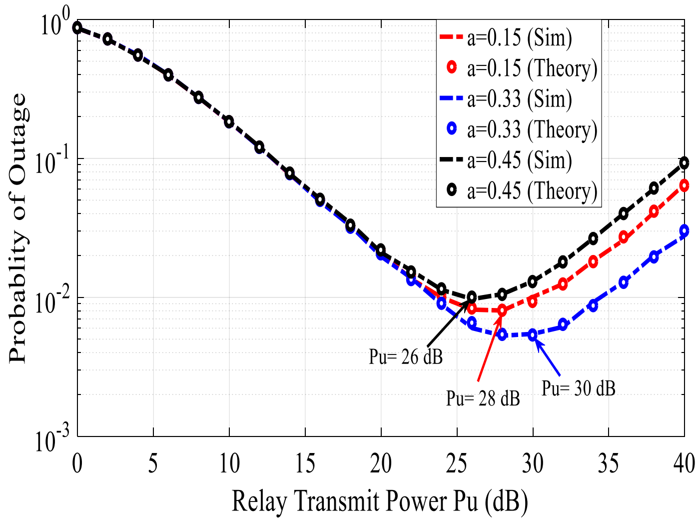

Fig.4. Probability of w.r.t Relay Power Pu with BS power P=40 dB and with variable power allocation coefficient .

V. Conclusions

In this paper we have studied and analyzed a two user full-duplex relaying based cooperative NOMA system where user closer to the base station functions as a full duplex relay for the user away from the base station. We first presented the closed form expressions for probability of outage with static power assignments at base station and user assisted relay. We have also investigated the outage performance with variable relay power allocations. In the numerical analysis it is evident that perfect self- interference cancellation plays a vital role in improving the outage performance. Secondly relay transmit can also be varied upto certain limit for reducing the probability of outage. Furthermore, we can conclude that there is a tradeoff between power allocation coefficient at base station and relay transmit power so, one extension may be the joint optimization of these two parameters to further im-

May – June 2020
ISSN: 0193-4120 Page No. 5456-5460

prove the performance of full-duplex relaying based cooperative NOMA systems.

References

[1] L. Dai, B. Wang, Y. Yuan, S. Han, C. l. I and Z. Wang, “Non-orthogonal multiple access for 5G: solutions, challenges, opportunities, and future research trends,” IEEE Commun. Mag., vol. 53, no. 9, pp. 74-81, Sep. 2015.

[2] M. Shirvanimoghaddam, M. Dohler, S. J. Johnson, "Massive non-orthogonal multiple access for cellular IoT: Potentials and limitations", *IEEE Commun. Mag.*, vol. 55, no. 9, pp. 55-61, 2017.

[3] Y. Saito, Y. Kishiyama, A. Benjebbour, T. Nakamura, A. Li, and K. Higuchi, “Non-orthogonal multiple access (NOMA) for cellular future radio access,” in Proc. of IEEE Vehicular Technology Conference (VTC Spring), June 2013.

[4] Z. Ding, M. Peng, and H. V. Poor, “Cooperative non-orthogonal multiple access in 5G systems,” IEEE Commun. Lett., vol. 19, no. 8, pp. 1462–1465, Aug. 2015.

[5] T. Riihonen, S. Werner, and R. Wichman, “Mitigation of loopback selfinterference in full-duplex MIMO relays,” IEEE Transactions on Signal Processing, vol. 59, no. 12, pp. 5983–5993, Dec. 2011.

[6] R. Sun, Y. Wang, X. Wang, and Y. Zhang, “Transceiver design for cooperative non-orthogonal multiple access systems with wireless energy transfer,” IET Communications, vol. 10, no. 15, pp. 1947–1955, Oct. 2016.

[7] B. Su, Q. Ni, and W. Yu, “Robust transmit beamforming for SWIPT enabled cooperative NOMA with channel uncertainties,” IEEE Transactions on Communications, vol. 67, no. 6, pp. 4381–4392, Jun. 2019.

[8] F. Tian and X. Chen, “Multiple-antenna techniques in non-orthogonal multiple access: A review,” Frontiers of Information Technology & Electronic Engineering, vol. 20, no. 12, pp. 1665–1697, Dec. 2019

[9] J. Liu, G. Wu, S. Xiao, X. Zhou, G. Y. Li, S. Guo, and S. Li, “Joint power allocation and user scheduling for Device-to-Device-Enabled heterogeneous networks with Non-Orthogonal multiple access,” IEEE Access, vol. 7, pp. 62 657–62 671, May 2019.

[10] W. Wu, X. Yin, P. Deng, T. Guo, and B. Wang, “Transceiver Design for Downlink SWIPT NOMA Systems with Cooperative Full-Duplex Relaying,” IEEE Access, vol. 7, pp. 33 464–33 472, Mar. 2019.

[11] Y. Alsaba, C. Y. Leow, and S. K. A. Rahim, “Full-duplex cooperative non-orthogonal multiple access with beamforming and energy harvesting,” IEEE Access, vol. 6, pp. 19 726–19 738, Apr. 2018.

[12] G. Li, H. Chen, J. Cai, "Joint user association and power allocation for hybrid half-duplex/full-duplex relaying in cellular networks", *IEEE Syst. J.*, vol. 13, no. 2, pp. 1145-1156, Jun. 2019.