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A Novel Cooperative Network Using Down-link Non-orthogonal Multiple Access Scheme

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Abstract— A novel downlink cooperative non-orthogonal multiple access (DC-NOMA) scheme is proposed in this paper to achieve higher performance in the spectral efficiency compared to the classical NOMA schemes. The communication system consists of one base station and two users (e.g., strong user and weak user). In down link phase, the base station transmits a superimposed signal to both users, and in the cooperative phase, the weak user sends its decoded message to the strong user. The main idea is how the weak user can help the strong user to improve the performance of both users. This occurs by enabling the weak user to perform a cooperative transmission with the strong user during the cooperative phase. The outage probability, outage throughput, and diversity order are derived and analyzed. Numerical results are provided to show that the spectral efficiency gain achieved through our proposed scheme is better than the conventional cooperative NOMA schemes.

1. INTRODUCTION

The increase in the demands of the expected new services and data traffic, such as cloud-based architectural applications and among such, is the main challenge for the 5G wireless network. Thus, there are challenging requirements to achieve these services, such as high massive connectivity, much higher data rates (100-1000 times faster than current 4G technology), and low latency. As a result, these requirements cannot be achieved by using OMA [1–3]. Non-orthogonal multiple access (NOMA) is proposed to address the drawbacks of OMA scheme. Serving multiple users at the same time, frequency, code and space domain, but with different power levels, at the expense of minimal inter-user interference (IUI) is the main concept of NOMA scheme [4, 5]. NOMA Scheme intends to share domains among users via superposition and consequently it requires to employ multiple user detection (MUD) strategy to separate interfered users sharing the same degree of freedom, as illustrated in Fig. 1 [6]. As result, interesting multiple access technique for the fifth generation (5G) network, can be obtained by NOMA scheme [7, 8]. Moreover, NOMA techniques are classified into two domains, i.e. the power and code domains. Power domain NOMA is more interesting technique regarding to its implementation in 4G techniques. In addition, Serving and supporting multiple users with some degree of freedom (DoF) can be satisfied by using power domain NOMA, in which it performs successive interference cancellation (SIC) at receivers with better channel condition. In practice, multiplexing technique is achieved by using superposition coding at the transmitter and SIC at the receiver [10], [11]. On the other hand, the code domain NOMA uses user-specific spreading sequence which are either non-orthogonal cross-correlated sequences of low correlation coefficient or sparse sequences. This scheme is further divided into different classes, such as low-density spreading-based OFDM (LDS-OFDM), low-density spreading CDMA (LDS-CDMA), and sparse code multiple access (SCMA) [12, 13]. Generally, there are three NOMA transmission scenarios viz. downlink NOMA transmission scenario, cooperative NOMA transmission scenario and uplink NOMA transmission scenario. In this paper, we take a consideration of the downlink NOMA transmission scenario as well as cooperative NOMA transmission scenario.

In [7], the authors proposed power domain user multiplexing technique at base-station (BS) based on the discrete Fourier transform (DFT)-spread OFDM or the orthogonal frequency division multiple access (OFDMA). In addition, they studied the successive interference cancellation (SIC)-based signal reception at receivers for robust multiple access. The overall system throughput proposed in [14] to show the superiority of NOMA over OMA schemes. These benefits include the following; higher spectral efficiency, fairness, and higher connection density. The performance

Figure 1: Comparison between NOMA and OMA in the power domain multiplexing [9].

of deployed users with NOMA scheme is investigated in [15]. In addition, for two users, they discussed the closed form expression of ergodic sum rate and outage probability. In contrast, the fairness's concept in downlink NOMA scheme with a known channel state information (CSI) feedback in-term of a power allocation was studied in [16]. In [17], the authors proposed a cooperative diversity technique that considers a suitable scheme to combat the multipath propagation fading in wireless channel. The space diversity between cooperating terminals will be exploited by cooperative diversity techniques to relaying signals from one terminal to another. In [18], they studied the cooperative relay to improve the physical layer security in the wireless medium. They exploited several advantages in cooperative relay such as provision of reduced access distance and distributed diversity. In [19], and [20], the authors proposed a cooperative relay, which is one of the important techniques to improve the link reliability coupled with an increase in the range of the communication system.

The authors in [21] proposed a cooperative NOMA (CNOMA) scheme which helps the weak user to increase its reception reliability by exploiting the prior information about the messages of other users obtained at the strong user. Particularly, in the NOMA scheme, the strong user acts as forward and decode (FD) relay to deliver the message to the weak user. In [22, 23], full-duplex relaying network, multiple-antenna relaying networks were studied which maybe considered as an extension of the (FD) relay in NOMA. In addition, the transmit antennas at the relay can increase the signal to-noise ratio (SNR), whereas the receive antennas at the mobile users adopt the Maximum Ratio Combining (MRC). As a result, it is noted that the spectral efficiency at the aforementioned NOMA schemes is reduced owing to the duplication in the transmission during the cooperative phase.

Recently, in [24, 25], non-orthogonal relay in CNOMA scheme was proposed to achieve higher spectral efficiency, however, this increment came at the expense of the signal reception reliability of the weak user. Noting that, in [26] the authors proposed a hybrid downlink-uplink CNOMA (HDU-CNOMA) scheme with an aim to improve the spectral efficiency. In this scheme, the strong user can simultaneously perform uplink transmission and cooperative transmission during the cooperative phase. Nevertheless, the signal reception reliability has been slightly decreased in [26] scheme.

In this paper, we propose a novel downlink cooperative NOMA (DC-NOMA) scheme and investigate its performance. The given scheme performs its work in two stages, i.e., (1) First, the base-station transmits superimposed signal to the deployed users in a given geographic area. (2) the weak user, in the second step, transmits its decoded signal to the strong user. By comparison to other similar schemes, our scheme allocates more power to the weak user. This in turns promises an improved SINR for the weak user and consequently an improved channel capacity. Moreover, we also achieve higher SINR for the strong user with improved channel capacity. This implies, our proposed scheme provides better system performance through improved SINR at both strong and weak user.

This paper is organized as follows: Section 1 discusses the introduction of the paper including the motivation and contribution. The main contribution and organization of the paper are also summarized. In Section 2, the system model is presented which includes the introduction of the proposed scheme, the analysis of system performance for the DC-NOMA scheme with exponential fading channel. This section also includes the derivation of the outage probability for the proposed scheme, the diversity order and the throughput based on the outage probabilities to evaluate the performance of our system. In Section 3, The numerical results of our work is provided to verify the analytical results and to illustrate the effectiveness of our proposed scheme. In connection to this, in this section, we also presented the performances of the throughput and the diversity order

by using the numerical results of the outage probability. In section 4, the summary and conclusion of the paper are discussed and the future research work and way-forward are given.

2. SYSTEM MODEL

A communication system model shown in Fig. 2 consists of a downlink transmission with one base station and two users.

Figure 2: The proposed DC-NOMA scheme with one BS and two users.

As shown in Fig. 2, downlink phase occurs from the base-station to the users and cooperative transmission takes place between the two users. The base station and the two users share a single antenna and work in half-duplex mode [27]. Hereafter, subscripts BS, UE₁, UE₂ denote to the base-station, user one, and user two respectively. Also, the time indexes t_1 and t_2 denote to the first time slot and second time slot respectively.

$h_{BS,UE1}$ and $h_{BS,UE2}$ are the coefficient of channels between the base station and users one and two, respectively, and $h_{UE1,UE2}$ is the channel coefficient between both users. For easy signal detection, the channel state information (CSI) is assumed to be available at the receiver while only statistical CSI is available at the transmitter [26]. The block of transmission denotes here to the time slot, where each block represents one time slot [28]. In addition, the channel is supposed to be a rayleigh fading channels h_δ in which the distribution is followed the circularly symmetric complex Gaussian distribution with zero-mean and variance β_δ distributions for the channel coefficient power are given by [26]

$$f_{|h_\delta|^2} = \frac{1}{\beta_\delta} \exp\left(-\frac{x}{\beta_\delta}\right), x \geq 0 \quad (1)$$

and

$$F_{|h_\delta|^2} = 1 - \exp\left(-\frac{x}{\beta_\delta}\right) \quad (2)$$

respectively, where $|h_\delta|^2$ is the channel gain of link δ . In addition, the strong user is the user that performs successive interference cancellation (SIC), where the classification of the strong users and weak users depends on the value of h_δ [29]. Therefore, the user that has larger h_δ is considered as the strong user and the user that has small h_δ is considered as the weak user. In contrast, the optimal SIC can't be achieved in our scheme because the transmitter has only statistical SCI [30]. Thus, we use the sup-optimal SIC in order to distinguish between the users. Without loss of generality, the strong user is the user that has a larger β_δ and the weak user is the one that has the smaller β_δ . In other words, when the condition $\beta_{BS,UE1} > \beta_{BS,UE2}$ is satisfied that mean that the strong user is

UE₁ and the weak user is UE₂. The sub-optimal SIC occurs when the condition $\beta_{BS,UE1} > \beta_{BS,UE2}$ is satisfied, but that is not guarantee to meet $|h_{BS,UE1}|^2 > |h_{BS,UE2}|^2$. However, Under statistical CSI, it is a simple and efficient technique [31]. In NOMA scheme, there are two criteria in terms of transmitting power and fairness which are used to formulated two optimization problems, subjected to outage probability and the optimal decoding order [32]. In our scheme, we follow a similar, yet different approach to the scheme in [26] to get improvement in the system performance. In other words, the user with the weak channel conditions(UE₂) acts as a relay to assist the strong user.

As shown in Fig. 2, our proposed scheme has two phases. The first phase is the downlink phase (i.e., first time slot) and the second phase is the cooperative phase (i.e., second time slot), both phases represent by time slots and have same time duration.

2.1. The Proposed DC-NOMA Scheme

2.1.1. First Phase: Downlink Phase

During the first time slot (i.e., downlink phase), the BS transmits a superimposed signal to UE₁ and UE₂ as follows:

$$x_{BS}^{t_1} = \sqrt{\alpha_{UE1}^{t_1} P_0} s_1 + \sqrt{\alpha_{UE2}^{t_1} P_0} s_2 \quad (3)$$

where P_0 is the transmit power from the source (BS), s_1 and s_2 are the data symbols for UE₁ and UE₂ respectively. The parameters $\alpha_{UE1}^{t_1}$ and $\alpha_{UE2}^{t_1}$ denote the power allocation factors for UE₁ and UE₂ respectively, and t_1 denote the first time slot. In our proposed scheme, we allocate more power to the weak user in order to achieve some measure of fairness, for that we should achieve the condition $\alpha_{UE1}^{t_1} \leq \alpha_{UE2}^{t_1}$ and $\alpha_{UE1}^{t_1} + \alpha_{UE2}^{t_1} = 1$. In the users side, UE₁ and UE₂ are ready to receive a superimposed signal from the BS. Thus, the received signals at both users are given as follows:

$$\begin{aligned} y_{UE1}^{t_1} &= h_{BS,UE1} x_{BS}^{t_1} + z_{UE1}^{t_1} \\ &= h_{BS,UE1} \left(\sqrt{\alpha_{UE1}^{t_1} P_0} s_1 + \sqrt{\alpha_{UE2}^{t_1} P_0} s_2 \right) + z_{UE1}^{t_1} \end{aligned} \quad (4)$$

and

$$\begin{aligned} y_{UE2}^{t_1} &= h_{BS,UE2} x_{BS}^{t_1} + z_{UE2}^{t_1} \\ &= h_{BS,UE2} \left(\sqrt{\alpha_{UE1}^{t_1} P_0} s_1 + \sqrt{\alpha_{UE2}^{t_1} P_0} s_2 \right) + z_{UE2}^{t_1} \end{aligned} \quad (5)$$

where $z_{UE1}^{t_1} \sim CN(0, \sigma^2)$ and $z_{UE2}^{t_1} \sim CN(0, \sigma^2)$ are the complex additive white Gaussian noise (AWGN) at UE₁ and UE₂ respectively. Note that noise power σ^2 is the same for both users.

In this paper, we follow a similar, yet different approach to the scheme in [26]. In the first phase, when UE₁ receives the superimposed signal, it will keep this signal in the memory without decoding and will wait for the next phase operations (i.e. cooperative phase operation). Meanwhile, UE₂ decodes its message by considering UE₁ message as noise. Thereby, the SINR for UE₂ to decode its own message is given by:

$$SINR_{UE2}^{t_1} = \frac{\rho |h_{BS,UE2}|^2 \alpha_{UE2}^{t_1}}{\rho |h_{BS,UE1}|^2 \alpha_{UE1}^{t_1} + 1} \quad (6)$$

where $\rho = \frac{P_0}{\sigma^2}$ is the transmit signal to noise ratio. Note that UE₁ and UE₂ transmit their signals at constant downlink rates (R_{UE1}^{DL}) and (R_{UE2}^{DL}) respectively. In order to decode s_2 message of UE₂, the achievable data rate must be at least equal the target data rate (R_{UE2}^{DL}). Therefore, the achievable data rate of UE₂ for the first phase is given by:

$$R_{UE2} \leq C_{UE2} = \frac{1}{2} \log_2 (1 + SINR_{UE2}^{t_1}) \quad (7)$$

2.1.2. Second Phase: Cooperative Phase

As mentioned previously, the decoding operation for UE₂ message occurred in the first time slot. Consequently, UE₂ will broadcast its decoded signal s_2 to UE₁. Therefore, the transmitted signal from UE₂ to UE₁ in the second time slot is given by:

$$x_{UE2}^{t_2} = \sqrt{\alpha_{UE1}^{t_2} P_0} s_2 \quad (8)$$

where $\alpha_{UE1}^{t_2}$ is the power allocation factor for UE1 at t_2 . As a result, the received signal at UE₁ is given by:

$$\begin{aligned} y_{UE1}^{t_2} &= h_{UE1,UE2} x_{UE2}^{t_2} + z_{UE1}^{t_2} \\ &= h_{UE1,UE2} \sqrt{\alpha_{UE1}^{t_2} P_0 s_2} + z_{UE1}^{t_2} \end{aligned} \quad (9)$$

We note that the BS usually is un-limited in power, whereas the users are power-limited. Thus, we can increase the power allocation coefficient factors to UE₂ to enhance its performance and thus increase the SINR for UE₂. Furthermore, we can improve the decoding of UE₂ message (s_2) at UE₁ due to the cooperation between the two users. Accordingly, we can increase the SINR of the strong user (UE₁) to achieve higher channel efficiency through cooperation with UE₂. Noting that, the power allocation factors can be controlled by either increasing or decreasing its value to improve the spectral efficiency in both users.

In our scheme, we note that UE₁ has two independent received signals for s_2 , one signal comes from the BS at the first time slot which is $y_{UE1}^{t_1}$ and the other signal comes from UE₂ at the cooperative phase which is $y_{UE1}^{t_2}$, each signal has different weight. Therefore, to apply the SIC at UE₁ with the two signals, UE₁ will use maximum ratio combining(MRC) to decode the s_2 message [33, 34]. Therefore, the SINR for UE₁ to decode UE₂ message with MRC is given by:

$$SINR_{UE1,UE2 \rightarrow MRC}^{t_1,t_2} = SINR_{UE1,UE2}^{t_1} + SINR_{UE1,UE2}^{t_2} \quad (10)$$

where $SINR_{UE1,UE2}^{t_1}$ is the SINR for UE₁ to decode the message of UE₂ at t_1 , which given by:

$$SINR_{UE1,UE2}^{t_1} = \frac{\rho |h_{BS,UE1}|^2 \alpha_{UE2}^{t_1}}{\rho |h_{BS,UE1}|^2 \alpha_{UE1}^{t_1} + 1} \quad (11)$$

and $SINR_{UE1,UE2}^{t_2}$ is the SINR for UE₁ to decode the UE₂ message at t_2 , which is given by :

$$SINR_{UE1,UE2}^{t_2} = \rho |h_{UE1,UE2}|^2 \alpha_{UE1}^{t_2} \quad (12)$$

The message s_2 cannot be decoded and cancelled at UE₁ except if the following condition is satisfied, which is given as:

$$\frac{1}{2} \log_2 \left(1 + SINR_{UE1,UE2 \rightarrow MRC}^{t_1,t_2} \right) \geq R_{UE2}^{DL} \quad (13)$$

where R_{UE2}^{DL} is the target data rate of downlink transmission of UE₂. In contrast, if the above condition in Equation (13) is not satisfied, then the SIC process will be failed. Meanwhile, if the SIC process fails, UE₁ cannot decode its message s_1 . Furthermore, with a successful SIC process, UE₁ can decode its message by subtract the message of UE₂ from its observation $y_{UE1}^{t_1}$, therefore, the SINR for UE₁ to decode its message s_1 is given by

$$SINR_{UE1}^{t_2} = \rho |h_{BS,UE1}|^2 \alpha_{UE1}^{t_1} \quad (14)$$

Then, the achievable rate at UE₁ is given by

$$C_{UE1} = \frac{1}{2} \log_2 \left(1 + SINR_{UE1}^{t_2} \right) \quad (15)$$

2.2. Performance Analysis

In this section, the outage performance, throughput, and diversity order of the proposed DC-NOMA scheme are investigated. These three metrics are used to characterize the spectral efficiency of our proposed scheme.

The outage probability (P_{out}) is the probability that the capacity of the channel (C) fails to satisfy its pre-defined threshold (R). Thus, the outage probability can be expressed mathematically as follows:

$$P_{out} = Pr(C < R) = Pr(\log_2(1 + SINR) < R) \quad (16)$$

where C is the channel capacity and R is the target data rate. For a given data rate, the outage probability becomes a crucial metric in the analysis process. For that, we analyze this outage for

each link in accordance with (QoS) requirements of each user. Furthermore, We can obtain the diversity order for each path to characterize the spectral efficiency in the proposed scheme. In addition, the system outage throughput is calculated to show the increase in spectral efficiency.

In the given scheme, the target data rates for the downlink transmission of UE₁ and UE₂ are adjusted according to the channels conditions of these users. For example, if the achievable data rates for UE₁ and UE₂ in our scheme are greater or equal the target data rates $R_{UE_1}^{DL}$ and $R_{UE_2}^{DL}$ respectively, then we successfully decode the signals for both users. Otherwise, the proposed scheme will fail to decode the signals of both users, and thus the outage of the system completely occurs.

2.2.1. Outage Probability

To measure the performance of our proposed scheme in the wireless communication system, we will derive the outage probability of downlink transmission for UE₁ and UE₂ in this sub-section. For notational convenience, we define $\gamma_{UE_1}^{DL} = 2R_{UE_1}^{DL} - 1$, and $\gamma_{UE_2}^{DL} = 2R_{UE_2}^{DL} - 1$ to be the corresponding SNR for each given data rate.

At the beginning of our analysis, We will derive the outage probability of UE₂. Outage occurs when UE₂ fails to decode its message (s_2). For that, the outage probability of downlink transmission for UE₂ is derived as follows:

$$P_{out}^{UE_2 DL} = Pr \left\{ \frac{1}{2} \log_2 (1 + SINR_{UE_2}^{t_1}) < R_{UE_2}^{DL} \right\} \quad (17)$$

After some manipulations, we substitute $R_{UE_2}^{DL} = \frac{1}{2} \log_2 (1 + \gamma_{UE_2}^{DL})$ into Equation (17) to obtain the following result:

$$P_{out}^{UE_2 DL} = \{ SINR_{UE_2}^{t_1} < \gamma_{UE_2}^{DL} \} \quad (18)$$

Substituting Equation (6) in Equation (18) as follows:

$$\begin{aligned} P_{out}^{UE_2, DL} &= Pr \left\{ \frac{\rho |h_{BS, UE_2}|^2 \alpha_{UE_2}^{t_1}}{\rho |h_{BS, UE_1}|^2 \alpha_{UE_1}^{t_1} + 1} < \gamma_{UE_2}^{DL} \right\} \\ &= Pr \left\{ |h_{BS, UE_2}|^2 < \frac{\gamma_{UE_2}^{DL}}{(\alpha_{UE_2}^{t_1} - \gamma_{UE_2}^{DL} \alpha_{UE_1}^{t_1}) \rho} \right\} \end{aligned} \quad (19)$$

Then, we use the CDF of channel coefficient h_{BS, UE_2} to express the outage probability for UE₂ in the following form:

$$P_{out}^{UE_2 DL} = 1 - \exp \left(\frac{-\gamma_{UE_2}^{DL}}{(\alpha_{UE_2}^{t_1} - \gamma_{UE_2}^{DL} \alpha_{UE_1}^{t_1}) \rho \beta_{BS, UE_2}} \right) \quad (20)$$

The result in Equation (20) is only satisfied when $\gamma_{UE_2}^{DL} < \frac{\alpha_{UE_2}^{t_1}}{\alpha_{UE_1}^{t_1}}$, otherwise, the outage probability is always one.

As for UE₁, the outage probability is given as:

$$\begin{aligned} P_{out}^{UE_1 DL} &= Pr \left\{ \frac{1}{2} \log_2 (1 + SINR_{UE_1, UE_2 \rightarrow MRC}^{t_1, t_2}) < R_{UE_1}^{DL} \right\} \\ &\quad + Pr \left\{ \frac{1}{2} \log_2 (1 + SINR_{UE_1, UE_2 \rightarrow MRC}^{t_1, t_2}) \geq R_{UE_1}^{DL}, \right. \\ &\quad \left. \frac{1}{2} \log_2 (1 + SINR_{UE_1}^{t_1}) < R_{UE_1}^{DL} \right\} \end{aligned} \quad (21)$$

We note that the outage for UE₁ occurs at two cases, (1) when UE₂ fails to decode MRC signal s'_2 , (2) when UE₁ fails to decode its message (s_1) even if UE₂ successes to decode its message. In addition, each event in the outage probability is independent of other events, so we can rewrite the

above equation in the following form:

$$\begin{aligned}
P_{out}^{UE_1 DL} &= Pr \left\{ \frac{1}{2} \log_2 \left(1 + SINR_{UE_1, UE_2 \rightarrow MRC}^{t_1, t_2} \right) < R_{UE_2}^{DL} \right\} \\
&\quad + Pr \left\{ \frac{1}{2} \log_2 \left(1 + SINR_{UE_1, UE_2 \rightarrow MRC}^{t_1, t_2} \right) \geq R_{UE_2}^{DL} \right\} \\
&\quad Pr \left\{ \frac{1}{2} \log_2 \left(1 + SINR_{UE_1}^{t_1} \right) < R_{UE_1}^{DL} \right\}
\end{aligned} \tag{22}$$

based on Equation (22), we can define Q_2 as follows:

$$Q_2 = Pr \left\{ \frac{1}{2} \log_2 \left(1 + SINR_{UE_1}^{t_1} \right) < R_{UE_1}^{DL} \right\} \tag{23}$$

To deriving Q_2 , we substitute $R_{UE_1}^{DL} = \frac{1}{2} \log_2 (1 + \gamma_{UE_1}^{DL})$, and Equation (14) in Equation (23) to obtain the following:

$$\begin{aligned}
Q_2 &= Pr \left\{ \rho |h_{BS, UE_1}|^2 \alpha_{UE_1}^{t_1} < \gamma_{UE_1}^{DL} \right\} \\
&= Pr \left\{ |h_{BS, UE_1}|^2 < \frac{\gamma_{UE_1}^{DL}}{\rho \alpha_{UE_1}^{t_1}} \right\}
\end{aligned} \tag{24}$$

Again, by applying the CDF of $|h_{BS, UE_1}|^2$ in the above equation, we can simplify Q_2 as:

$$Q_2 = 1 - \exp \left\{ \frac{-\gamma_{UE_1}^{DL}}{\rho \alpha_{UE_1}^{t_1} \beta_{BS, UE_1}} \right\} \tag{25}$$

According to Equation (22), we can also express Q_1 as follows:

$$Q_1 = Pr \left\{ \frac{1}{2} \left(1 + SINR_{UE_1, UE_2 \rightarrow MRC}^{t_1, t_2} \right) < R_{UE_2}^{DL} \right\} \tag{26}$$

To evaluate Q_1 , we first derive the distributions of $SINR_{UE_1, UE_2}^{t_1}$ and $SINR_{UE_1, UE_2}^{t_2}$ respectively. Again, we use a similar procedure that used in Q_2 to applying it in Q_1 . Thus, we can obtain the following result:

$$Q_1 = Pr \left\{ \left(\frac{\rho |h_{BS, UE_1}|^2 \alpha_{UE_2}^{t_1}}{\rho |h_{BS, UE_1}|^2 \alpha_{UE_1}^{t_1} + 1} + \rho |h_{UE_1, UE_2}|^2 \alpha_{UE_1}^{t_2} \right) < \gamma_2^{DL} \right\} \tag{27}$$

Now, we apply the double integration for Q_1 as follows:

$$Q_1 = \iint_A f_{SINR_{UE_1, UE_2}^{t_1}}(x) f_{SINR_{UE_1, UE_2}^{t_2}}(y) dy dx \tag{28}$$

where A correspond to the event $SINR_{UE_1, UE_2}^{t_1} + SINR_{UE_1, UE_2}^{t_2} < \gamma_{UE_2}^{DL}$. To find the PDF for $SINR_{UE_1, UE_2}^{t_1}$, we first give the CDF expression of $SINR_{UE_1, UE_2}^{t_1}$ as follows:

$$F_{SINR_{UE_1, UE_2}^{t_1}}(x) = Pr \left\{ SINR_{UE_1, UE_2}^{t_1} < x \right\} \tag{29}$$

where $0 < x < \frac{\alpha_{UE_2}^{t_1}}{\alpha_{UE_1}^{t_1}}$. Thus, the CDF and PDF of $SINR$ for UE_1 to decode the message of UE_2 at the first phase (t_1) are given by:

$$F_{SINR_{UE_1, UE_2}^{t_1}}(x) = F_{|h_{BS, UE_1}|^2} \left(\frac{x}{\rho (\alpha_{UE_2}^{t_1} - x \alpha_{UE_1}^{t_1})} \right) \tag{30}$$

$$f_{SINR_{UE_1, UE_2}^{t_1}}(x) = \frac{\alpha_{UE_2}^{t_1}}{\rho (\alpha_{UE_2}^{t_1} - x \alpha_{UE_1}^{t_1})^2} f_{|h_{BS, UE_1}|^2} \left(\frac{x}{\rho (\alpha_{UE_2}^{t_1} - x \alpha_{UE_1}^{t_1})} \right) \tag{31}$$

respectively. By following the same procedure, we can obtain the CDF and PDF of $SINR$ for UE_1 to decode the message of UE_2 at the second phase (t_2) for $0 < y < \gamma_{UE_2}^{DL}$ as follows:

$$F_{SINR_{UE_1,UE_2}^{t_2}}(y) = F_{|h_{UE_1,UE_2}|^2} \left(\frac{y}{\rho \alpha_{UE_1}^{t_2}} \right) \quad (32)$$

$$f_{SINR_{UE_1,UE_2}^{t_2}}(y) = \frac{1}{\rho \alpha_{UE_1}^{t_2}} f_{SINR_{UE_1,UE_2}^{t_2}} \left(\frac{y}{\rho \alpha_{UE_1}^{t_2}} \right) \quad (33)$$

respectively. Then, substituting equations(31),and (33) into Equation (28) to obtain the following:

$$\begin{aligned} Q_1 = & \int_0^{\phi_1} \int_0^{\gamma_{UE_2}^{DL}-x} \frac{1}{\rho \alpha_{UE_1}^{t_2}} \\ & f_{|h_{UE_1,UE_2}|^2} \left(\frac{y}{\rho \alpha_{UE_1}^{t_2}} \right) \frac{\alpha_{UE_2}^{t_1}}{\rho (\alpha_{UE_2}^{t_1} - x \alpha_{UE_1}^{t_1})^2} \\ & f_{|h_{BS,UE_1}|^2} \left(\frac{x}{\rho (\alpha_{UE_2}^{t_1} - x \alpha_{UE_1}^{t_1})} \right) dy dx \end{aligned} \quad (34)$$

where $\phi_1 = \min \left(\gamma_{UE_2}^{DL}, \frac{\alpha_{UE_2}^{t_1}}{\alpha_{UE_1}^{t_1}} \right)$. Since $|h_{BS,UE_1}|^2$ and $|h_{UE_1,UE_2}|^2$ are independent, we can further integrate each part separately. Lets define B as follows:

$$B = \int_0^{\gamma_{UE_2}^{DL}-x} \frac{1}{\rho \alpha_{UE_1}^{t_2}} f_{|h_{UE_1,UE_2}|^2} \left(\frac{y}{\rho \alpha_{UE_1}^{t_2}} \right) dy \quad (35)$$

Thus, we can integrate B to obtain the following result:

$$B = 1 - \exp \left(-\frac{\gamma_{UE_2}^{DL} - x}{\rho \alpha_{UE_1}^{t_2} \beta_{UE_1,UE_2}} \right) \quad (36)$$

So, by substituting Equation (36) into Equation (34), we can complete the integration of Q_1 as follows:

$$\begin{aligned} Q_1 = & \int_0^{\phi_1} \left(1 - \exp \left(\frac{x - \gamma_{UE_2}^{DL}}{\rho \beta_{UE_1,UE_2} \alpha_{UE_1}^{t_2}} \right) \right) \frac{\alpha_{UE_2}^{t_1}}{\rho \beta_{BS,UE_1} (\alpha_{UE_2}^{t_1} - x \alpha_{UE_1}^{t_1})^2} \\ & \cdot \exp \left(\frac{-x}{\rho \beta_{BS,UE_1} (\alpha_{UE_2}^{t_1} - x \alpha_{UE_1}^{t_1})} \right) dx \\ = & \int_0^{\phi_1} \frac{\alpha_{UE_2}^{t_1}}{\rho \beta_{BS,UE_1} (\alpha_{UE_2}^{t_1} - x \alpha_{UE_1}^{t_1})^2} \\ & \exp \left(\frac{-x}{\rho \beta_{BS,UE_1} (\alpha_{UE_2}^{t_1} - x \alpha_{UE_1}^{t_1})} \right) dx - \frac{\alpha_{UE_2}^{t_1}}{\rho \beta_{BS,UE_1}} \\ & \int_0^{\phi_1} \frac{1}{(\alpha_{UE_2}^{t_1} - x \alpha_{UE_1}^{t_1})^2} \\ & \exp \left(-\frac{\gamma_{UE_2}^{DL} - x}{\rho \beta_{UE_1,UE_2} \alpha_{UE_1}^{t_2}} - \frac{x}{\rho \beta_{BS,UE_1} (\alpha_{UE_2}^{t_1} - x \alpha_{UE_1}^{t_1})} \right) dx \end{aligned} \quad (37)$$

The above equation can be simplified as

$$Q_1 = F_{SINR_{UE_1,UE_2}^{t_1}}(\phi_1) - \frac{\alpha_{UE_2}^{t_1}}{\rho \beta_{BS,UE_1}} C \quad (38)$$

Where the first term in Equation (37) is the CDF of $SINR_{UE1,UE2}^{t_1}$, which given as :

$$F_{SINR_{UE1,UE2}^{t_1}}(\phi_1) = 1 - \exp\left(\frac{-\phi_1}{\rho\beta_{BS,UE1}(\alpha_{UE2}^{t_1} - \phi_1\alpha_{UE1}^{t_1})}\right) \quad (39)$$

Defining C in the second term of Equation (37) as follows:

$$C = \int_0^{\phi_1} \frac{1}{(\alpha_{UE2}^{t_1} - x\alpha_{UE1}^{t_1})^2} \exp\left(-\frac{\gamma_{UE2}^{DL} - x}{\rho\beta_{UE1,UE2}\alpha_{UE1}^{t_2}} - \frac{x}{\rho\beta_{BS,UE1}(\alpha_{UE2}^{t_1} - x\alpha_{UE1}^{t_1})}\right) dx \quad (40)$$

This integration is more complicated to derive it directly. So, to achieve the final result of $P_{out}^{UE1,DL}$, we apply the Gauss-Chebyshev integration [35] to obtain C via a closed-form approximation as follows:

$$C = \frac{\phi_1}{m} \sum_{i=1}^m \frac{\pi}{m} |\sin(w)| f(l_i) \quad (41)$$

where m is the number of Gauss-Chebyshev integral approximation terms [35], $w = \frac{2i-1}{2m}\pi$, $l_i = \frac{\phi_1}{2} + \frac{\phi_1}{2} \cos(w)$ and $f(x)$ is a function which is given by

$$f(x) = \frac{1}{(\alpha_{UE2}^{t_1} - x\alpha_{UE1}^{t_1})^2} \exp\left(-\frac{\gamma_{UE2}^{DL} - x}{\rho\beta_{UE1,UE2}\alpha_{UE1}^{t_2}} - \frac{x}{\rho\beta_{BS,UE1}(\alpha_{UE2}^{t_1} - x\alpha_{UE1}^{t_1})}\right) \quad (42)$$

Now, substituting Equations (39) and (41) into Equation (38) to obtain Q_1 as follows:

$$Q_1 = \left(1 - \exp\left(\frac{-\phi_1}{\rho\beta_{BS,UE1}(\alpha_{UE2}^{t_1} - \phi_1\alpha_{UE1}^{t_1})}\right)\right) - \frac{\alpha_{UE2}^{t_1}\phi_1}{2\rho\beta_{BS,UE1}} \sum_{i=1}^m \frac{\pi}{m} |\sin(w)| f(l_i) \quad (43)$$

Substituting Q_1 and Q_2 into Equation (22) to obtain $P_{out}^{UE1,DL}$ as follows:

$$\begin{aligned} P_{out}^{UE1,DL} &= 1 - \exp\left(\frac{-\phi_1}{\rho\beta_{BS,UE1}(\alpha_{UE2}^{t_1} - \phi_1\alpha_{UE1}^{t_1})}\right) - \frac{\alpha_{UE2}^{t_1}\phi_1}{2\rho\beta_{BS,UE1}} \sum_{i=1}^m \frac{\pi}{m} |\sin(w)| f(l_i) \\ &+ \left(\exp\left(\frac{-\phi_1}{\rho\beta_{BS,UE1}(\alpha_{UE2}^{t_1} - \phi_1\alpha_{UE1}^{t_1})}\right) + \frac{\alpha_{UE2}^{t_1}\phi_1}{2\rho\beta_{BS,UE1}} \sum_{i=1}^m \frac{\pi}{m} |\sin(w)| f(l_i)\right) \\ &\left(1 - \exp\left(\frac{-\gamma_{UE1}^{DL}}{\rho\alpha_{UE1}^{t_1}\beta_{BS,UE1}}\right)\right) \end{aligned} \quad (44)$$

which can be simplified as:

$$\begin{aligned} P_{out}^{UE1,DL} &= 1 - \exp\left(\frac{-\gamma_{UE1}^{DL}}{\rho\alpha_{UE1}^{t_1}\beta_{BS,UE1}}\right) \exp\left(\frac{-\phi_1}{\rho\beta_{BS,UE1}(\alpha_{UE2}^{t_1} - \phi_1\alpha_{UE1}^{t_1})}\right) \\ &- \exp\left(\frac{-\gamma_{UE1}^{DL}}{\rho\alpha_{UE1}^{t_1}\beta_{BS,UE1}}\right) \frac{\alpha_{UE2}^{t_1}\phi_1}{2\rho\beta_{BS,UE1}} \sum_{i=1}^m \frac{\pi}{m} |\sin(w)| f(l_i) \end{aligned} \quad (45)$$

The above result for $P_{out}^{UE1,DL}$ is only non-trivial if $(\alpha_{UE2}^{t_1} - \gamma_{UE1}^{DL}\alpha_{UE1}^{t_1}) > 0$, otherwise, $P_{out}^{UE1,DL}$ is always one.

2.2.2. Diversity Order

in this subsection, to gain a better understanding of the system outage efficiency, we examine the diversity order for each link. The diversity order can be defined as the slope of the bit error rate (BER), the capacity, or the outage probability as SNR gets higher. So that, we can measure the diversity order when the SNR is very large [36]. Therefore, the mathematical definition of diversity order is given by:

$$D = \lim_{\rho \rightarrow \infty} -\frac{\log P_{out}}{\log \rho} \quad (46)$$

The achievable diversity order in the DC-NOMA scheme can be obtained by both users. Although UE₁ gets signal from UE₂ (i.e., s'_2 message), and gets another signal from BS, we can't decide the diversity order value for UE₁ directly. At the high SNR regime, we can use this approximation (i.e., $e^{-x} \approx 1 - x$ where $x \rightarrow 0$) to obtain the outage probability and the diversity order [21].

To measure the diversity order for UE₂, we apply the above approximation to obtain the outage probability of UE₂ as follows:

$$P_{out}^{UE_2, DL} = \frac{\gamma_{UE_2}^{DL}}{(\alpha_{UE_2}^{t_1} - \gamma_{UE_2}^{DL} \alpha_{UE_1}^{t_1})} \frac{1}{\rho \beta_{BS, UE_2}} \quad (47)$$

Now, substituting this result in Equation (46) to obtain the diversity order for UE₂ as follows:

$$\begin{aligned} D_{out}^{UE_2, DL} &= \lim_{\rho \rightarrow \infty} -\frac{\log P_{out}^{UE_2, DL}}{\log \rho} \\ &= \lim_{\rho \rightarrow \infty} \frac{-\log \left(\frac{\gamma_{UE_2}^{DL}}{\rho \beta_{BS, UE_2} (\alpha_{UE_2}^{t_1} - \gamma_{UE_2}^{DL} \alpha_{UE_1}^{t_1})} \right)}{\log \rho} \end{aligned} \quad (48)$$

To simplify this equation, We can use L'Hospital's Rule (i.e., $\lim_{\rho \rightarrow \infty} \frac{f(x)}{g(x)} = \lim_{\rho \rightarrow \infty} \frac{f'(x)}{g'(x)}$). After some manipulation in this equation, the diversity order can be given as:

$$D_{out}^{UE_2, DL} = \lim_{\rho \rightarrow \infty} \frac{1/\rho}{1/\rho} = 1 \quad (49)$$

Therefore, the diversity order of UE₂ for the downlink transmission is one. This value is reasonable because we only have one path to transmit s_2 message from BS to UE₂.

Now, we find the diversity order of UE₁ for the downlink transmission by following a similar procedures of $D_{out}^{UE_2, DL}$. First, the outage probability for UE₁ at high SNR is given as:

$$\begin{aligned} P_{out}^{UE_1, DL} &= \frac{\phi_1}{\rho \beta_{BS, UE_1} (\alpha_{UE_2}^{t_1} - \phi_1 \alpha_{UE_1}^{t_1})} + \frac{\gamma_{UE_1}^{DL}}{\rho \alpha_{UE_1}^{t_1} \beta_{BS, UE_1}} \\ &\quad - \frac{\gamma_{UE_1}^{DL} \phi_1}{\rho^2 \alpha_{UE_1}^{t_1} \beta_{BS, UE_1}^2 (\alpha_{UE_2}^{t_1} - \phi_1 \alpha_{UE_1}^{t_1})} \end{aligned} \quad (50)$$

Substituting Equation (50) into Equation (46) to obtain the diversity order of UE₁ as follows:

$$D_{out}^{UE_1, DL} = \lim_{\rho \rightarrow \infty} -\frac{\log P_{out}^{UE_1, DL}}{\log \rho} \quad (51)$$

where $P_{out}^{UE_1, DL}$ is given in Equation (50). Again, by applying L'Hospital's Rule, and after some manipulations in Equation (51), we can obtain the final result of diversity order for UE₁ as follows:

$$\begin{aligned} D_{out}^{UE_1, DL} &= \frac{\frac{\phi_1}{\beta_{BS, UE_1} (\alpha_{UE_2}^{t_1} - \phi_1 \alpha_{UE_1}^{t_1})} + \frac{\gamma_{UE_1}^{DL}}{\alpha_{UE_1}^{t_1} \beta_{BS, UE_1}}}{\frac{\phi_1}{\beta_{BS, UE_1} (\alpha_{UE_2}^{t_1} - \phi_1 \alpha_{UE_1}^{t_1})} + \frac{\gamma_{UE_1}^{DL}}{\alpha_{UE_1}^{t_1} \beta_{BS, UE_1}}} = 1 \end{aligned} \quad (52)$$

We can note that the diversity order of UE_1 is also one because the transmission in cooperative phase occurs for s_2 only. In addition, the transmission for UE_1 message occurs only in a single path which is between BS and this user.

2.2.3. System Throughput

The rate of successful information delivery over a wireless communication channel is known as throughput [37, 38]. Thus, the throughput considers as an important measurement to evaluate the quality of data links. In general, to achieve a maximum rate of throughput, the SINR must be in the optimum level. Therefore, To study the throughput, there are several variables taking into account when we examine it, such as size of packet, transmission rate, received noise power spectral density, received signal power, and channel conditions [39].

In the proposed NOMA scheme, we note that both users transmit their signals at their corresponding data rate. In addition, UE_1 can achieve the throughput gain by decoding and cancelling UE_2 message before decoding its desired signal [40].

In our scheme, we analyze the throughput according to the outage probabilities and data rates for UE_1 and UE_2 . For that, the mathematical expression of system outage throughput of downlink transmission can be given as:

$$R = \left(1 - P_{out}^{UE_1, DL}\right) R_{UE_1}^{DL} + \left(1 - P_{out}^{UE_2, DL}\right) R_{UE_2}^{DL} \quad (53)$$

3. NUMERICAL RESULTS

Here, the performance of the proposed scheme is discussed by numerical results. The power allocation factors are used to give us flexible control in the amount of power for each user. In downlink NOMA, we compare between our proposed scheme and scheme in [26]. Without loss of generality, The major numerical parameters are listed in Table 1.

Table 1: Numerical parameters for DC-NOMA scheme.

Parameter	Value
channel coefficient variances β_{BS, UE_1}	1
channel coefficient variances β_{BS, UE_2}	0.05
channel coefficient variances β_{UE_1, UE_2}	0.8
Power allocation factor $\alpha_{UE_1}^{t_1}$	0.05
Power allocation factor $\alpha_{UE_2}^{t_1}$	0.95
Power allocation factor $\alpha_{UE_1}^{t_2}$	0.01
Target data rate $R_{UE_1}^{DL}$	0.5, 1, 1.5 bit/s/Hz
Target data rate $R_{UE_2}^{DL}$	0.5, 1, 1.5 bit/s/Hz
approximation parameter for Gauss-Chebyshev integration (m)	100

In our proposed scheme, the operating condition for the DC-NOMA system to determine the outage probabilities is $\alpha_{UE_2}^{t_1} - \alpha_{UE_1}^{t_1} \gamma_{UE_2}^{DL} > 0$. Otherwise, the outage probabilities are always one.

The outage probability versus the normalized average SNR of DC-NOMA system and HDU-CNOMA system is presented in Figs. 3 and 4 respectively. Noting that, for a fair comparison, we assume the same duration of time for the frame in the proposed scheme and HDU-CNOMA scheme. Therefore, When the target data rates $R_1 = R_2 = 1$ bit/s/Hz, we demonstrate the numerical results for our proposed scheme and HDU-CNOMA scheme in this figures. We can observe that the outage probability ($P_{out}^{UE_1, DL}$) in Fig. 3 for the proposed scheme outperforms the HDU-CNOMA scheme. Noting that, this improvement in the performance occurs due to not only the transmission of s_1 from BS to UE_1 , but also UE_1 get helps from UE_2 in the cooperative phase. For that, we confirm the importance of the cooperation between the two users to increase their SINR's and their spectral efficiency.

Figure 4 illustrates the outage probability for $P_{out}^{UE_2, DL}$ of our proposed scheme compared to that in the HDU-CNOMA scheme at $R_1 = R_2 = 1$ bit/s/Hz. Note that the improvement in the outage probability for our scheme over the HDU-CNOMA scheme results from the great power that allocated to UE_2 from BS in the downlink phase. In general, the performance of our proposed

Figure 3: Outage probability of $P_{out}^{UE1,DL}$ for the proposed DC-NOMA scheme and a conventional CNOMA scheme when $R_1 = R_2 = 1$ bit/s/Hz.

Figure 4: Outage probability of $P_{out}^{UE2,DL}$ for the proposed DC-NOMA scheme and a conventional CNOMA scheme when $R_1 = R_2 = 1$ bit/s/Hz.

Figure 5: Outage probability of $P_{out}^{UE1,DL}$ for the proposed DC-NOMA scheme and a conventional CNOMA scheme when $R_1 = R_2 = 0.5, 1$ bit/s/Hz.

Figure 6: Outage probability of $P_{out}^{UE2,DL}$ for the proposed DC-NOMA scheme and a conventional CNOMA scheme when $R_1 = R_2 = 0.5, 1$ bit/s/Hz.

scheme in-term of outage probability for both users is better than the that in HDU-CNOMA scheme.

To demonstrate the comparison between the outage probabilities at different data rates, Fig. 5 illustrates that for the outage probability of UE₁ when $R_1 = R_2 = 0.5$ bit/s/Hz and $R_1 = R_2 = 1$ bit/s/Hz. We can observe that the outage probability for our proposed scheme at $R_1 = R_2 = 0.5$ bit/s/Hz is better than the same outage probability at $R_1 = R_2 = 1$ bit/s/Hz. In other words, as the target data rate is low as the outage probability is better due to that the capacity of the channel for a user will increase as the target data rate is decrease. On the other hand, the outage probability for HDU-CNOMA scheme will be affected by changing the target data rate values, but the performance of our scheme is still better than the HDU-CNOMA scheme.

Figure 6 illustrates the comparison between the outage probabilities of UE₂ when we have different target data rate values. Noting that, the outage probability of UE₂ for our proposed scheme and HDU-CNOMA scheme changes as the target data rate changes. In addition, the performance of $P_{out}^{UE2,DL}$ at $R_1 = R_2 = 0.5$ bit/s/Hz is better than the permanence of that when $R_1 = R_2 = 1$ bit/s/Hz either in our proposed scheme or in HDU-CNOMA scheme. However, in both cases, the performance of our proposed scheme is still better than the HDL-CNOMA scheme.

The system outage throughput for our proposed scheme and HDU-CNOMA scheme is shown in Fig. 7. We can notice from this figure that the throughput for our proposed scheme is greater

Figure 7: System outage throughput (bits/s/Hz) for DC-NOMA scheme, and HDU-CNOMA scheme at $R_1 = R_2 = 1 \text{ bit/s/Hz}$.

Figure 8: System outage throughput (bits/s/Hz) for DC-NOMA scheme, and HDU-CNOMA scheme at $R_1 = R_2 = 0.5, 1 \text{ bit/s/Hz}$.

than the HDU-CNOMA scheme. In particular, the performance gains that are achieved by the proposed scheme results from several reasons. First, we can increase the power level for the two users from BS because the power in BS is un-constrained. Second, the cooperation between both users in the cooperative phase assists UE_1 to easily decode s'_2 , resulting in an increase in the SINR and an improvement in the total performance of the system.

In contrast, HDU-CNOMA has lower outage throughput due to that the HDU-CNOMA loss more power for the interference-free uplink transmission in the cooperative phase, besides, the loss in allocated power for the strong user while it attempts to help the weak user. It is noted that at high SNR, the outage throughput for the proposed scheme is almost to that in the HDU-CNOMA scheme because the outage probabilities for both schemes are almost the same at high SNR. In other words, the outage probabilities equations at high SNR for the proposed scheme is approximated to the outage probabilities equations for HDU-CNOMA scheme which lead to the same throughput in both systems.

Figure 8 illustrates the system outage throughput of our proposed scheme and HDU-CNOMA scheme at different values of target data rates (i.e., $R_1 = R_2 = 0.5, 1 \text{ bit/s/Hz}$). Moreover, when the target data rate values are small, the outage throughput is high. In contrast, when the target data rate values are large, the outage throughput is low. Although we have different values of target data rates, the performance of our scheme is still better than HDU-CNOMA scheme.

4. CONCLUSION AND FUTURE RESEARCH WORK

4.1. Conclusion

In this paper, we proposed DC-NOMA scheme to increase the spectral efficiency and throughput of cooperative NOMA scheme. We proposed a similar, yet different approach to the other cooperative NOMA scheme. Particularly, the weak user sent a copy of its message to the strong user in order to obtain perfect decoding for the weak user message at the strong user. The transmission occurred in two phases; the downlink phase which is the phase used to transmit the superimposed signal to both users, and the cooperative phase which used to implement the cooperation between the weak and strong users. To evaluate the proposed scheme's performance, we derived the corresponding outage probability, diversity order, and system outage throughput. The performance of the system was improved in the proposed scheme and this shown by using numerical results. The proposed scheme outperforms the HDU-CNOMA scheme in terms of spectral efficiency. The outage throughput was analyzed in order to study the (QoS) for the link and to evaluate the spectral efficiency. The numerical results for our proposed scheme in-term of the outage throughput demonstrated the better performance over the HDU-CNOMA scheme.

4.2. Future Research Work

The main future work for this paper is given as the following; when the weak user UE_2 transmits its signal to the strong user UE_1 , it can simultaneously transmit interference-free uplink superposed

signal to the BS during the cooperative phase.

Another idea which can be applied is the idea of a relay. In this future work, the relay can act between the BS and the two users to perform decode and forward operation for the signals during the transmission.

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