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Performance Analysis of Hybrid Relay Selection in Cooperative NOMA Systems

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ABSTRACT- Cooperative NOMA is a method to improve the system performance, this could be done by enabling a user to relay the signal to other users or a dedicated relay. Several dedicated hybrid relays are distributed to forward the source's signal to the destinations to further enhance the system and serve the users at the cell edge. However, operating several relays simultaneously reduces the spectral efficiency because they need orthogonal channels. Thus, hybrid relay selection is proposed and investigated as a cooperative technique to improve NOMA performance. The relay that provides the highest SNR channel is enabled to relay the signal while the other relays are disabled. BER, outage probability, and channel capacity are measured and investigated to assess the overall system performance. These indicators show that this relay selection is feasible, moreover, relay selection enhances the system reliability, flexibility, and data throughput.

Keywords: Cooperative NOMA, Hybrid Relay, and Relay Selection.

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1. INTRODUCTION

Nowadays, there is a dramatic increase in data demand, such growth results from the upsurge in the number of internet-connected devices, in addition, higher data tare per device like video-on-demand services [1]. Therefore, improving the spectral efficiency is one of the main objectives of several researchers by exploring the multiple access techniques [2]. Non-Orthogonal Multiple Access (NOMA) has shown promising features to meet this increasing data rate demand by allowing multiple users to share the same time-frequency resources [3]. That results in leverage of the power domain for user multiplexing and subsequently, enhanced spectral efficiency and user fairness [4]. To further improve the spectral efficiency and accommodate more users within a network cell, cooperative communication is suggested as another technique to improve the coverage, reliability, and capacity. It is using repeaters to assist in data retransmission. This technique assists in overcoming natural limitations such as channel fading and path loss [5]. However, integrating the cooperative technique with the NOMA would further improves the overall performance by merging the advantages of both techniques [6]. There are two main methods of cooperative NOMA. Firstly, since NOMA users are separated by the power level, the near user with lower power has to detect the other users' signal to then apply Successive Interference Cancellation (SIC). Thus, enabling this user to relay other users' signals instead of dropping them. Secondly, a dedicated relay method is proposed to improve poor channels. The wireless channel fading is very sensitive to the environment and it would change significantly in response to the line of propagation. Thus, the relay needs to be located at the right spot for better performance.

However, to improve the performance of cooperative NOMA and avoid any drop in the channels, multi-relay NOMA networks have been investigated. Too many relays increase the system complexity, in addition to reducing the channel efficiency because each relay needs a dedicated time slot [7]. Therefore, Relay Selection (RS) is an effective technique, which selects a relay to forward the signal, without complicating the system while maintaining the full diversity gain for the overall network. Several RS techniques have been proposed and investigated as follows. Two-stage max-min scheme for cooperative NOMA is presented and investigated in [8]. This technique predetermines the Power Allocation (PA) and Quality of Service (QoS) of relays and users. This involves two stages checking, firstly, identify which relays satisfy the users' QoS, and the second stage is applying the max-min scheme to choose a relay from the selected ones that can serve higher data rate to the users. The work in [9] presents a similar technique but with adaptive PA, this method outperformed the fixed PA as the price of higher overhead packages for the channel statement and the updated PA values.

In this paper, a cooperative NOMA network with two users and M hybrid relays is proposed. The RS of the optimum relay is based on the higher SNR of the total channel i.e. the source-relays and relays-destinations channels. Once a relay is selected; it relays the source's signal to the destination. At the two destinations, an assessment of the system performance is conducted such as Bit Error Rate (BER) channel capacity and outage probability.

In this paper, a new hybrid relaying protocol for cooperative NOMA systems is proposed that select between AF and DF relaying depending on the instantaneous channel state information. A new relay selection method that uses the maximum SNR to choose the relay is presented to improve the link quality and decrease the computational complexity. BER, outage probability and channel capacity are used for performance analysis to show considerable enhancement over traditional NOMA systems.

The efficiency of the protocol in actual networks is examined to demonstrate the protocol's versatility. Also, the effects of relay density and network topology on the performance of the system are evaluated and conclusions are drawn on the best location and configuration for the relays and the network.

The extensibility of the proposed protocol is also discussed and the protocol is shown to be easily extendible to larger networks and future wireless technologies, including 5G and beyond with the inclusion of signal processing and machine learning. By these contributions, knowledge of cooperative NOMA systems is enhanced, which offers a basis for the enhancement of better communication protocols in wireless networks.

2. RELATED WORKS

Table 1 provides the summary of related works in the areas of full-duplex relaying, multichip communications, and cooperative techniques like SWIPT. Every entry gives information about what the study was about, what has been offered in terms of contribution and what has been left out. From these works, one can conclude that although multiple aspects of these technologies have been studied in detail, there is a lack of research on combining the state-of-the-art techniques including NOMA with full-duplex relaying and multi-hop communications. The issues of concern identified in these studies call for more research to fill these gaps and improve the system's performance.

Table 1. Related Works Analysis

Reference	**Study Focus**	**Key Contributions**	**Limitations**
[10]	Full-Duplex Relaying	Analyzed OP and SE with PRS and FRS schemes; FRS showed dramatic improvement in SER	Does not apply near-field path-loss
[11]	Two-Way Half-Duplex Relaying	Studied with direct link; Provided tractable closed-form expression for Pcov in Poisson cellular networks	NOMA technique not used
[12]	Coverage Probability (Pcov)	Accurate approximation of Pcov using joint probability of SIR and SNR	Does not consider near-field path-loss
[13]	5G Massive MIMO Exposure	Studied statistical exposure in 5G massive MIMO networks	NOMA and multihop communications not included
[14]	FD with SWIPT in WSNs	Investigated FD combined with SWIPT	NOMA technique not applied
[15]	FD Relaying with SWIPT	Studied over nonidentical Rayleigh fading	Does not use NOMA or multihop communications
[16]	Multi-hop Communications	Proposed novel routing algorithm improving network lifespan, stability, and throughput	No combination with advanced techniques like NOMA or FD relaying
[17]	Multi-hop DF Systems	Derived closed-form expressions for ergodic capacities	Does not combine with NOMA or FD relaying
[18]	Nonlinear SWIPT Systems	Focused on minimizing total power consumption in downlink and uplink	Did not derive OP and system throughput

3. SYSTEM MODEL

In this work, we considered a downlink cooperative NOMA system. It has a source signal BS which has data that needs to be sent to two users, the BS modulates these data, allocates each modulated signal to a certain power level, and then transmits them. In terms of the relays, they are located between the BS and the users, they use a half-duplex hybrid relaying protocol. The users have different channel conditions, U1 has a poor channel and hence is located at a higher power level while U2 with strong channel, thus, its signal is transmitted with lower power to achieve users' fairness. Furthermore, in this system, there is no direct channel between the source and the destination. *Figure 1* demonstrates the proposed system model.

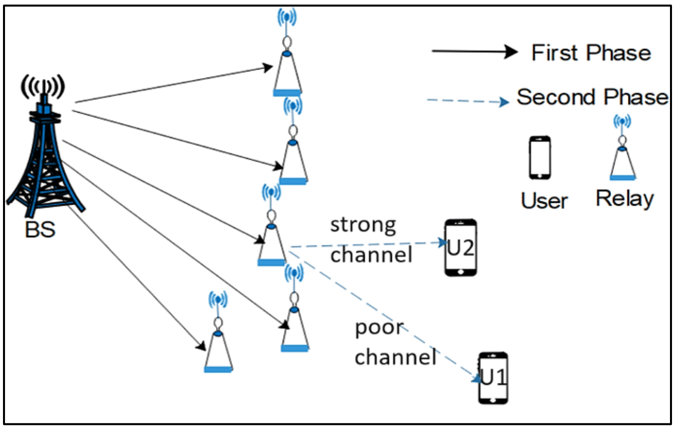

Figure 1. The system model of the proposed cooperative NOMA system

3.1 The Transmitter

The transmitter has the data that needs to be sent to both users, each one is modulated separately. These two signals are combined using superposition coding, and each has a different power allocation level. The resulting signal is described by *equation 1*.

$$X = \sqrt{P}\left(\sqrt{\alpha}\, x_1 + \sqrt{(\alpha - 1)}\, x_2\right) \tag{1}$$

Where X: the transmitted signal, P: is the total power, α: is the power allocation, and x1 and x2: are the users' modulated signals.

3.2 Channel Fading and Noise Interference

Channel fading (h), in wireless communication, weakens the signal's power. It is assumed to be suffering a slow fading which means that the channel's parameters do not change during the entire package transmission. This system simulates an outdoor network; thus, Rayleigh fading is used to simulate the transmission channel and face some blocks such as trees and buildings that cause scattering and multipath propagation. In addition, Additive White Gaussian Noise (AWGN) is added to the transmitted signal as a background noise. Therefore, the received signal is described in *equation 2* below.

$$Y = h\,X + w \tag{2}$$

Where Y: is the received signal, h: is the channel attenuation factor, and w: is the noise.

3.3 Hybrid Relays

Since the main objective of this research is to investigate the relay selection, thus, M relays are in different places between the source and destination in a way that the first one is closer to the source and the latest one is closer to the destination. Meanwhile, there are two main approaches of relaying a signal; Amplify and Forward (AF) relaying protocol, which amplifies the received signal and then forwards it [19], it is simple and consumes less power.

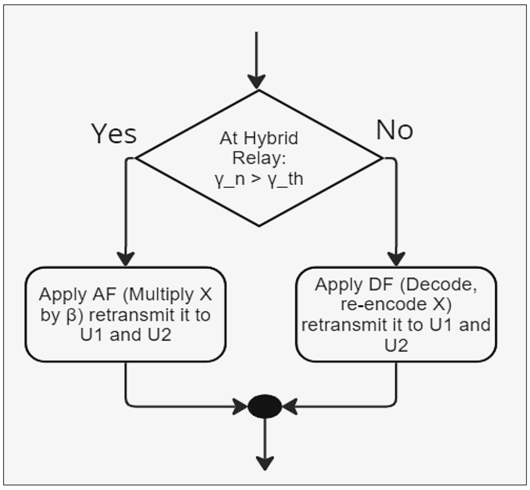

Figure 2. Hybrid Relay Criteria

Decode and Forward (DF), on the other hand, the relay needs the transmission parameters such as the number of users and power allocation. These data are essential to decode the received signal by applying SIC and re-encodes them before the retransmission [20]. Subsequently, higher processing and hence power and time are required.

Thus, a hybrid relaying scheme is used in this work to take the advantages of both two relaying techniques and hence better performance. It switches between AF and DF depending on the instantaneous channel conditions [21]. This offers a balance between performance and complexity. In terms of switching criteria, there are several methods are proposed as thresholds to select between AF and DF, for instance, Signal to Noise Ratio (SNR) and Cyclic Redundancy Check (CRC). In this study, the SNR threshold is used to decide for switching [22]. The relay uses AF when the SNR is lower than the threshold and then switches to DF when the SNR of the received signal exceeds the threshold. **Error! Reference source not found.** demonstrates the hybrid criteria.

3.4 The Receivers

Since there are two users, U_1 with poor channel condition is located to a higher power, thus U_1 decodes its signal considering all other layover signals as noise. On the other hand, U_2 with lower power allocation, needs to apply the SIC algorithm to extract its own received signal as illustrated in *Figure* 1.

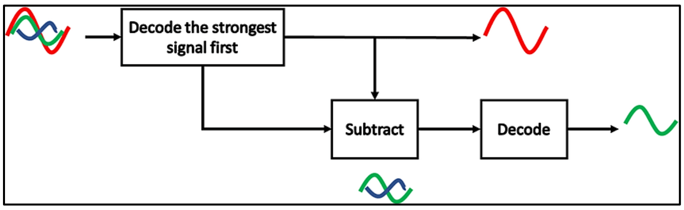

Figure 1. SIC algorithm at U2 [20], the red line for U1 signal, the green for U2 signal, and the blue line for the noise

4. RELAY SELECTION

The relay selection process is conducted at the beginning of each block transmission process by sending a preamble package to the relay nodes, these relays resend this package to the users in dedicated time slots [23]. The users at the destination then calculate the end-to-end SNR for every link individually. The channel fading gains between the source-relays and relays-destination for each subcarrier are denoted as h_{s,r_i} and $h_{r_i,d}$ respectively, where $i = 1,2, \dots, M$. Thus, the received signal at each relay at the first time slot can be denoted as in *equation 3*.

$$y_{sr_i} = \sqrt{P_s}\, h_{sr_i}\, x(n) + w_{r_i} \tag{3}$$

Where P_s is the transmission power, $x(n)$ the transmitted signal, and w_{r_i} the AWGN of the corresponding relay. At the second time slot, the signal is forwarded after it was amplified by the amplification factor that is calculated by *equation 4*.

$$\beta_i = \sqrt{\frac{P_{r_i}}{\left|h_{sr_i}\right|^2 P_s + \sigma_r^2}} \tag{4}$$

Where β_i is the amplification factor of the *i*th relay, P_{r_i} is the transmission power of the corresponding relay, and σ_r^2 is the variance of AWGN for the same relay. Subsequently, the received signal can be expressed as:

$$y_{r_i d} = \beta_i \, h_{r_i d} \, y_{sr_i} + w_d$$

$$y_{r_i d} = \beta_i \, h_{r_i d} \left(\sqrt{P_{sr_i}} \, h_{sr_i} \, x(n) + w_{r_i}\right) + w_d$$

Where w_d is the AWGN at the destination. The instantaneous SNR at the destination through the corresponding channels and relays can be calculated as follows.

$$\gamma_i = \frac{\left|\beta_i \sqrt{P_s} \, h_{sr_i} \, h_{r_i d}\right|^2}{\left|\beta_i \, h_{r_i d} \, w_{r_i} + w_d\right|^2}$$

$$\gamma_i = \frac{\frac{P_s \left|h_{sr_i}\right|^2}{\sigma_r^2} \frac{P_{r_i} \left|h_{r_i d}\right|^2}{\sigma_d^2}}{\frac{P_s \left|h_{sr_i}\right|^2}{\sigma_r^2} + \frac{P_{r_i} \left|h_{r_i d}\right|^2}{\sigma_d^2} + 1} \tag{5}$$

$$\gamma_i = \frac{\gamma_{sr_i} \gamma_{r_i d}}{\gamma_{sr_i} + \gamma_{r_i d} + 1} \tag{6}$$

Where γ_{sr_i} and $\gamma_{r_i d}$ are the instantaneous SNR for the source-relay phase and relay-destination phase respectively, these values can be calculated by the following mathematical by the following equation.

$$\gamma_{sr_i} = \frac{P_s \left| h_{sr_i} \right|^2}{\sigma_r^2} = \bar{\gamma} \left|h_{sr_i}\right|^2$$

$$\gamma_{r_i d} = \frac{P_{r_i} \left| h_{r_i d} \right|^2}{\sigma_d^2} = \bar{\gamma} \left| h_{r_i d} \right|^2$$

Where $\bar{\gamma}$ is the average SNR.

Once the assessment is completed, each user sends its feedback package through the safety channel informing the source of the values of the SNR of each channel. Since there are two receivers in this work, the selection protocol might depend on the priority of the users. For instance, if U1 has higher priority, it will consider its reading. However, in this research, the average SNR is considered in the selection criteria.

5. PERFORMANCE ANALYSIS

To evaluate the system performance, three parameters are measured and investigated in this study.

5.1 Bit Error Rate (BER)

BER is a key parameter for measuring the reliability of digital transmission systems. It computes the number of error bits at the receiver divided by the total number of sent bits during a specified time interval and lower BER means better system performance.

$$\text{BER} = \frac{\text{Number of error bits}}{\text{Total number of transmitted bits}} \tag{7}$$

5.2 Channel Capacity

Channel capacity is an important parameter that indicates the maximum rate of data that can be transmitted through this channel. Subsequently, assigning the higher capacity to the user that needs a higher data rate like video streaming. The capacity depends on SNR as well as the bandwidth and it is calculated by *equation 8*.

$$\text{channel capacity} = \text{B}\log_2(1 + \text{SNR}) \tag{8}$$

Where B is the channel bandwidth in Hz.

5.3 Outage Probability

The outage probability is another vital parameter that measures the possibility of system failure to deliver its data package because the signal quality falls below a threshold SNR level.

$$\mathit{outage\ probability} = Pr\left(\gamma_i < \gamma_{th_i}\right) \tag{9}$$

Where γ_{th_i} is the SNR threshold of the *i*th relay that is calculated by equation.

$$\gamma_{th_i} = 2^{2R} - 1 \tag{10}$$

Where R is the ratio of signal power to the noise and other interfering signals' power

$$P_{out_i} = Pr\left(\frac{\gamma_{sr_i} \gamma_{r_i d}}{\gamma_{sr_i} + \gamma_{r_i d} + 1} \le \gamma_{th_i}\right) \tag{11}$$

$$P_{out_i} = \int_0^\infty Pr\left(\frac{\gamma_{sr_i} \mathcal{Y}_i}{\gamma_{sr_i} + \mathcal{Y}_i + 1} \le \gamma_{th_i}\right) f_{\gamma_{r_i d}}(\mathcal{Y}_i) d\mathcal{Y}$$

$$\gamma_i = \frac{P\,|h|^2}{\sigma^2} = \bar{\gamma}\,|h|^2 \tag{12}$$

Where: P represents the transmitting power, h is the corresponding channel fading, σ is the average noise and $\bar{\gamma}$ is the average SNR.

By dividing the period of integration in equation 11 into two parts: from 0 to γ and from γ to ∞, we get

$$P_{out_i} = \int_0^\gamma Pr\left(\gamma_{sr_i} > \frac{\gamma_i \mathcal{Y}_i + \gamma_i}{\mathcal{Y}_i - 1}\right) f_{\gamma_{r_i d}}(\mathcal{Y}_i) d\mathcal{Y} + \int_\gamma^\infty Pr\left(\gamma_{sr_i} \le \frac{\gamma_i \mathcal{Y}_i + \gamma_i}{\mathcal{Y}_i - 1}\right) f_{\gamma_{r_i d}}(\mathcal{Y}_i) d\mathcal{Y}$$

the value of $Pr\left(\gamma_{sr_i} > \frac{\gamma_i \mathcal{Y}_i + \gamma_i}{\mathcal{Y}_i - 1}\right) = 1$ and $Pr\left(\gamma_{sr_i} \le \frac{\gamma_i \mathcal{Y}_i + \gamma_i}{\mathcal{Y}_i - 1}\right) = 1 - e^{-\frac{\gamma_i \mathcal{Y}_i + \gamma_i}{\gamma_{sr_i} (\mathcal{Y}_i - 1)}}$

By substituting these values in *equation 11* and *equation 12*, and letting $z = \mathcal{Y} - \gamma$ to calculate the Cumulative Distribution Function (CDF) to determine the probability that the noise amplitude will exceed a certain threshold.

$$F_\gamma(\gamma_i) = 1 - \frac{1}{\gamma_{r_id}} \int_0^\infty e^{\frac{\gamma_i(z+\gamma_i+1)}{\overline{\gamma}_{sr_i}z}} e^{-\frac{1}{\overline{\gamma}_{r_id}}(z+\gamma_i)} dz \qquad (13)$$

By simplifying and solving the above equation we get:

$$F_\gamma(\gamma_i) = 1 - e^{-\gamma_i\left(\frac{1}{\overline{\gamma}_{sr_i}}+\frac{1}{\overline{\gamma}_{r_id}}\right)} \qquad (14)$$

Since $\frac{1}{\overline{\gamma}_i} = \frac{1}{\gamma_{sr_i}} + \frac{1}{\gamma_{r_id}}$ *equation 15* becomes

$$F_\gamma(\gamma_i) = 1 - e^{-\frac{\gamma_i}{\overline{\gamma}_i}} \qquad (15)$$

The first derivative of CDF gives the Probability Density Function (PDF) [10]. Thus, the approximation of the first derivative of *equation 15* is:

$$f_\gamma(\gamma_i) = \frac{1}{\overline{\gamma}_i} e^{-\frac{\gamma_i}{\overline{\gamma}_i}} \qquad (16)$$

6. RESULTS AND DISCUSSION

This section demonstrates the results of the work simulation as well as discusses these results. As mentioned above, three parameters are used to measure the system performance. Firstly, BER performance is demonstrated in
Figure **2**.

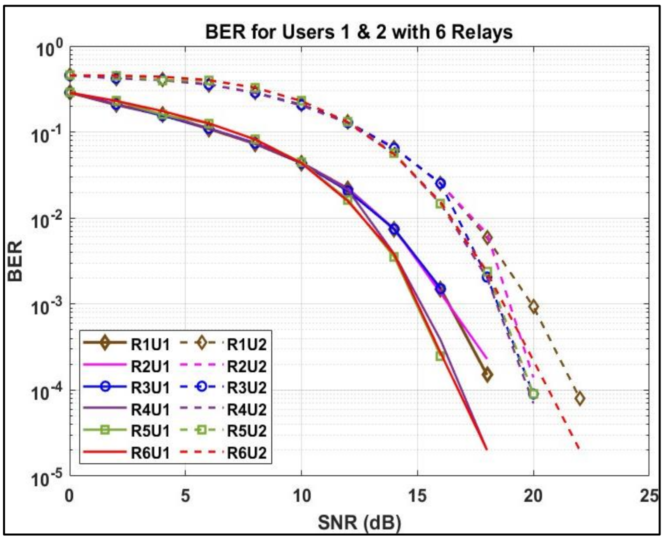

Figure 2. BER performance of 2 users with 6 hybrid relays

It shows that the BER generally has a better performance when the relays become closer to the users and farther from the source especially at the regain when SNR is large. Moreover, this trend is more distinct for the first user. However, for user1, the 5th and 6th relays have identical performance, while the fifth relay shows better results for user2. Thus 5th relay outperforms in terms of total BER.

That means a hybrid relay achieves lower BER when it is located closer to the destination rather than the source. However, too close to the receiver cause could ruin the achieved rate.

Error! Reference source not found. demonstrates the outage probability performance of both users with 6 relays.

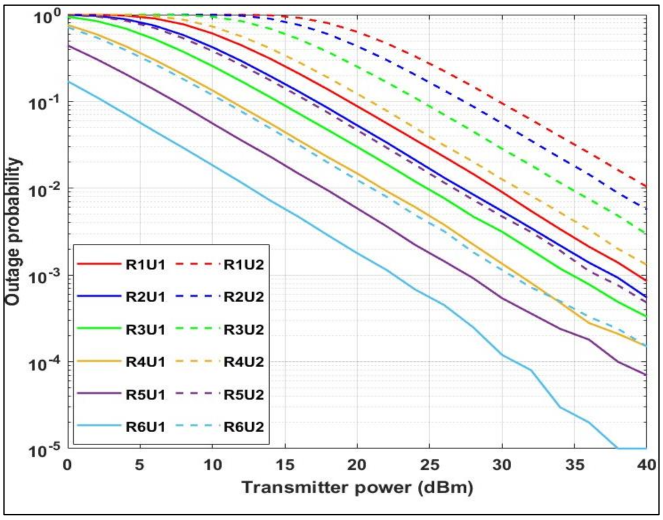

Figure 5. outage probability of 2 users with 6 relays

The outage probability indicates the chance that a certain channel is no longer functional. The curves show that the closer relay from the users has a lower chance of outage while the farther relays of the destination i.e. first and second relays have a higher probability and they become unfunctional when the transmission power drops. However, these curves state the channels between the relay and the users despite the BER which measures the total channel performance.

Regarding the channel capacity which is another indicator of the system. illustrates the channel capacity of all the channels which are; relay-U1, relay-U2, and U2-U1.

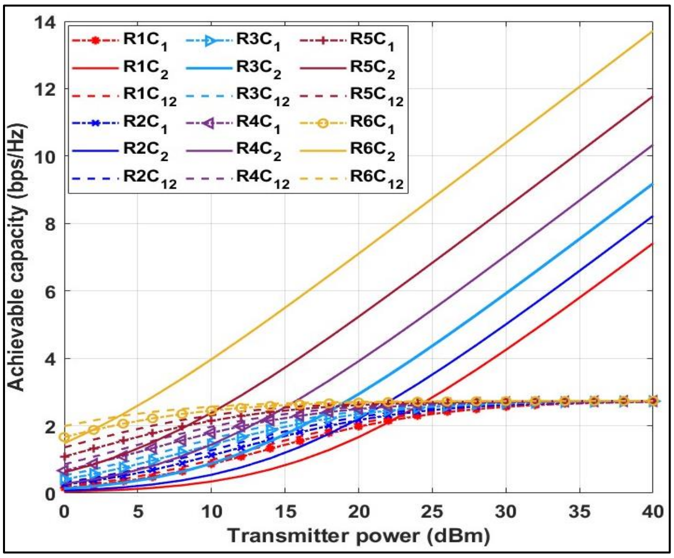

Figure 6. channel capacity of both users with 6 relays

Like the outage probability, channel capacity curves show that the 6th relay has better results. These curves illustrate the channel's maximum data rate per hertz. For instance, $R6C_1$

shows the capacity of the link between the 6th relay and user1 while C_2 for the user2, and C_{12} refers to the channel capacity between both users in case further cooperation between these two users is needed. The relay-user2 channel shows a growing curve as the transmission power increases which means this channel can deliver a higher data rate, in other words, it is feasible with a more density modulation method such as 8 QAM or higher. That is because user 2 uses SIC and hence cancels any other signals and cleans its data from any noise resulting from the channel interference.

6.1. Although the system model and analysis are based on existing theories, the new features and enhancements of this paper are the application of the hybrid relaying protocol in the context of cooperative NOMA systems. Unlike previous works, this study describes a new mode-switching

Tween AF and DF relaying, which adapts to the actual channel conditions in real time. This approach not only improves the system performance but also solves the problems of relay selection and network adaptation in the environment with changes.

In addition, the developed relay selection algorithm that focuses on relaying nodes with the highest Signal to Noise Ratio (SNR) is another new addition that cuts down on computational intensity and boosts the general performance of the network. From the extensive simulation and analysis presented in this paper, it is evident that the proposed hybrid relaying protocol provides a substantial enhancement over the existing hybrid relaying protocols and hence proving its importance in the development of cooperative NOMA systems.

7. CONCLUSION

To conclude this study, the results show that the location of the relay has a huge impact on the system's overall performance. Since the wireless channel characteristics are changing dramatically in response to the surrounding environment, in addition to the fact that the mobility of the users. Thus, this study demonstrates that an array of relays is a feasible application to enhance the system's reliability as well as data throughput.

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