BER performance in NOMA downlink transmission using AWGN, Rayleigh, and Rician fading channels

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ABSTRACT

5G wireless technology is accessible to a much larger user base compared to previous cellular networks. Users can connect to base stations (BSs) in a variety of methods, including of frequency division multiplexing (FDM), orthogonal frequency division multiplexing (OFDM), orthogonal multiple access (OMA), and non-orthogonal multiple access (NOMA). NOMA is considered to be the best one for 5G. Additionally, NOMA employs radio resource optimization and interference control techniques to enhance spectrum network efficiency and support extremely large connections, such as successive interference cancellation (SIC). Users can be divided into two categories: strong and weak. While weak users may experience a low data rate, strong users need a high one. In this paper, we examine the two users in relation to transmit power, the indicative bit error rate (BER), outage probability (OP), and rate attainable capacity using additive white gaussian noise (AWGN) channel. Moreover, we compare the BER and signal-to-noise ratio (SNR) per bit for two users, showing that the Rician fading channel performs better than the Rayleigh fading channel. The use of NOMA technology is the optimal choice and indicates an improvement in the precision of data transmission within the communication system, particularly in the presence of noise and interference.

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1. INTRODUCTION

The demand for cellular technology and IoT applications in 5G wireless communication systems has posed challenges related to network efficiency, connectivity, latency, and spectral efficiency (SE) [1]. Conventional orthogonal multiple access (OMA) techniques have limitations in accommodating a growing number of users and suffer from reduced SE due to bandwidth allocation. To address these challenges, researchers have explored alternative methods like beamforming, millimeter wave technology, and non-orthogonal multiple access (NOMA). NOMA enables simultaneous access to the communication medium, promoting spectrum sharing without interference. NOMA offers advantages such as higher SE, increased connectivity, lower latency, fairness, and robustness compared to OMA. While NOMA has drawn interest from the scientific community, it presents challenges like higher expenses due to intricate receivers and potential issues with power level assignment, interference, resource distribution, user pairing [2], and handling varying quality of service (QoS) needs. Proper handling of NOMA's complexity is crucial to avoid performance problems. Overall, NOMA is considered a feasible solution with the potential to enhance SE in 5G wireless networks [3]-[5]. Due to NOMA advantages such capability of the receiver to employ the interference control technique namely successive interference cancellation (SIC), superposition coding (SC) to decode the output signals and cancel the interference between users [6]. In this paper, we present an evaluation of bit error rate (BER) performance in NOMA downlink transmission for two users. We also provide a basic NOMA system architecture additive white gaussian noise (AWGN) and compare BER for near and far users, and we provide the NOMA performance analysis in the Rayleigh and Rician fading channels [7], for achievable capacity, BER and outage probability (OP) in technical terms, a fading channel is a wireless communication channel that is characterized by variations in signal force and quality over time and space. These variations are caused by factors such as multipath propagation like reflection, diffraction and scattering, interference, and obstacles in the propagation environment [8]. The AWGN fading channel represents an idealized scenario where the received signal is corrupted only by AWGN. This channel assumes no fading or multipath propagation, making it a baseline for performance evaluation and comparison. In the AWGN channel, the received signal experiences random fluctuations due to noise, and the performance of communication systems is primarily determined by the signal-to-noise ratio (SNR). Fading channels can be categorized into different types, including Rayleigh fading channel which is widely used to model wireless communication scenarios where there is no dominant line-of-sight (LOS) component [9]. In Rayleigh fading, the received signal experiences random variations in amplitude and phase due to the constructive and destructive interference of multipath components [10]. The Rician fading model assumes a Rician distribution, where the received signal consists of a dominant component and a random multipath component [11], [12]. The ever-growing demand for wireless communication systems has necessitated a deep understanding of the challenges posed by fading channels [13]-[15]. It poses several challenges that can significantly impact wireless communication systems. These channels cause signal attenuation, leading to a decrease in received signal strength, resulting in reduced coverage, increased path loss, and degraded signal quality, ultimately affecting the overall system performance. Multipath propagation in fading channels introduces interference, causing signal fading and time dispersion, leading to errors and degradation in communication quality [16], [17]. Furthermore, fading channels impose limitations on the achievable channel capacity, as variations in signal strength and quality introduce uncertainties and impairments, reducing the available capacity for reliable data transmission [18].

The remaining of this paper is organized as below. A study proposal pertaining to the notion of downlink-NOMA (DL-NOMA) and its possible attributes is introduced in section 2, as well as its system architecture. In section 3, we present results and discussion. In this part, we focus on achieving a higher sum rate [19]. Also, lower OP and BER in NOMA downlink transmission through appropriate power allocation (PA) [20], [21]. The simulation considers a NOMA network with two users communicating over AWGN, Rayleigh, and Rician fading channels. Finally, section 4 serves as a conclusion to this work.

2. PROPOSED WORK

In this section, we present an overview of downlink-NOMA (DL-NOMA) and its distinctive features [22]. Focusing on a two-user scenario. SC transmission is used to send signals between the base station (BS) and users 1 and 2, with each user having dedicated broadcast and receive antennas. Figure 1 illustrates the BS transmitting with designated power for each user. To simulate fading effects, various channel models are utilized to account for issues such as multipath propagation. Initially, we focus on analyzing the NOMA system model, signal model, and conducting simulations to evaluate capacity, OP [23], and BER in the downlink transmission between near and far users and the BS [24], [25].

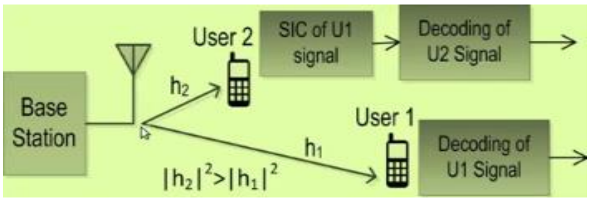

Figure 1. Two-user downlink NOMA system’s model

For both users U_1 and U_2, the channels connecting both users to the BS, respectively, should be represented by the channel coefficients h_1 and h_2 [26]. The NOMA signal transmitted by the BS using SC is given by (1):

$$x = \sqrt{p}(\sqrt{\alpha_1}x_1 + \sqrt{\alpha_2}x_2) \quad (1)$$

where p is the transmit power. Following transmission through channel represented by h_1, the version of x received by U_2 is as (2a):

$$y_1 = h_1 x + w_1 \quad (2a)$$

Comparably, the copy of x that traveled over channel h_2 and was received by U_1 is:

$$y_2 = h_2 x + w_2 \quad (2b)$$

Extending the signal that was received at U_1.

$$\begin{aligned} y_1 &= h_1 x + w_1 \\ &= h_1\sqrt{p}(\sqrt{\alpha_1}x_1 + \sqrt{\alpha_2}x_2) + w_1 \\ &= h_1\sqrt{p}\sqrt{\alpha_1}x_1 + h_2\sqrt{p}\sqrt{\alpha_2}x_2 + w_1 \end{aligned} \quad (3)$$

The term that contains the x_2 component would be considered as interference. Direct decoding of y_1 would produce x_1. The SNR for U_1 is, as $\alpha_1 > \alpha_2$, expressed by (4):

$$\gamma_1 = \frac{|h_1|^2 p\alpha_1}{|h_1|^2 p\alpha_2 + \sigma^2} \quad (4)$$

and its data rate of achievement is given by (5):

$$R_1 = \log_2(1+\gamma_1) = \log_2\left(1 + \frac{|h_1|^2 p\alpha_1}{|h_1|^2 P\alpha_2 + \sigma^2}\right) \quad (5)$$

The same thing: extending the signal that was received at U_2.

$$\begin{aligned} y_2 &= h_2 x + w_2 \\ &= h_2\sqrt{p}(\sqrt{\alpha_1}x_1 + \sqrt{\alpha_2}x_2) + w_2 \\ &= h_2\sqrt{p}\sqrt{\alpha_1}x_1 + h_2\sqrt{p}\sqrt{\alpha_2}x_2 + w_2 \end{aligned} \quad (6)$$

Before U_2 can decode his own signal, he must first conduct SIC. Before the application of SIC, U_2 deciphers the signal from U_1. The SNR measurements is provided by (7):

$$\gamma_{1,2} = \frac{|h_2|^2 P\alpha_1}{|h_2|^2 P\alpha_2 + \sigma^2} \quad (7)$$

Consequently, the attainable data rate is given by (8):

$$R_{1,2} = \log_2(1+\gamma_{1,2}) = \log_2\left(1 + \frac{|h_2|^2 p\alpha_1}{|h_2|^2 P\alpha_2 + \sigma^2}\right) \quad (8)$$

when U_1 uses SIC to cancel its signal, to decode its signal, U_2 takes advantage of the SNR, given by (9):

$$\gamma_2 = \frac{|h_2|^2 P\alpha_2}{\sigma^2} \quad (9)$$

Accordingly, the achievable data rate is expressed by (10):

$$R_2 = \log_2(1+\gamma_2) = \log_2\left(1 + \frac{|h_2|^2 p\alpha_2}{\sigma^2}\right) \quad (10)$$

2.1. Non-orthogonal multiple access system architecture

Power domain multiplexing is used by NOMA to share time and frequency resources. To accomplish this, SIC at the receiver and SC at the transmitter are used. By dividing the total number of bits received in error by the total number of bits transmitted, BER of the digital link is defined as the BER to total bits received. The BER performance of NOMA will be shown on an AWGN channel [27]. The general design of the fundamental NOMA system is seen in Figure 2.

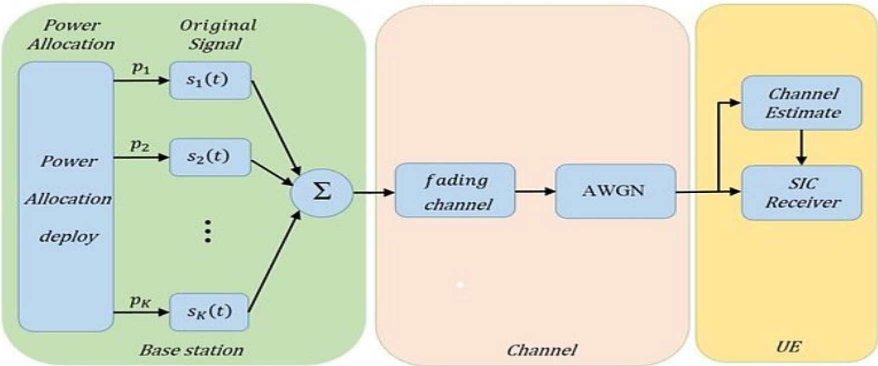

Figure 2. NOMA system architecture

3. RESULTS AND DISCUSSION

This study's NOMA simulator used MATLAB simulations version R2021a. We describe the methodology adopted in this paper. Maximizing the overall data flow while reducing the possibility of errors and communication breakdowns is the main objective of researching the BER Performance in NOMA downlink transmission. Using appropriate PA strategies helps achieve this Two users interact via several channels, such as AWGN, Rayleigh fading, and Rician fading, in a simulated NOMA network [11].

3.1. NOMA's performance evaluation in AWGN

As seen in Figure 3, where U_2 is located closer to the BS than the other U_1, NOMA operates better. Assume for the moment that users are equally spaced apart. We consider that an AWGN channel has been used with binary phase shift keying (BPSK) modulation for both users [28].

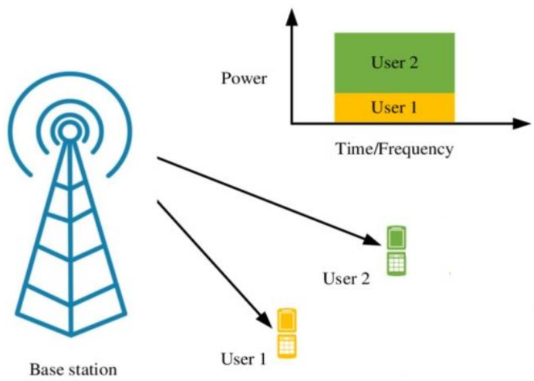

Figure 3. Downlink NOMA system with two users

It uses the same frequency carrier in NOMA to transmit signals simultaneously to both users 1 and 2. We note that α_1=0.6 is power weight given to user 1 and α_2=0.4 is power weight given to user 2 ($\alpha_1+\alpha_2=1$). In NOMA, user 1 (far user) is granted greater power and user 2 (near user) has less power to improve user fairness. In other words, $\alpha_1>\alpha_2$. We shall observe that NOMA functions even with this supposition.

We can see the progression of the BER for two users (near/far) in Figure 4, with user 2 (U2) experiencing a slightly higher BER than user 1 (U1), particularly in the low SNR region. This is because U2 needs to perform SIC, requiring accurate estimation of both its own and U1's data. Any errors in this estimation process impact U2's BER, resulting in a higher BER compared to U1 [29]-[31].

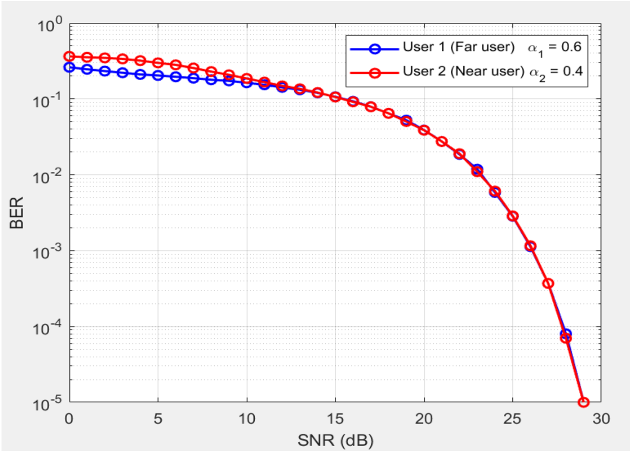

Figure 4. BER graph for NOMA in AWGN channel for two users

3.2. NOMA's performance evaluation in the Rayleigh fading channel

Rayleigh fading is one such model. When multiple indirect paths, such as LOS links, connect the transmitter and receiver, but no dominant path is easily identifiable, the application of the Rayleigh fading model is feasible, where each multipath element undergoes small-scale fading phenomena such as shadowing, diffraction, scattering, and reflection. In this case study, an extreme type of Rayleigh fading known as multipath transmission results in a distinct attenuation and phase shift for every transmitted bit. To put it another way, the channel varies with every single bit.

3.2.1. Performance to model capacity

In this section, we present the study's approach where U_1 decode U_2's transmission but faces interference due to U_2's signal impact and successive interference. To address this, a wireless receiver employing SIC is proposed [26]. Figure 5 illustrates the rate difference based on PA and distance between U_1 and U_2. By computing the SNR and considering distinct user goals, increasing transmission power to bring U_1 closer can enhance the capacity for U_2, resulting in increased overall capacity between the users [32].

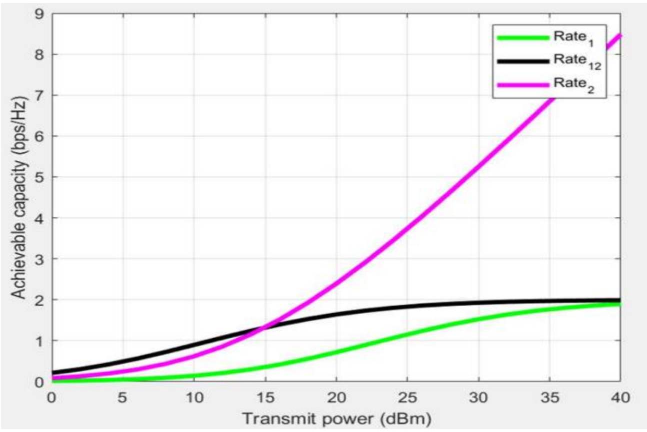

Figure 5. Transmit power influence on indicative achievable capacity rate between two users

3.2.2. Performance to model outage probability

The OP in a communication system varies for near and far users. A lower OP for near users indicates a higher chance of maintaining a successful connection, while a higher OP for far users implies a higher likelihood of successful communication. Figure 6 shows our investigation on increasing energy results in reduced OP for both user categories, particularly for U_2, demonstrating lower outage likelihood. This suggests that being closer to the BS reduces the probability of experiencing an outage [32]-[34].

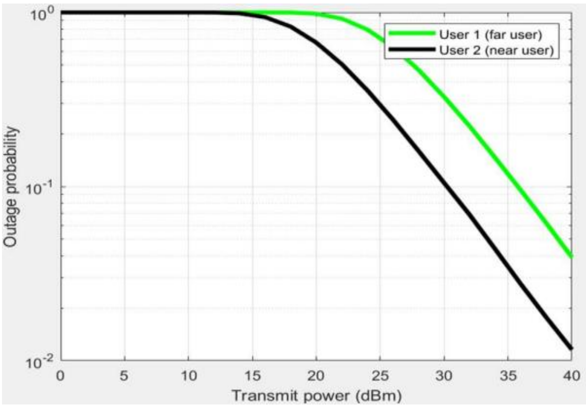

Figure 6. Indicative analysis of OP in relation to transmit power for two users

The analysis of OP in relation to transmit power for both users lead to an insightful discussion about the trade-offs and implications for wireless communication systems. For near users, increasing the transmit power generally results in a lower OP, indicating a higher probability of maintaining a successful connection. This is due to the stronger received signal power and improved SNR at shorter distances. However, for far users, the impact of transmit power on OP is more nuanced. While increasing the transmit power can enhance the received signal power, the attenuation and path loss over longer distances limit the achievable SNR. Therefore, the reduction in OP for far users may be less significant compared to near users.

3.2.3. Performance to model bit error rate

Increasing transmission power generally leads to a lower BER for near users due to stronger received signal power and higher SNR. This enables more reliable decoding of transmitted information and reduces the probability of bit errors. However, for far users, the impact of increasing transmission power on BER improvement is limited due to weaker received signal power caused by distance attenuation and path loss. While increasing transmission power can still help improve BER for far users, the challenging signal propagation conditions restrict its effectiveness. Figure 7 illustrates the BER between U_1 and U_2, showing that increasing transmission power results in a decreased BER for U_2, leading to better relative user performance compared to U_1 [32]-[34].

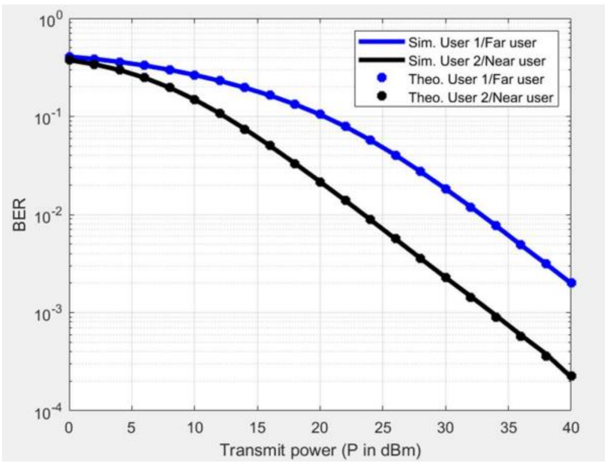

Figure 7. Indicative transmission power impact on BER for both users

The analysis of transmission power's impact on BER is crucial in wireless communication systems. Increasing transmission power generally lowers BER for near users due to stronger received signal power and improved SNR at shorter distances, leading to more reliable decoding and reduced bit errors. However, for far users, the relationship between transmission power and BER is more complex due to attenuation and path loss. The limited improvement in BER for far users necessitates the use of additional techniques such as advanced coding schemes, signal processing, or adaptive modulation to achieve significant improvement. This analysis highlights the need to carefully optimize transmission power, considering distance, signal strength, and desired error performance, to strike a balance between improving BER for near users and addressing challenges faced by far users in wireless communication systems.

3.3. NOMA's performance evaluation in the Rician fading channel

Rician fading is a type of fading channel model that incorporates a LOS signal component along with scattered multipath components [35]. In comparison, the Rician and Rayleigh fading channel are similar, with the exception of the LOS path. The h=x+i*y defines the relationship between the Rayleigh fading coefficients, Gaussian random variables, denoted by x and y, have a mean of 0. h can alternatively be written as h=x+i*y for Rician fading but now the mean of y is zero, and the mean of x is a non-zero Gaussian random variable. The variances of x and y are equal. The Rician parameter K, defined as the ratio of power in the dominant paths to power in the scattered paths, determines the variance of x, y, and the mean of x. As we can see in Figure 8, the impact of the Rician parameter K on BER for both users are observed. It is observed that as K increases, the BER decreases rapidly, indicating improved performance [36].

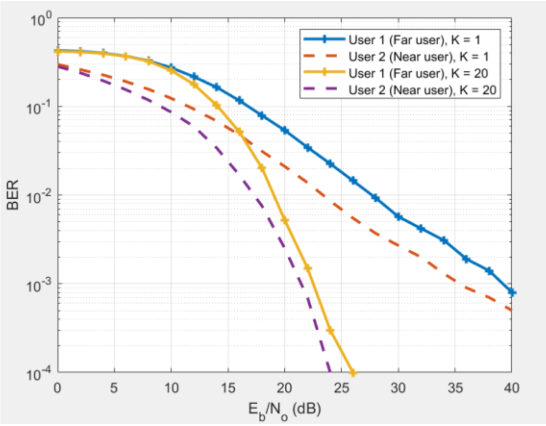

Figure 8. BER for two users indicatively SNR per bit

In a Rician fading channel, the Rician K-factor quantifies the power ratio between the LOS component and scattered multipath components. For near users, a higher K-factor has a more significant impact. With a stronger LOS signal compared to multipath components, near users experience a more predictable channel, improved signal quality, and reduced fading effects. This leads to higher received signal power, favorable SNR, and better communication performance [37]. On the other hand, for far users, the K-factor's impact is diminished. The LOS component weakens with distance, making multipath components more influential. Far users are more affected by fading and multipath propagation, regardless of the K-factor. A higher K-factor benefits near users by minimizing fading, while a lower K-factor suits far users due to the dominant influence of multipath components. By adjusting the K-factor appropriately and considering user distance from the transmitter, the performance and robustness of wireless communication systems in Rician fading channels can be optimized [38].

4. CONCLUSION

Compared to OMA, NOMA technic provides a number of benefits like higher SE, massive connectivity, lower-latency, fairness, and robustness. Its qualities have drawn a lot of interest from the scientific community lately and make it a feasible solution for increasing SE. There are some potential problems for transmission download in NOMA in which NOMA depends on assigning various power levels to various users. In this paper we propose to implement the architecture of downlink NOMA system with two users, and investigate the evaluation of wireless NOMA communication performance in various communication channels. To achieve this goal, firstly, we carry out the performance in terms of the transmit power, the indicative BER, OP, and rate attainable capacity, using AWGN, and secondly, we evaluate the performance, in terms of the BER indicatively SNR per bit for two users, using Rayleigh and Rician fading channel. the Rician fading channel performs better in terms of BER compared to the Rayleigh fading channel. The obtained results are promising and demonstrate the potential of using NOMA technology to mitigate issues such as interference, SE, and fairness in downlink communication. In forthcoming research, we plan to explore the potential enhancement of a specific user's energy through beamforming, concurrently minimizing interference to other users. This approach holds promise for NOMA and is expected to yield significant benefits.

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