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Evaluation of NOMA Downlink BER Performance in Various Fading Channels using Successive Interference Cancellation (SIC)

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Abstract

This research paper delves into the bit error rate (BER) performance of non-orthogonal multiple access (NOMA) in the downlink (DL) power domain (PD). NOMA is a promising access method for upcoming radio access networks, owing to its ability to support numerous connections and high spectral efficiency. However, its performance can be adversely affected by successive interference cancellation (SIC) errors. To mitigate this problem, the study investigates the BER of NOMA for various Signal to Noise Ratio (SNR) levels in AWGN, Rayleigh, and Rician fading channels using QPSK modulation for three different scenarios. The paper also analyzes the BER of two, three, and four NOMA users using BPSK modulation in AWGN, Rayleigh, and Rician fading channels. Initially, the BER performance is assessed by assuming two users equally spaced from the base station (BS) for different SNR values. Later, the BER performance is evaluated for varying transmit powers and distances from the BS for different numbers of users. The objective is to examine the impact of factors such as distance, bandwidth (BW), and power allocation coefficients on BER in NOMA. MATLAB simulation software is used to obtain BER versus SNR and BER versus Transmit Power results for different scenarios. The research findings highlight the importance of careful optimization in NOMA to improve its overall performance while maximizing spectral efficiency and connection capacity.

Keywords: Non-orthogonal multiple access (NOMA), power domain (PD), successive interference canceller (SIC), bit-error rate (BER).

1. Introduction

The development of radio access technology for mobile cellular communications is a pivotal constituent in augmenting system capacity with greater efficiency [1][2][3]. This process can be categorized into two primary branches. The first division pertains to Orthogonal Multiple Access (OMA), which is a rational approach towards achieving optimal system-level transmission efficiency by simplifying the design of packet domain services receivers [4]. OMA consists of

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numerous access systems, including Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA), Code Division Multiple Access (CDMA), and Orthogonal Frequency Division Multiple Access (OFDMA) that permit a multitude of users to simultaneously access and share system resources [5][6]. However, future designs need to be formulated to curtail intracellular and/or intracellular interference, thus enhancing the efficiency of the spectrum in the foreseeable future. The combination of MIMO, Cognitive Radio and NOMA holds great promise for the future of wireless communication systems [7].

The second variant is non-orthogonal multiple access (NOMA). The utilization of time or rates segregation allows for the attainment of multi-user capacity via NOMA. The fundamental principle of NOMA is that the number of orthogonal resources accommodates an amplified quantity of users [8]. The innovative aspect of NOMA is its ability to opportunistically distribute transmit power among various users by taking advantage of their various channel circumstances [9]. There exist two principal classifications for NOMA, namely (1) NOMA power domain (PD) and (2) NOMA code domain. The former classification involves the simultaneous deployment of the same frequency resource or time by numerous users with varying power transfers. For the latter category, a sparse codebook with data matched to the codebook design is utilized for every user [10]. The enhancement of the future system's capacity is indispensable for catering to the exponential growth in traffic volume. The augmentation of system capacity is of particular importance for 5G networks [11].

Despite the numerous benefits offered by this technology, the issue of interference remains a significant obstacle that requires immediate attention, with the discovery of effective solutions being paramount. One such technique utilized to tackle this challenge is the successive interference cancellation (SIC) method [12]-[13][15]-[16]-[17].

In the publication [19], the authors formulated closed expressions for the bit error rate (BER) at the near user (U1) and remote user (U2) in a DL-NOMA system, which they subsequently compared to OMA plots. However, the influence of factors such as distances and bandwidths, as well as their effects on BER, were not taken into account. The accuracy of the BER rate for BPSK modulation was also investigated in both the perfect and imperfect SIC states for the DL NOMA network, utilizing the AWGN, Rayleigh and Rician fading channels. However, noteworthy BER-affecting characteristics such as distance and power allocation coefficients were not considered in [20].

This work aims to analyze the performance of Bit Error Rate (BER) against Signal to Noise Ratio (SNR) and Transmit Power for different distances, bandwidths, and power allocation coefficients in the downlink Non-Orthogonal Multiple Access (NOMA) Power Domain (PD).

2. NOMA BER Performance

NOMA (Non-Orthogonal Multiple Access) is a multiple access technology that can improve the spectral efficiency of wireless communication systems by allowing multiple users to share the same frequency band. NOMA has gained significant attention in recent years due to its potential to support a large number of users with high data rates.

In wireless communication systems, the BER (Bit Error Rate) is a critical performance metric that measures the probability of errors in the transmitted bit stream. The BER of NOMA technology depends on various system parameters and design choices, including the number of users, the power allocation scheme, and the modulation and coding schemes used.

One of the primary challenges in NOMA systems is the interference among the users. In a conventional orthogonal multiple access (OMA) system, users are assigned mutually exclusive subchannels, which can effectively reduce the interference between them. In traditional Orthogonal Multiple Access (OMA) systems, only one secondary user can transmit using an available resource block, which can result in significant transmission delays[7]. However, in NOMA, users share the same subchannel, and their signals interfere with each other. To mitigate this interference, power allocation schemes such as the Successive Interference Cancellation (SIC) technique can be used. In SIC, users with stronger channel conditions are given higher power allocations and decoded first. After decoding the signal of one user, the decoded signal is subtracted from the received signal to remove the interference from the decoded signal of the previous user. This process continues until all users' signals are decoded.

The choice of modulation and coding schemes also impacts the BER of NOMA. For example, high-order modulation schemes can increase the data rate, but they are more susceptible to noise and interference. On the other hand, low-order modulation schemes are more robust to noise and interference, but they offer lower data rates. Similarly, the use of forward error correction (FEC) coding schemes can improve the BER performance by adding redundancy to the transmitted data, but they also increase the transmission delay.

The BER of NOMA technology is a complex concept that depends on various system parameters and design choices. With careful optimization and appropriate design, NOMA can achieve better BER performance compared to conventional communication systems. The use of advanced power allocation schemes, modulation and coding schemes, and interference management techniques can effectively reduce the BER of NOMA systems and enhance their performance.

3. Related Work

The proposed work involves a downlink NOMA over the AWGN, Rayleigh and Rician Fading channels with different number of users, bandwidths, and the impact of changing these factors on BER performance is explored across different scenarios. The paper also discusses previous studies on BER performance in the downlink NOMA system using various channel fading types and evaluation methods. The focus of this paper is to compare the BER and SNR performance of downlink NOMA for different channel fading types.

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The author of this study focused on investigating the performance of downlink NOMA systems with particular attention given to the Bit Error Rate (BER). Through various scenarios, the exact BER of downlink NOMA systems was calculated, taking into account Successive Interference Cancellation (SIC) as described in [20]. The author also analyzed the performance of DL NOMA networks with binary shift phase key modulation in [13], where they determined the precise BER equation for each user in AWGN, Rayleigh and Rician fading channels in perfect and imperfect SIC situations. Furthermore, in [14], the author mathematically evaluated the highest BER in a NOMA user system with a combined maximum probability detector in a multi-antenna base station. The author highlighted that inter-user interferences during SIC pose a significant disadvantage to NOMA, as mentioned in [15]. In [16], the author studied the performance of Visible Light Communication (VLC) systems that are NOMA-enabled using different modulation methods and presented a bit-decision axis and signal space-based analytical framework to achieve closed-form BER expressions for NOMA-enabled VLC systems.

Finally, in [18], the author jointly examined the Symbolic Error Rate (SER) and considered the DL/UL transmission, the number of information streams, and canal coding BER. The resultant SER and BER were represented in closed form, which helps assess transmission performance effectively.

4. System Model

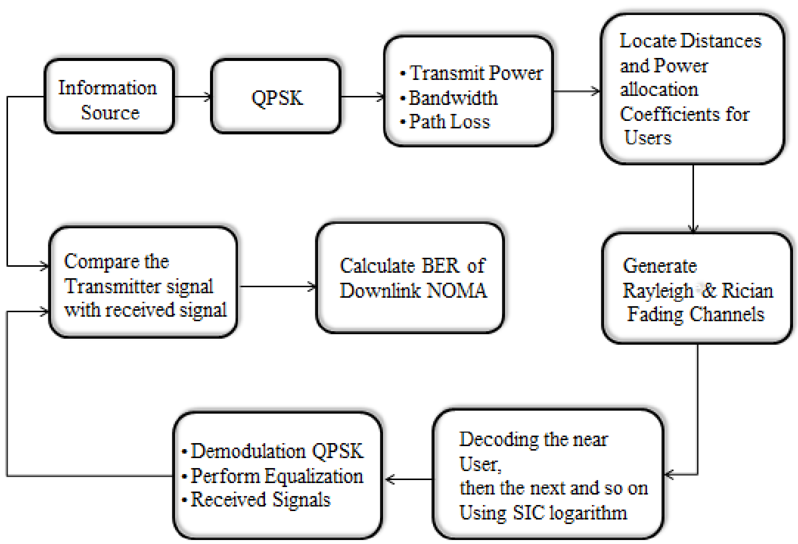

Figure 1: Block diagram for steps of downlink NOMA and calculate the BER

4.1 The First Circumstance

Assume that the wireless network in figure 2 has three NOMA users (U1, U2, and U3). Let r1, r2, and r3 represent the distances between each Base Station (BS), with r1 > r2 > r3. U1 is the weak/far user for BS, while U3 is the strong/near user, according to distances. Let h1, h2 and h3 indicate the Rayleigh Fading Coefficients that they match where $|h_1|^2 < |h_2|^2 < |h_3|^2$ (the channels are arranged this way because $h_i \; \alpha \; 1/r_i$). Their relative power coefficients are indicated in a_1, a_2, and a_3. By the principles of NOMA PD, the weaker user should have more power and less power should be provided to the stronger user. The power coefficients must thus be adjusted accordingly as $a_1 > a_2 > a_3$. We use a set of power coefficients in this paper for simplicity. Several dynamic power coefficient strategies are available to improve efficiency.

Let x_1, x_2 and x_3 list the quadrature phase-shift keying (QPSK) formed messages to transmit to U_1, U_2 and U_3 the base stations. Then the encoded overlay signal from the base stations. Then the encoded overlay signal from the base station is provided, $x = \sqrt{P}\left(\sqrt{a_1}x_1 + \sqrt{a_2}x_2 + \sqrt{a_3}x_3\right)$.

The received signal at the i^{th} user is delivered through $y_i = h_i x + n_i$, where n_i denotes AWGN at the receiver of U_i. In figure, 2 users are U_1, U_2 *and* U_3, their respective BS distances are indicated by r_1, r_2 *and* r_3 , and their respective Rayleigh fading coefficients are indicated by h_1, h_2 *and* h_3.

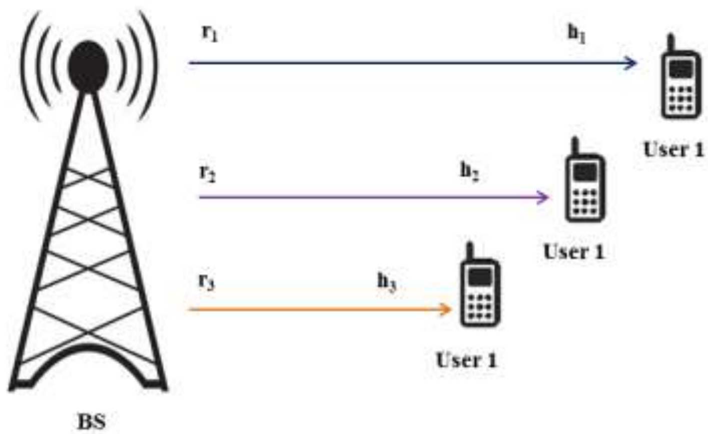

Figure 2: Wireless network NOMA PD with 3 users

SIC Decoding Procedure

Figure 3 shows a technique of work (SIC), as the farthest user receives and decodes message directly without using (SIC) technics, but the closest users need to use (SIC), to decode and remove data of other users.

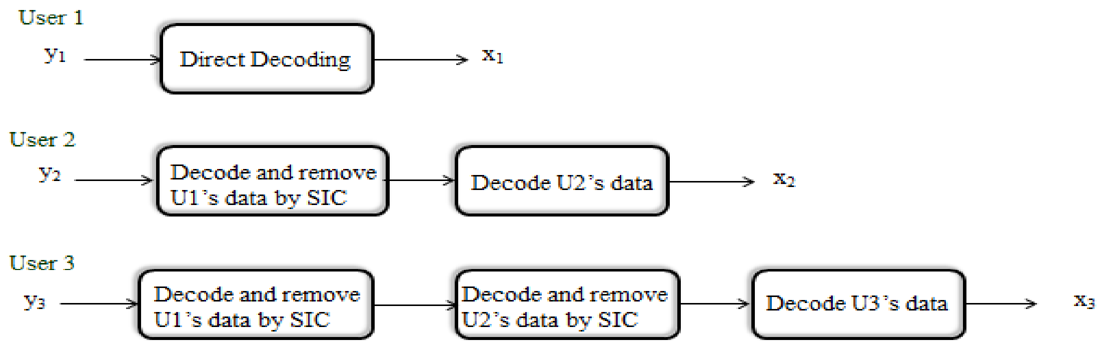

Figure 3: The working method of SIC

As U1 is assigned the highest power, it directly decodes y_1, which interferes with second and third users signals. The attainable first-rate is , given by as in [22]-[23].

$$R_1 = \log_2\left(1 + \frac{a_1 P|h_1|^2}{a_2 P|h_1|^2 + a_3 P|h_1|^2 + \sigma^2}\right)$$

which can be further simplified as, $R_1 = \log_2\left(1 + \frac{a_1 P|h_1|^2}{(a_2 + a_3)P|h_1|^2 + \sigma^2}\right)$

One crucial observation to make from the given equation is that for $a_1 > a_2 + a_3$ to hold true, the denominator must be $a_2 + a_3$. Consequently, the dominant power U1 is contributed by both the transmitted signal x and the received signal y_1.

Next, let's write the equation for the rate of U2. First to remove U1's data and regard U3 it as interference, as $a_2 < a_1$ and $a_2 > a_3$, U2 must perform SIC. The achieved rate is U2 after the deletion of U1 data by SIC.

$$R_2 = \log_2\left(1 + \frac{a_2 P|h_2|^2}{a_3 P|h_2|^2 + \sigma^2}\right)$$

To fulfill $a_2, a_2 > a_3$, as the a_3 is in the overlapping term of the denominator.

Finally, deleting data from y_3 both U1 and U2, U3 $(a_3 < a_1,\ a_3 < a_2)$needs to execute two SIC functions. Because a_1 prevails y_3, it must first be deleted. The a_2 term must be deleted after that. The attainable rate is

$$R_3 = \log_2\left(1 + \frac{a_3 P|h_3|^2}{\sigma^2}\right)$$

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4.2 The Second Circumstance

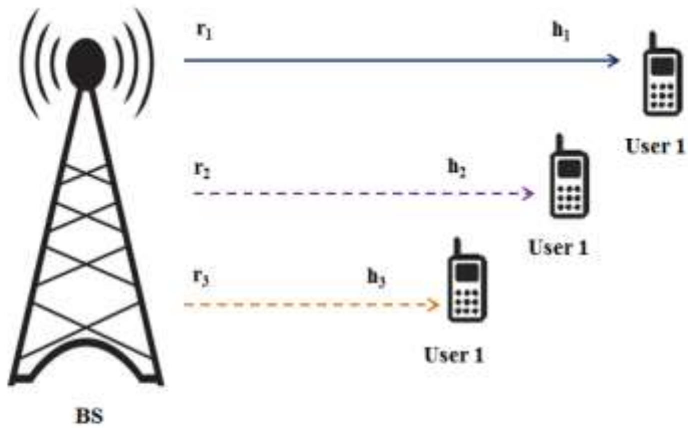

Figure 4: Wireless network consisting of one user NOMA with different distance

We consider a wireless network consisting of one user NOMA PD as shown in figure 4. U1 moves from r_1 *to* r_2 and finally to r_3 signify the respective BS distances, thus $r_1 < r_2 < r_3$. Consider that the power coefficient (a) is constant. The corresponding Rayleigh fading coefficients are denoted by (h).

4.3 The Third Circumstance

Consider a wireless network consisting of one user NOMA PD as shown in figure 5. The change in these times will be in the BW, the distance factor (r) and power coefficient (a) is constant.

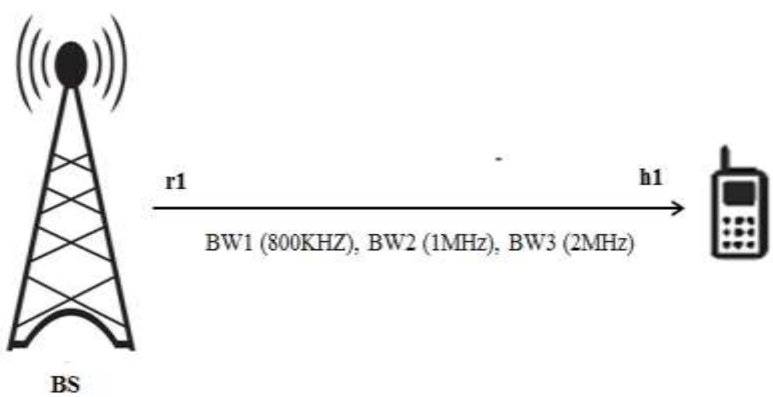

Figure 5: Wireless network consisting of one user NOMA with different bandwidths

5. Simulation Model

To begin with, we need to define the simulation parameters presented in the following tables 1, 2 and 3 for three different scenarios. Specifically, we should set the path loss exponent (η) to four and generate Rayleigh fading coefficients h_1, h_2 *and* h_3 for each user. The amount of data to be transmitted in this scenario is denoted as N, and since QPSK modulation is used, each symbol carries two bits. Therefore, the total number of symbols transmitted can be calculated by dividing N by two. Finally, a fading Rayleigh coefficient should be generated for each symbol.

To set the noise power level, we must take into account several factors. Specifically, we need to consider the bandwidth (BW) of the communication channel, the thermal noise power (KTB), and the noise power in $\log_{10}(KT) = -174\, dBm$ with a BW of 1 Hz. Based on these considerations, the noise power can be calculated as $-174 + \log_{10}(BW\ MHz)$. Additionally, to compare the noise strength at the final stage, each of the three users should use n_i to produce noise samples. It's important to note that n_i has a zero mean and a variance of σ^2.

After setting the noise power level and generating the appropriate noise samples, we can begin the data transmission process. To do this, we first need to generate random message bits for each user and then perform modulation and demodulation using QPSK. This process creates the non-orthogonal multiple access (NOMA) signal through superposition coding.

Finally, to delete the estimate of the data of any user, we perform successive interference cancellation (SIC). This process involves decoding the signal of the user with the strongest power level first and then removing that signal from the overall received signal. We can then proceed to decode the signal of the next user with the strongest power level and continue this process until we have decoded the signals of all users. By using SIC, we can accurately estimate the data of each user, even in scenarios where the users are transmitting simultaneously over the same channel

Table 1: Parameters used for the first Scenario

Parameters	**User 1**	**User 2**	**User 3**
	r_1	**r_2**	**r_3**
Distance (m) from BS	1500	800	250
Power allocation Coefficients	a1=0.8	a2=0.18	a3=0.02

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Bandwidth	BW 1 = 10^5, BW 2 = 10^6, BW 3 = 10^7

Table 2: Parameters used for the second Scenario

Parameters	Single User		
	r_1	r_2	r_3
Distance (m) from BS	1500	1000	500
Power allocation Coefficient, (a1)	0.6		
Bandwidth (BW)	BW = 1 MHz		

Table 3: Parameters used for the third Scenario

Parameters	One User		
	BW 1	BW 2	BW 3
Bandwidth (BW)	800KHz	1 MHz	2 MHz
Power Coefficient (a1)	a1=0,8		
Distance (m) from BS	1000		

6. Results and Discussions

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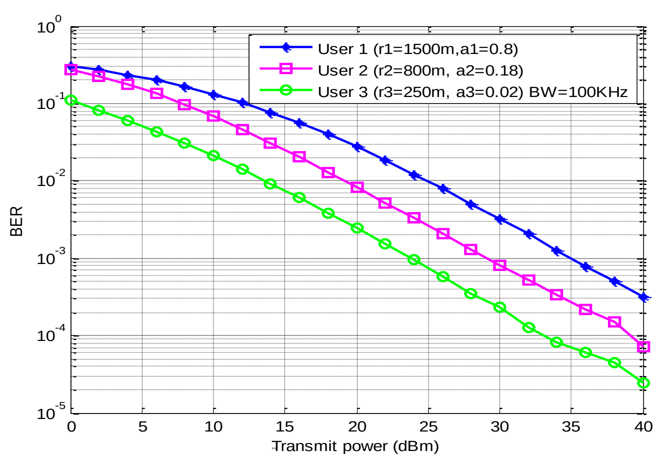

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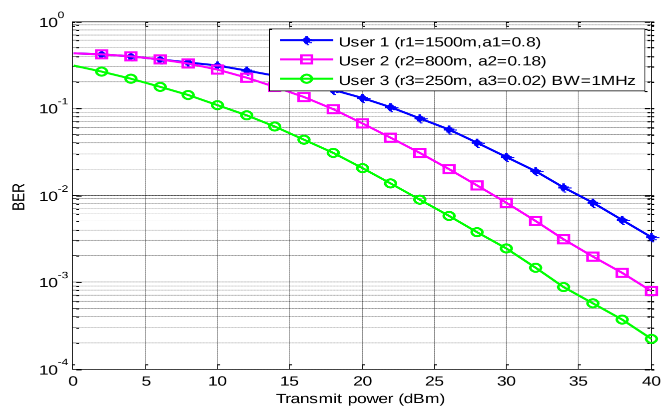
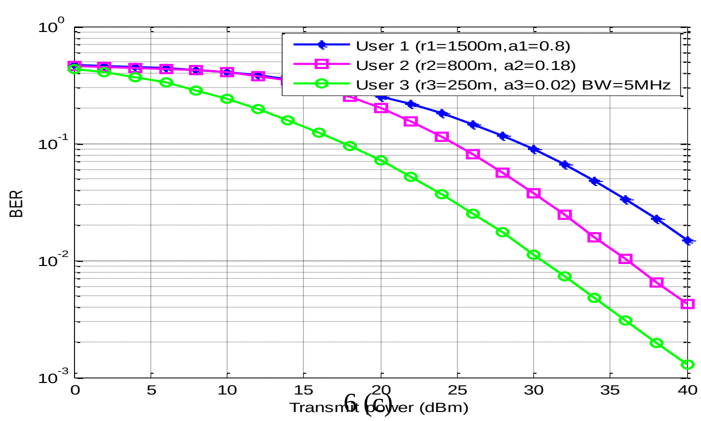
Figure 6(a) plots the BER performance against transmit power at a bandwidth of 100 kHz. The results demonstrate that the BER performance declines as transmit power increases, and that distance and the power allocation coefficient have a noticeable impact as well. The BER rate improved from user 2 to user 1 as the distance decreased from 1.5 to 0.8 Km and the power allocation coefficient decreased from 0.8 to 0.18 Km, and from user 3 to user 2 as the distance decreased from 0.8 to 0.25 Km. As a result of user 3 being closest, user 3's BER performance is superior than that of other users. Due to interference from users 2 and 3, user 1 has the poorest BER performance.

Using the same values of distance and power allocation coefficients as in the prior cases, the bandwidth was increased from 100 KHz to 1 MHz, as shown in figure 6(b), and it was discovered that the BER rate increased from user 2 to user 1 and improved from user 3 to user 2. The findings indicate that until transmit power approaches 10 dBm, users 1 and 2 function similarly, and that BER performance has greatly improved.



6 (b)



6 (c)

Figure 6: BER against Transmit Power for different distances and bandwidths for three users

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Figure 6(c) illustrates the BER performance as a function of transmit power at a 5 MHz bandwidth, with the BER rate increasing from user 2 to user 1 and improving from user 3 to user 2 while maintaining the same values of the distance and power allocation coefficients as in the prior cases. According to the results, user 1 and user 2's BER performance is close to one another up to 15 dBm of transmit power, and there is a discernible improvement in the BER performance.

Figure 7 shows the single user BER performance for transmit power at 1 MHz bandwidth and 0.6 power allocation coefficient over various ranges. As transmit power increased, the effect of differing distances became more apparent. The BER rate increased as the distance decreased from 1.5 to 1 Km and increased again as the distance decreased from 1 to 0.5 Km.

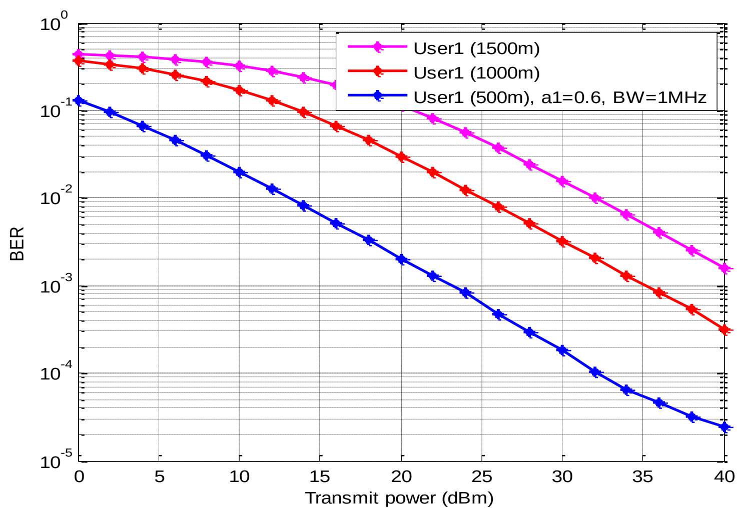

Figure 7: BER against Transmit Power for single user with different distances

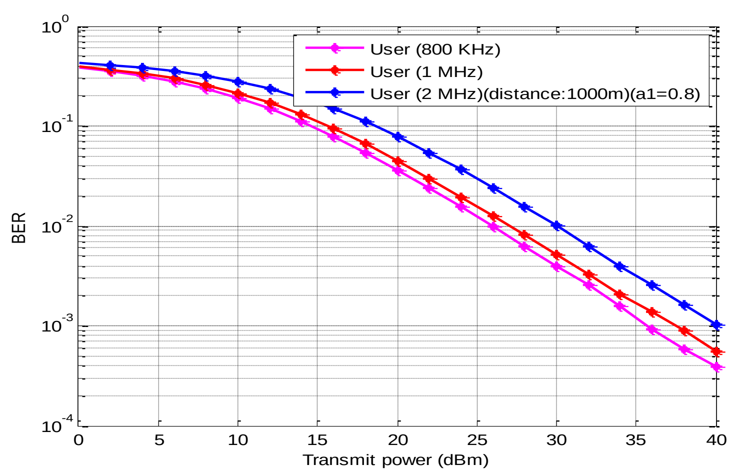

Figure 8: BER against Transmit Power for single user with different bandwidths

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Figure 8 depicts an example of a single user's performance at a fixed distance of 1 km, a power coefficient of 0.8, and various bandwidths of 800 kHz, 1 MHz, and 2 MHz. The BER rate increased as the bandwidth was changed from 2 MHz to 1 MHz and from 1 MHz to 800 KHz, respectively. It becomes obvious that the BER increases as the bandwidth increases.

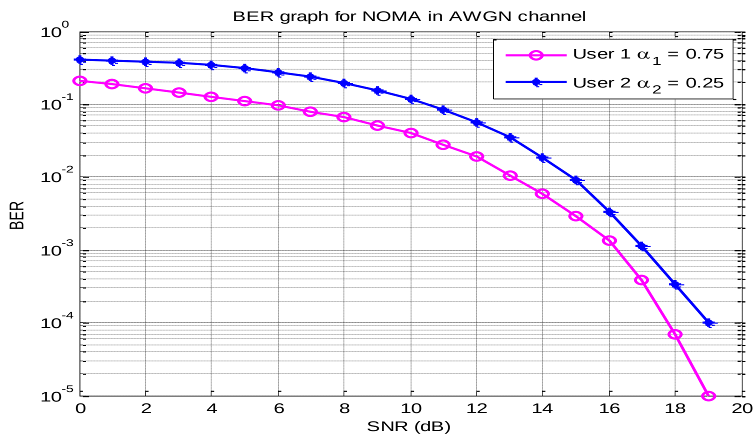

Figure 9: BER against SNR for different power allocation coefficients for two users

From figure 9, we can observe the waterfall trend. Also, we observe that user 2 has slightly higher BER than user 1, especially in the low SNR regime. This is because user 2 has to do SIC. While performing SIC, user 2 must first estimate user 1's data from y. If this estimate is wrong, then, this error will reflect in the decoding of its own information because the wrong data would be subtracted from y. In other words, user 2 **must** decode **both** user 1's data and its own data correctly. Any error in decoding user 1's data or its own data will impact its BER. That is why user 2 experiences higher BER than user 1.

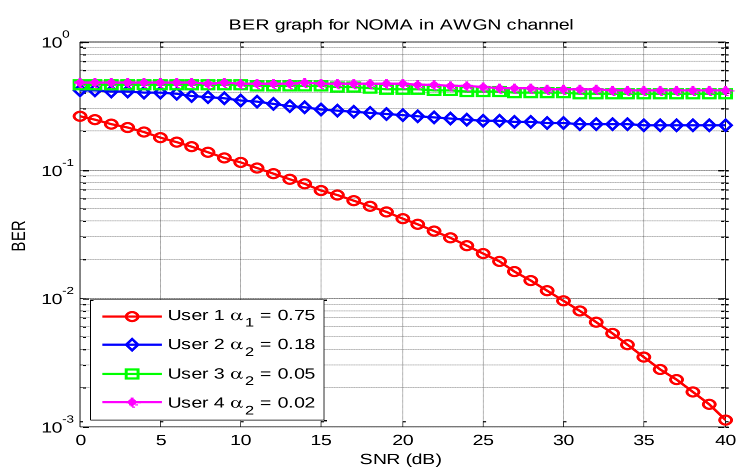

Figure 10: BER against SNR for different power allocation coefficients for four users

Figure 10 depicts the BER versus SNR plot in NOMA technology for four users with the first user having a higher power allocation coefficient shows that that the BER decreases with an increase in SNR, and the performance is better for the first user due to a higher power allocation coefficient. The performance is worse for the last user due to the lowest power allocation coefficient, and the performance of the middle users is intermediate. Finally, NOMA technology offers better BER performance compared to OMA.

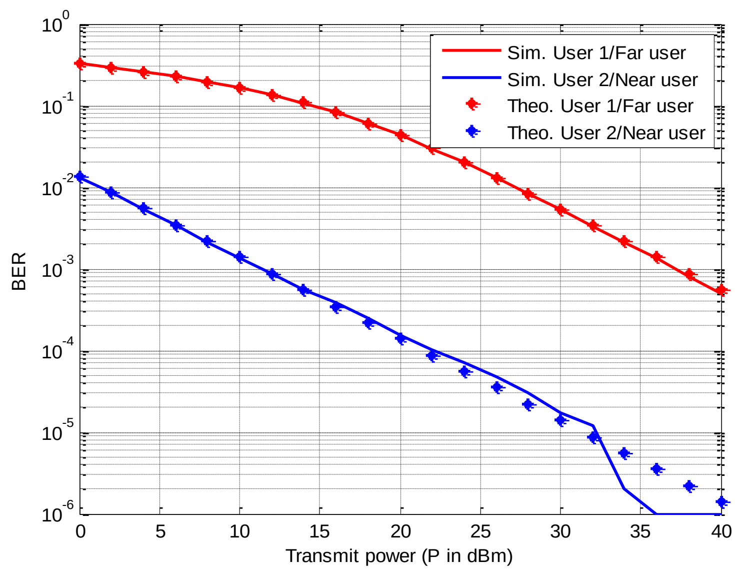

Figure 11: BER against Transmit power of Rayleigh Channel

Figure 11 shows the BER versus transmit power plot in NOMA technology shows that the BER decreases with an increase in transmit power, and the rate of decrease depends on the channel conditions of the users. The near user requires a lower transmit power to achieve a low BER, while the far user requires a higher transmit power. Hence, the BER versus transmit power plot for the near user has a steeper slope than that of the far user.

The BER analysis of two user NOMA in the Rician channel is shown in Figure 12. Because the Rician channel has a line-of-sight component, it produces superior results than the Rayleigh channel. Figure clearly depicts the influence of the line-of-sight factor on system performance. The BER of the system with K=10 is bigger than the BER of the system with K=1.and 5. This is due to the fact that line of sight allows for improved receiver detection.

From figure 13, we can observe that at low SNR, OMA performs slightly better than NOMA. This is because, NOMA users suffer from interference (due to simultaneous transmission), while OMA users do not experience any such interference. At high SNR, however, NOMA outperforms OMA by offering high capacity. In addition, NOMA accomplishes this while utilizing minimal resources. In this example, TDMA requires 3 times slots to complete the whole transmission. If the duration of 1 time slot is 1 ms, TDMA requires 3 ms to complete the transmission. NOMA, on the other hand, completes the transmission in a single time slot itself (i.e., in 1 ms). This significantly reduces the latency. This demonstrates the usefulness of NOMA in future communication technologies.

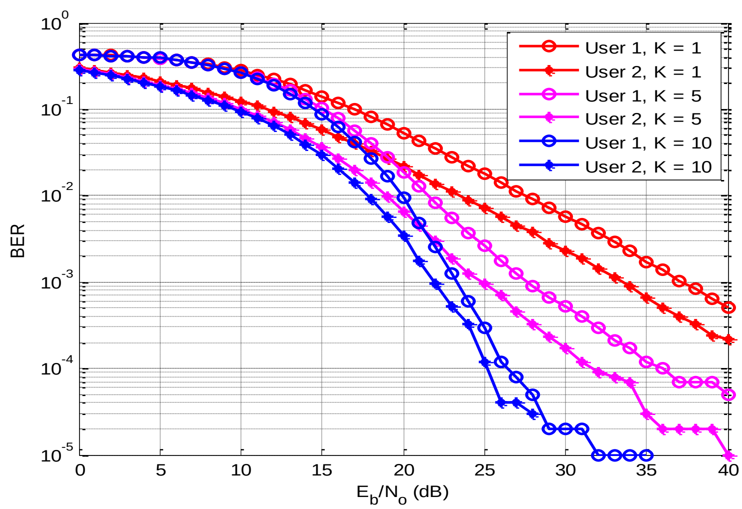

Figure 12: BER vs SNR of Rician channel at K=1, 5 and 10

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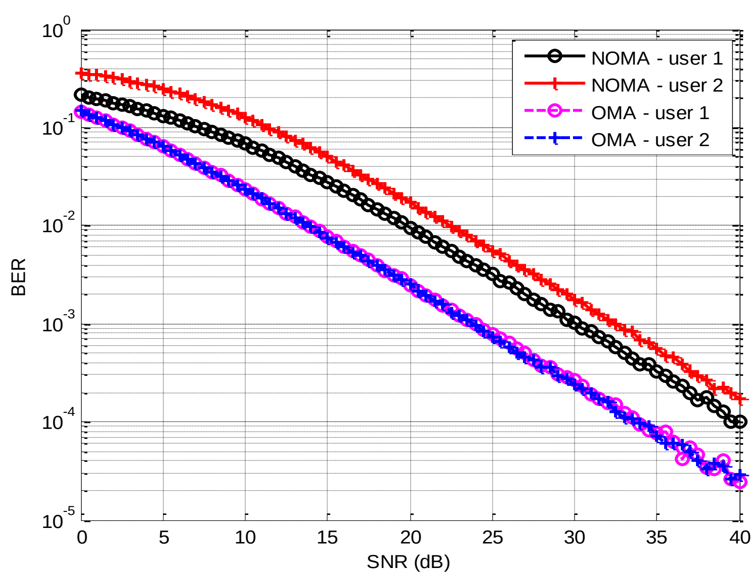

Figure 13: BER Comparison between NOMA and OMA

Conclusion

This paper has analyzed and explored the BER performance of DL NOMA PD against SNR for different scenarios with different BW, distances, and power allocation coefficients under AWGN and Rayleigh and Rician fading channels using QPSK and BPSK with SIC. The BER performance for user 3 is better than other users because user 3 is the nearest one. For the second scenario with one user and fixed BW and power coefficient with different distances. For the third scenario with one user at the fixed distance and power coefficient with different BW. As the BW, distance, and power allocation coefficients rise, the BER increases. In comparison between BW, distance and power allocation coefficient factors, the BW parameter has the greatest influence on BER DL NOMA PD, according to the obtained results. For 5G communications, NOMA is preferred because it provides high connection, dependability, and low latency. This NOMA aids huge networking with higher spectrum efficiency.

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