



Modeling and Simulating NOMA Performance for Next Generations

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Abstract

Non-orthogonal multiple access (NOMA) is a multiple access technique that allows multiple users to share the same communication resources, resulting in increased spectral efficiency and throughput. NOMA has been shown to provide significant performance gains over orthogonal multiple access (OMA) in terms of spectral efficiency and throughput. In this paper, two scenarios of NOMA are analyzed and simulated, involving two users and multiple users (four users) in order to evaluate the performance of NOMA in terms of bits per error ratio (BER) and achievable sum-rate (R-sum), then comparing NOMA with OMA in terms of achievable sum rate. The obtained results indicate that an improvement is achieved for two users NOMA (16.7 (bps/Hz)) compared with OMA (15.53(bps/Hz)), while for multi-users NOMA (20.69 (bps/Hz)) compared with OMA (15.79 (bps/Hz)) at transmitted power equal to 25 dBm.

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1. Introduction

In the future, mobile internet and the internet of things will be the main driving force for mobile communication development. In order to meet the requirements for future generations of wireless communication, new multiple access technologies will be need. Non-orthogonal multiple access (NOMA) is an important enabling technology that can provide high system throughput, low latency, and massive connectivity [1,2].

NOMA is a multiple access technique that allows multiple users to share the same time-frequency resource by using non-orthogonal signals. This makes it possible to increase the number of users that can be supported by a given time-frequency resource. NOMA has been shown to be able to provide significant performance gains over traditional orthogonal multiple access schemes (OMA) since orthogonality results in a capacity limitation. NOMA breaks this capacity limitation by allowing simultaneous transmission of

multiple users in the same frequency carrier, **Fig1.** shows the NOMA and OMA signal in the frequency domain [3,4].

As a result, interference will occur, but NOMA employs the successive interference cancellation (SIC) technique. The main difference between NOMA and OMA is that NOMA allows more data transmission, can serve more than one user at the same time and frequency resources, and has higher spectral efficiency. This allows NOMA to better serve cell edge users (users far from the base station) [5,6].

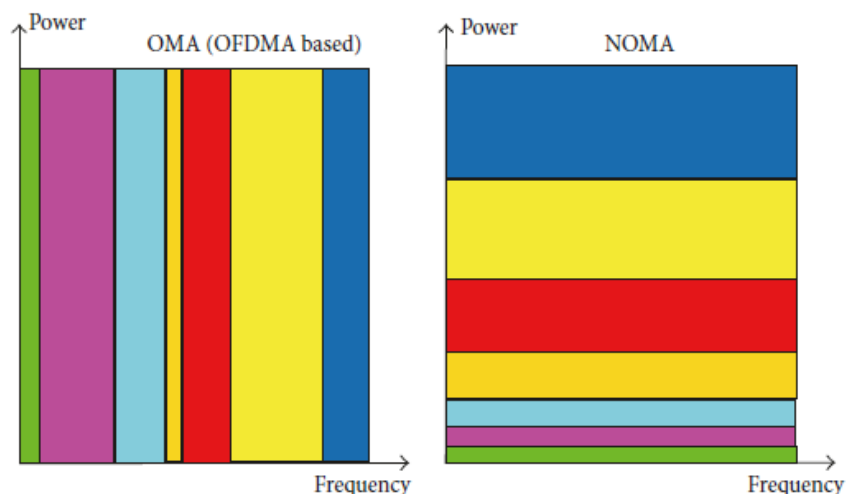


Figure 1. The NOMA and OMA signal in frequency-domain [7].

NOMA employs power domain multiplexing by using superposition coding, which means that different users share the same spectrum according to different amounts of power. The amount of power is specified by the location of each user with respect to the base station. Typically, users with poor channel conditions are allocated more power than users with good channel conditions. In addition, NOMA uses the concept of SIC at the receiver to recover the data stream vector of users with lower amounts of power. Users with good channel conditions can detect their signals using the SIC algorithm, and users with high power can detect their signals by treating low power signals as additive noise. Therefore, the decoding order depends on user channel power gains, which are determined by the propagation environments and user locations [8,9].

The current studies on the performance of power domain-NOMA (PD-NOMA) mainly focus on the sum rate and BER performance, as the BER of a digital communication system is an important metric used to quantify the quality of data transmitted through the Downlink NOMA system [10].

The authors in [11], derived exact closed-form BER expressions under SIC error over Rayleigh fading channels in a downlink NOMA system with one base station (BS) and two users.

In addition, looked at the symbol error rate for NOMA under imperfect SIC using quadrature amplitude modulation (QAM), and came up with closed form expression for the error rate for each user, under Rayleigh fading channels. It is worth noting that the BER performance of uplink NOMA was also widely studied. An exact average BER expression of QPSK modulation for uplink PD-NOMA with SIC was obtained under the additive white Gaussian noise channel (AWGN) channel [12]. The BER performance for uplink PD-NOMA in the presence of SIC error was also considered in [12,13].

Kara and Kaya [14] examined the BER of downlink and uplink NOMA, where phase shift keying (PSK) modulation is used and exact closed-form BER expressions over Rayleigh fading channels are derived for the scenario of imperfect SIC. The results demonstrate the impact of imperfect SIC for

different cases of power assignments and channel quality in downlink and uplink scenarios. The bit error rate (BER) of a NOMA system using binary phase shift keying (BPSK) is investigated in [15].

Closed-form BER expressions are composing for the ideal and practical scenarios of the SIC process. The results show that diversity and array gains can be achieve at high SNR when considering perfect SIC. However, if SIC is imperfect, the system performance exhibits an error floor at high SNRs. The authors of [16].

Investigated the bit error ratio (BER) performance of an uplink NOMA scheme while employing a joint maximum-likelihood (ML) detector at the base station with multiple antennas, instead of SIC. They derived closed-form BER expressions by considering quadrature phase shift keying (QPSK) modulation, and the results showed that the ML detector significantly outperforms the SIC. The authors of [17,18] have addressed the BER performance for various NOMA communication systems and modulation schemes.

The study in [19] looked at the effects of downlink NOMA (DL-NOMA) on the signal-to-noise ratio (SNR), achievable bit rate, and outage probability (OP) in cases of independent not identically distributed (i.n.i.d) Rayleigh fading channels. Furthermore, study investigated the effective capacity under the quality of service (QoS) requirements for multiple NOMA users and found that NOMA generally performs better than OMA [20].

The aim of this paper is to analyze and evaluate the performance of NOMA in terms of bits per error ratio (BER) and achievable sum rate (R-sum) for two users scenario and multi-users scenario, in addition, to compare NOMA and OMA performance according to their capacity (sum rates).

The rest of the paper is organize as follows; the basic concept of the downlink NOMA system will be in the second section, the analysis of system performance and system model are the third and fourth sections respectively, results and discussion are in the fifth section, and finally, conclusion will conclude the paper.

2. Basic Concept of Downlink NOMA System.

The **Fig. 2** shows a base station (BS), a far user (UE1), and a near user (UE2). The BS has selected to use the downlink NOMA technique to transmit signals to both the UE1 and UE2 using the same frequency band. Before transmission, the BS superimposes the UE1 and UE2 signals with different power levels to create a downlink NOMA signal. The received signal at both the UE1 and UE2 will contain both UE1 and UE2 signals, which causes inter-user interference. The transmitted power of the far user signal is usually larger than the transmitted power the near user signal in order to guarantee that both users are able to decode their desired signals. However, this means that at the near user, the interference signal overcomes the desired signal.

The near user first uses the SIC technique to cancel out the far user signal from the received signal, allowing them to decode the interference signal (far user signal). Then they subtract this from the received signal to get the interference-free received signal. The far user is then able to decode the desired signal (far user signal) from the received signal, as the desired signal is stronger than the interference signal (near user signal). Similarly, the BS can also serve more than two users on a single frequency band simultaneously, revealing a spectrum sharing gain [19,21].

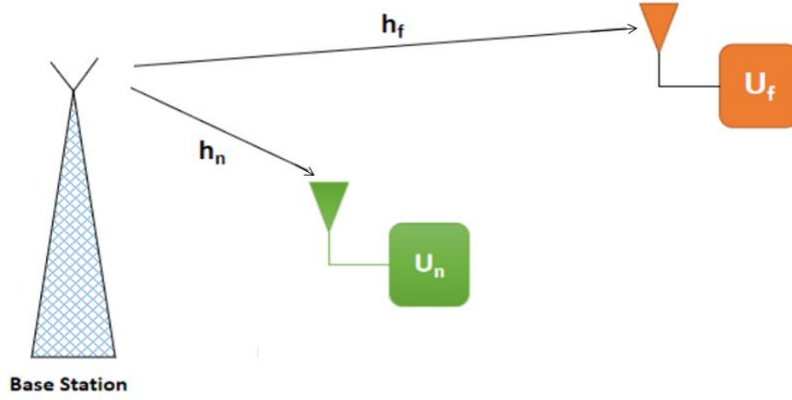


Figure 2: Downlink 2-UEs NOMA system [22].

3. Analysis of System Performance

In this section we illustrate system analysis for NOMA system in addition we analyze the achievable rates for both non-orthogonal and orthogonal multiple access techniques.

3.1. Analysis of Non-orthogonal Multiple Access Technique Performance

This sub-section illustrates the block diagram of the system. The block diagram consists of a transmitter, Rayleigh fading channel and a receiver as in **Fig. 3**. In the downlink NOMA, the far user is assigned to higher amount of power than that of near user. Thus the far user is decoded firstly than that the decoded data which is combined with the corresponding channel link then subtracted from the received vector to recover the data stream vector of the second user which is assigned to lower amount of power according to basic concept of downlink NOMA system [23].

For system analysis, assume that a BS transmits a signal for i^{th} user equipment (UEs) with a transmitted power then the transmitted signal according to El-Mokadem et al [10], will be expressed as in Eq. (1) [24].

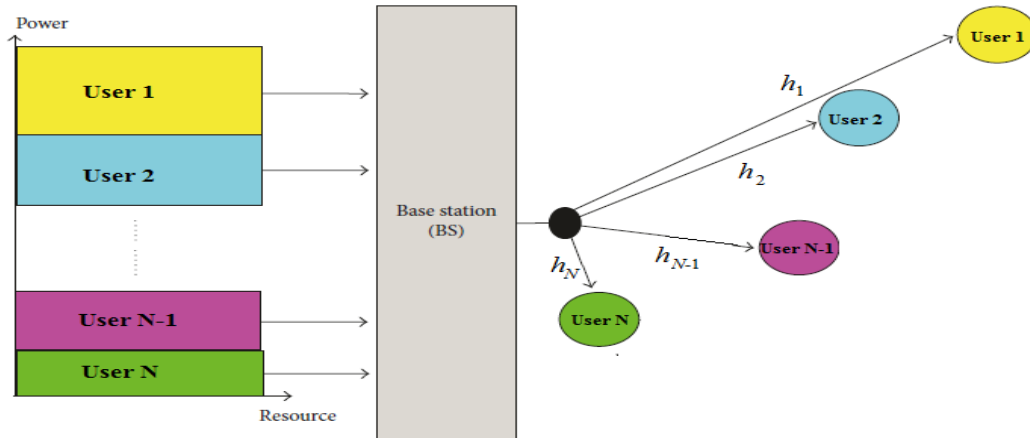


Figure 3: The downlink NOMA system model with N users [25].

$$X = \sum_{i=1}^N \sqrt{P_i} x_i \quad (1)$$

Where; x_i are superposition coded signals of the users and $i \in [1, 2, 3, \dots, N]$. Users are classified based on their distance from the BS. Where $i=1$ is the low gain user (FU) and $i=N$ is the high gain user (NU). The transmitted power P_i is given by Eq. (2) [10].

$$P_i = \alpha_i P_{BS} \quad (2)$$

Where; $P_{BS} = P$ is the transmitted power from BS (total available power at the BS) and α_i are the power allocation Coefficient of the UE_i, and the received signal for UE_i is given by Eq. (3) [26].

$$y_i = h_i X + w_i \quad (3)$$

The channel coefficient between UE_i and the base station is h_i , where w_i Additive White Gaussian Noise (AWGN) with zero mean and variance σ^2 .

In the downlink NOMA, The SIC process is implemented at the UEs receiver. The optimal order for decoding is in the order of decreasing channel gain normalized by noise and inter-cell interference power, which is equal to $\frac{|h_i|^2}{\sigma^2} = \frac{|h_i|^2}{N} = \frac{|h_i|^2}{N_0 BW}$ simply called channel-to-noise ratio (CNR) of UE_i. Where; N_0 is the noise power and BW is the bandwidth of the system, in addition $h_i = g_i * d_i^{-p}$; Where; g_i follows Rayleigh distribution, d_i is the distance between the BS and UE_i, and p is the pass loss exponent [26].

Based on channel gain order, assume each user can correctly decode the signals of other users whose decoding order comes before the corresponding user [27]. Thus, NU can remove the inter-user interference from the FU-user where $\frac{|h_N|^2}{N}$ is the highest channel gain.

Let's consider $x_1, x_2, \dots, x_N$ denote the messages to be transmitted to the users based on Fig. 3, where $|h_1|^2 < |h_2|^2 < \dots < |h_{N-1}|^2 < |h_N|^2$ Hence, the NOMA transmitted signal can be expressed by Eq.

(4) [24].

$$X_{NOMA} = \sqrt{P}(\sqrt{\alpha_1}x_1 + \sqrt{\alpha_2}x_2 + \dots + \sqrt{\alpha_N}x_N) \quad (4)$$

Where; $\alpha_1 > \alpha_2 > \dots > \alpha_N$, $\alpha_1 > \alpha_2 + \alpha_3 + \dots + \alpha_N$, and $\alpha_1 + \alpha_2 + \dots + \alpha_N = 1$.

Also, according to [10] Eq. (4) can be re-expressed in Eq. (5) [10], and the received signal at the i^{th} user can be expressed as in Eq. (6) [10]. In addition, by putting the Eq. (5) in Eq. (6) the received signal can be re-expressed by Eq. (7) [10]. At the first (far) user, the received vector is given by Eq. (8) [10], and direct decoding is performed to estimate x_1 . Thus the signal to interference plus noise ratio (SINR) for decoding the 1st user signal is given by Eq. (9) [7].

$$X_{NOMA} = \sqrt{P} \sum_{i=1}^N \sqrt{\alpha_i} x_i \quad (5)$$

$$y_{i, NOMA} = h_i x_{NOMA} + w_i \quad (6)$$

$$y_{i, NOMA} = h_i \sqrt{P}(\sqrt{\alpha_1}x_1 + \sqrt{\alpha_2}x_2 + \dots + \sqrt{\alpha_N}x_N) + w_i \quad (7)$$

$$y_{1, NOMA} = h_1 \sqrt{P}(\sqrt{\alpha_1}x_1 + \sqrt{\alpha_2}x_2 + \dots + \sqrt{\alpha_N}x_N) + w_1 \quad (8)$$

$$\gamma_{1, NOMA} = \frac{\alpha_1 P |h_1|^2}{\alpha_2 P |h_1|^2 + \alpha_3 P |h_1|^2 + \dots + \alpha_N P |h_1|^2 + \sigma^2} \quad (9)$$

At the second user, the received vector is given by Eq. (10) [10], the concept of the SIC is applied for achieving Eq. (11) [10]. Direct decoding is performed to estimate x_2 . Thus, the SINR for decoding the second user signal is given by Eq. (12) [7]. The same manner up to the N^{th} user. In general, the i^{th} SINR is given by Eq. (13) [7], and Eq. (13) can be re-expressed by Eq. (14) [7]. The achievable rate (bps/Hz) of the i^{th} user can be given by Eq. (15) [10] and the sum rate of all the NOMA users is given by Eq. (16), also Eq. (16) [10], can be re-expressed by Eq. (17) [10]. Fig.3. Spectrum of EVA-LTE Channel for QPSK modulation.

$$y_{2, NOMA} = h_2 \sqrt{P}(\sqrt{\alpha_1}x_1 + \sqrt{\alpha_2}x_2 + \dots + \sqrt{\alpha_N}x_N) + w_2 \quad (10)$$

$$y'_{2, NOMA} = h_2 \sqrt{P}(\sqrt{\alpha_2}x_2 + \dots + \sqrt{\alpha_N}x_N) + w_2 \quad (11)$$

$$\gamma_{2, NOMA} = \frac{\alpha_2 P |h_2|^2}{\alpha_3 P |h_2|^2 + \alpha_4 P |h_2|^2 + \dots + \alpha_N P |h_2|^2 + \sigma^2} \quad (12)$$

$$\gamma_{i, NOMA} = \frac{\alpha_i P |h_i|^2}{\alpha_{i+1} P |h_i|^2 + \dots + \alpha_N P |h_i|^2 + \sigma^2} \quad (13)$$

$$\gamma_{i, NOMA} = \frac{\alpha_i P |h_i|^2}{P |h_i|^2 \sum_{j=i+1}^N \alpha_j + \sigma^2} \quad (14)$$

$$R_{i, NOMA} = \log_2(1 + \gamma_{i, NOMA}) \quad (15)$$

$$R_{i, NOMA} = \sum_{i=1}^N R_{i, NOMA} \quad (16)$$

$$R_{i, \text{NOMA}} = \sum_{i=1}^{N-1} \log_2 \left(1 + \frac{\alpha_i P |h_i|^2}{P |h_i|^2 \sum_{j=i+1}^N \alpha_j + \sigma^2} \right) + \log_2 \left(1 + \frac{\alpha_N P |h_N|^2}{\sigma^2} \right) \quad (17)$$

3.2. Analysis of Orthogonal Multiple Access Technique Performance.

Based on Fig. 3, and reference [28], the achievable rate for OMA could be analyzed; Let $x_1, x_2, \dots, x_N$ denote the messages to be transmitted to the users. Hence, the OMA signal can be expressed by Eq. (18) [28], at the i^{th} user, the received vector is given by Eq. (19) [28] and the SINR for decoding the i^{th} user signal is given by Eq. (20) [28].

$$X_{i, \text{OMA}} = \sqrt{P} x_i \quad (18)$$

$$y_{i, \text{OMA}} = h_i \sqrt{P} x_{i, \text{OMA}} + w_i \quad (19)$$

$$\gamma_{i, \text{OMA}} = \frac{P |h_i|^2}{\sigma^2} \quad (20)$$

In OMA, each UE is allocated its own orthogonal frequency or time slot, in order to receive information. When the total bandwidth and power are shared among the UEs equally [28], the throughput achievable rate (bps/Hz) of the i^{th} user can be given by Eq. (21) [28], and the sum rate of all the OMA users is given by Eq. (22). In the same manner, Eq. (22) [28], can be re-expressed by Eq. (23) [28], Where; N is the users' number. In the case of two users, the achievable rates of the first and second users will be given by Eq. (24) [28] and by Eq. (25) [28] respectively. In addition, in the case of four users, the achievable rates from first to fourth users can be expressed by Eq. (26) [28], Eq. (27) [28], Eq. (28) [28], and Eq. (29) [28] respectively.

$$R_{i, \text{OMA}} = \frac{1}{N} \log_2 (1 + \gamma_{i, \text{OMA}}) \quad (21)$$

$$R_{i, \text{OMA}} = \sum_{i=1}^N R_{i, \text{OMA}} \quad (22)$$

$$R_{i, \text{OMA}} = \frac{1}{N} \sum_{i=1}^N \log_2 \left(1 + \frac{P |h_i|^2}{\sigma^2} \right) \quad (23)$$

$$R_{1, \text{two-UEs}} = \frac{1}{2} \log_2 \left(1 + \frac{P |h_1|^2}{\sigma^2} \right) \quad (24)$$

$$R_{2, \text{two-UEs}} = \frac{1}{2} \log_2 \left(1 + \frac{P |h_2|^2}{\sigma^2} \right) \quad (25)$$

$$R_{1, \text{four-UEs}} = \frac{1}{4} \log_2 \left(1 + \frac{P |h_1|^2}{\sigma^2} \right) \quad (26)$$

$$R_{2, \text{four-UEs}} = \frac{1}{4} \log_2 \left(1 + \frac{P |h_2|^2}{\sigma^2} \right) \quad (27)$$

$$R_{3, \text{four-UEs}} = \frac{1}{4} \log_2 \left(1 + \frac{P |h_3|^2}{\sigma^2} \right) \quad (28)$$

$$R_{4, \text{four-UEs}} = \frac{1}{4} \log_2 \left(1 + \frac{P |h_4|^2}{\sigma^2} \right) \quad (29)$$

4. System Model.

In this paper, we study the spectral efficiency of a downlink NOMA system in two different scenarios: a two-user scenario and a multiuser scenario. We assume that the channel between the transmitter and the receiver is a Rayleigh fading channel and that the transmitter uses QPSK modulation and superposition coding. At the receiver, SIC is used to decode the signal. We use Mat-Lab to simulate the system and the results show that NOMA can achieve a better performance in terms of spectral efficiency.

4.1 Two Users (2-UEs NOMA) Scenario

In the case of two users, the signal transmitted by the BS can be expressed through Eq. (30) [10]. The block diagram for this scenario is shown in Fig. 4.

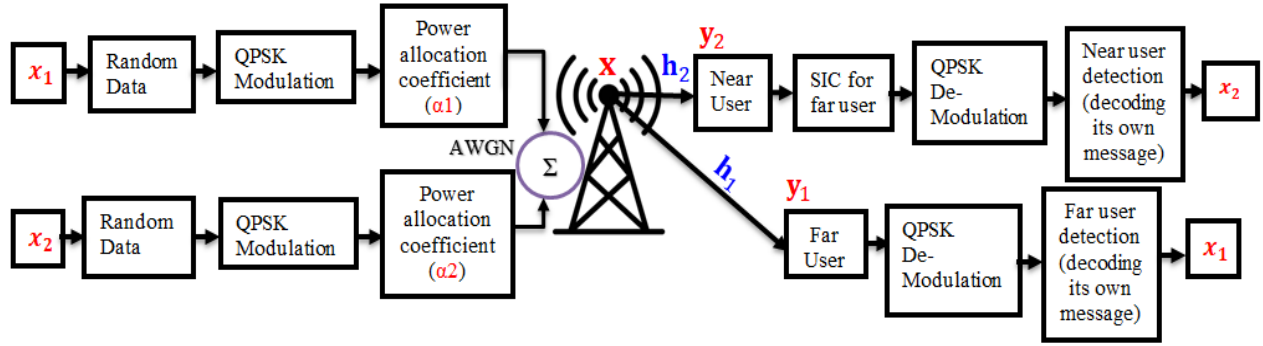


Figure 4: Block diagram of SISO-NOMA wireless communication system for two users over a Rayleigh fading channel.

$$X = \sqrt{P}(\sqrt{\alpha_1}x_1 + \sqrt{\alpha_2}x_2) \quad (30)$$

Where; P is the transmit power, $\alpha_1 > \alpha_2$, $\alpha_1 + \alpha_2 = 1$.

The first user (far) in the system will receive a vector that is described by Eq. (31) [10]. This vector can be used to directly decode and estimate x_1 . Eq. (31) can also be rewritten as Eq. (32) [10]. The SINR for decoding the first user's signal is given by Eq. (33) [7]. The achievable rate for the first user is given by Eq. (34) [10].

$$y_1 = h_1\sqrt{P}(\sqrt{\alpha_1}x_1 + \sqrt{\alpha_2}x_2) + w_1 \quad (31)$$

$$y_1 = h_1\sqrt{P}\sqrt{\alpha_1}x_1 + h_1\sqrt{P}\sqrt{\alpha_2}x_2 + w_1 \quad (32)$$

$$\gamma_1 = \frac{\alpha_1 P |h_1|^2}{\alpha_2 P |h_1|^2 + \sigma^2} \quad (33)$$

$$R_1 = \log_2 \left(1 + \frac{\alpha_1 P |h_1|^2}{\alpha_2 P |h_1|^2 + \sigma^2} \right) \quad (34)$$

The second (near) user receives the signal vector given by Eq. (35) [10]. First, the signal x_1 is decoded directly. Then, the SIC is applied through Eq. (36) [10], to decode the signal x_2 from the near user. After the first user's signal is canceled, the second user's signal-to-interference-plus-noise ratio (SINR) can be given by Eq. (37) [7]. The corresponding achievable rate (bps/Hz) for the second user is given by Eq. (38) [10].

$$y_2 = h_2\sqrt{P}\sqrt{\alpha_1}x_1 + h_2\sqrt{P}\sqrt{\alpha_2}x_2 + w_2 \quad (35)$$

$$y'_2 = h_2\sqrt{P}\sqrt{\alpha_1}x_1 + h_2\sqrt{P}\sqrt{\alpha_2}x_2 + w_2 - h_2\sqrt{P}\sqrt{\alpha_1}\hat{x}_1 \quad (36)$$

$$\gamma_2 = \frac{\alpha_2 P |h_2|^2}{\sigma^2} \quad (37)$$

$$R_2 = \log_2 \left(1 + \frac{\alpha_2 P |h_2|^2}{\sigma^2} \right) \quad (38)$$

4.2 Multi-Users (4-UEs NOMA) Scenario

In the second scenario which is Multi-Users NOMA, four users are used the block diagram for four users NOMA system is shown in Fig. 5. According to the NOMA performance analysis which is discussed in the second section the transmitted signal for four users can be expressed by Eq. (39) [10].

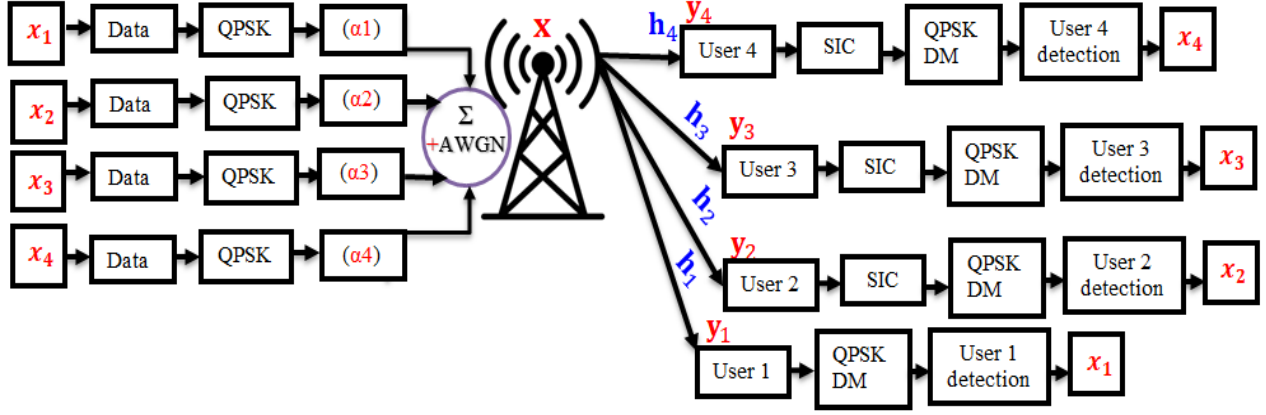


Figure 5. Block diagram of SISO-NOMA wireless communication system for four users over a Rayleigh fading channel.

$$X = \sqrt{P}(\sqrt{\alpha_1}x_1 + \sqrt{\alpha_2}x_2 + \sqrt{\alpha_3}x_3 + \sqrt{\alpha_4}x_4) \quad (39)$$

The signal received by the first (farthest) user can be expressed by Eq. (40) [10]. This user is assigned to α_1 and thus can decode its own data signal. The data signals of users 2, 3 and 4 are considered as interference. Therefore, the SINR for decoding the signal of the first user is given by Eq. (41) [7], and the achievable rate of the first user (bps/Hz) is given by Eq. (42) [10].

$$y_1 = h_1\sqrt{P}\sqrt{\alpha_1}x_1 + h_1\sqrt{P}\sqrt{\alpha_2}x_2 + h_1\sqrt{P}\sqrt{\alpha_3}x_3 + h_1\sqrt{P}\sqrt{\alpha_4}x_4 + w_1 \quad (40)$$

$$\gamma_1 = \frac{\alpha_1 P |h_1|^2}{\alpha_2 P |h_1|^2 + \alpha_3 P |h_1|^2 + \alpha_4 P |h_1|^2 + \sigma^2} \quad (41)$$

$$R_1 = \log_2 \left(1 + \frac{\alpha_1 P |h_1|^2}{\alpha_2 P |h_1|^2 + \alpha_3 P |h_1|^2 + \alpha_4 P |h_1|^2 + \sigma^2} \right) \quad (42)$$

The received vector at the second (second farthest) user is given by Eq. (43) [10]. Because of the data from the first user is dominating, as α_1 is greater than $\alpha_2 + \alpha_3 + \alpha_4$. Thus, the first user's data is decoded directly, and SIC is performed for the first user. Now, the data from the second user is dominating, as α_2 is greater than $\alpha_3 + \alpha_4$. Thus, the second user's data is decoded directly, and the data from users 3 and 4 is considered as interference. Thus, the SINR for decoding the second user's signal is given by Eq. (44) [7], and the achievable rate (bps/Hz) of the second farthest user can be expressed by Eq. (45) [10].

$$y_2 = h_2\sqrt{P}\sqrt{\alpha_1}x_1 + h_2\sqrt{P}\sqrt{\alpha_2}x_2 + h_2\sqrt{P}\sqrt{\alpha_3}x_3 + h_2\sqrt{P}\sqrt{\alpha_4}x_4 + w_2 \quad (43)$$

$$\gamma_2 = \frac{\alpha_2 P |h_2|^2}{\alpha_3 P |h_2|^2 + \alpha_4 P |h_2|^2 + \sigma^2} \quad (44)$$

$$R_2 = \log_2 \left(1 + \frac{\alpha_2 P |h_2|^2}{\alpha_3 P |h_2|^2 + \alpha_4 P |h_2|^2 + \sigma^2} \right) \quad (45)$$

At the third (third farthest = second near) user, the received vector is given by Eq. (46) [10], at user 3, since the user 1 data is dominating as $\alpha_1 > \alpha_2 + \alpha_3 + \alpha_4$. Thus, direct decoding for user 1 data is performed, then SIC for user 1 is performed. Now, the user 2 data is dominating as $\alpha_2 > \alpha_3 + \alpha_4$. Thus, direct decoding for user 2 data is performed, and then SIC for user 2 is performed. Now, the user 3 data is dominating as $\alpha_3 > \alpha_4$. Thus, direct decoding for user 3 data is performed, and consider the data of user

4, as interference. Thus the SINR for decoding the user 3 signal is given by Eq. (47) [7], and the achievable rate (bps/Hz) of the third (third farthest = second near) user is given by Eq. (48) [10].

$$y_3 = h_3\sqrt{P}\sqrt{\alpha_1}x_1 + h_3\sqrt{P}\sqrt{\alpha_2}x_2 + h_3\sqrt{P}\sqrt{\alpha_3}x_3 + h_3\sqrt{P}\sqrt{\alpha_4}x_4 + w_2 \quad (46)$$

$$\gamma_3 = \frac{\alpha_3 P |h_3|^2}{\alpha_4 P |h_3|^2 + \sigma^2} \quad (47)$$

$$R_3 = \log_2 \left(1 + \frac{\alpha_3 P |h_3|^2}{\alpha_4 P |h_3|^2 + \sigma^2} \right) \quad (48)$$

The received vector at the nearest user is given by Eq. (49) [10]. User 4 is the nearest user, so the direct decoding for user 1 data is performed, since the user 1 data is dominating as $\alpha_1 > \alpha_2 + \alpha_3 + \alpha_4$. Thus, direct decoding for user 1 data is performed, then SIC for user 1 is applied. Now, the user 2 data is dominating as $\alpha_2 > \alpha_3 + \alpha_4$. Thus, direct decoding for user 2 data is performed, then SIC for user 2 is performed. Now, the user 3 data is dominating as $\alpha_3 > \alpha_4$.

Thus, direct decoding for user 3 data is performed, then SIC for user 3 is performed. Finally, direct decoding for user 4 data is performed in order to recover its own data. Thus the SINR for decoding the user 4 (nearest user) signal is given by Eq. (50) [7], and the achievable rate (bps/Hz) of the nearest user is given by Eq. (51) [10].

$$y_4 = h_4\sqrt{P}\sqrt{\alpha_1}x_1 + h_4\sqrt{P}\sqrt{\alpha_2}x_2 + h_4\sqrt{P}\sqrt{\alpha_3}x_3 + h_4\sqrt{P}\sqrt{\alpha_4}x_4 + w_2 \quad (49)$$

$$\gamma_4 = \frac{\alpha_4 P |h_4|^2}{\sigma^2} \quad (50)$$

$$R_4 = \log_2 \left(1 + \frac{\alpha_4 P |h_4|^2}{\sigma^2} \right) \quad (51)$$

5. Results and Discussion

This section presents the results of simulations for downlink NOMA systems with two (2-UEs) and four users (4-UEs). All users are assumed to have a single antenna, QPSK modulation is used, and the channel between the BS and each user is modeled as a Rayleigh fading channel. The randomly generated channels are ordered based on their strength, with the weakest channel being assigned to the first user and the strongest channel to the Nth user. The BS transmits a signal with a power of 1:50 dBm to all users. The parameters for both scenarios are shown in Table 1.

Table1. System parameters.

Parameters	Values
Bandwidth (BW)	20×10^6 Hz = 20 MHz
Noise power (No)	8.23×10^{-14}
Boltzmann Constant	1.38×10^{-23}
Path loss exponent (p)	4
Channel Realization	5×10^5
Transmit power (Pt)	0:1:50 (dBm)
Power allocation coefficients (α) for 2-UEs scenario	$\alpha_1 = 0.75$ $\alpha_2 = 0.25$
Power allocation coefficients (α) for 4-UEs scenario	$\alpha_1 = 0.75, \alpha_2 = 0.1875$ $\alpha_3 = 0.046875, \alpha_4 = 0.015625$
Distances for two users scenario	$d_{\text{near}} = 200$ m $d_{\text{far}} = 300$ m
Distances for four users scenario	$d_{\text{nearest}} = 100$ m, $d_{\text{near}} = 200$ m

$$d_{\text{far}} = 300 \text{ m}, d_{\text{farthest}} = 500 \text{ m}$$

The simulated BER performance of the 2-UEs scenario, $N = 2$, is shown in **Fig. 6**, with power allocation coefficients $\alpha_1 = 0.75$ and $\alpha_2 = 0.25$.

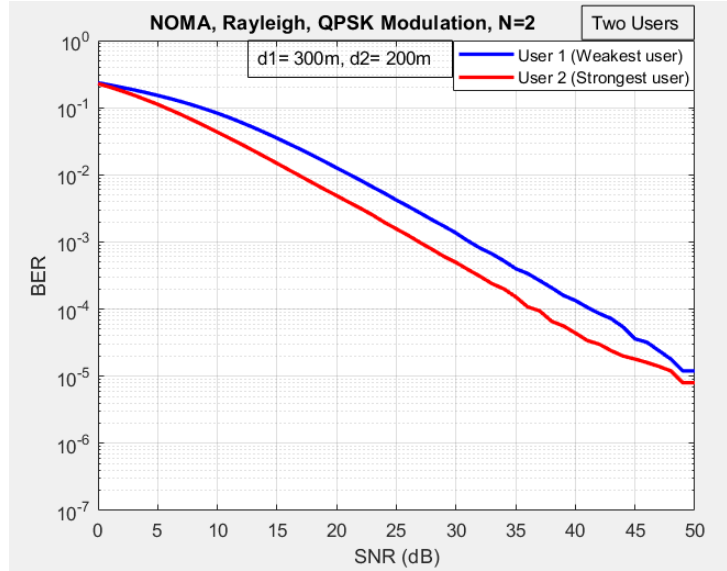


Figure 6. BER vs SNR for 2-UEs scenario over Rayleigh fading channel.

Fig. 6, illustrates the BER versus SNR for the 2-UEs scenario, the red line is for the strong user by a distance of 200 m, and the blue one is for the weak user by a distance of 300 m. As it is clear from Fig. 6, the amount of the BER of a strong user is less than the amount of BER of a weak user. This means that as the distance of the user from the BS decreases, the BER decreases and vice versa.

Fig. 7, is generally similar to Fig. 6, except that it considers the 4-UEs scenario, i.e., $N = 4$. The power allocation coefficients are $\alpha_1 = 0.75$, $\alpha_2 = 0.1875$, $\alpha_3 = 0.046875$ and $\alpha_4 = 0.015625$, four users are used in multi-users NOMA by distances that are shown in Table 1.

It is worth saying that two new users are increased for the 2-UEs scenario in order to become multi-users NOMA. One user is increased which is the nearest user from the base station, is represented by black color, and another new user is increased which is the farthest user from the base station is represented by green color in Fig. 7.

The amount of the BER is less for the strongest user compared to the other users who are farther from the BS, and vice versa for the farthest user. In addition, when the SNR is equal to 25 dB, the BER is equal to 0.004202 and 0.001564 for the weakest and strong users of the 2-UEs scenario respectively, while the BER is equal to 0.001738, 0.000706, 0.000286, and 0.000028 from the weakest toward the strongest user respectively for multi-users (4-UEs) scenario as shown in Table 2.

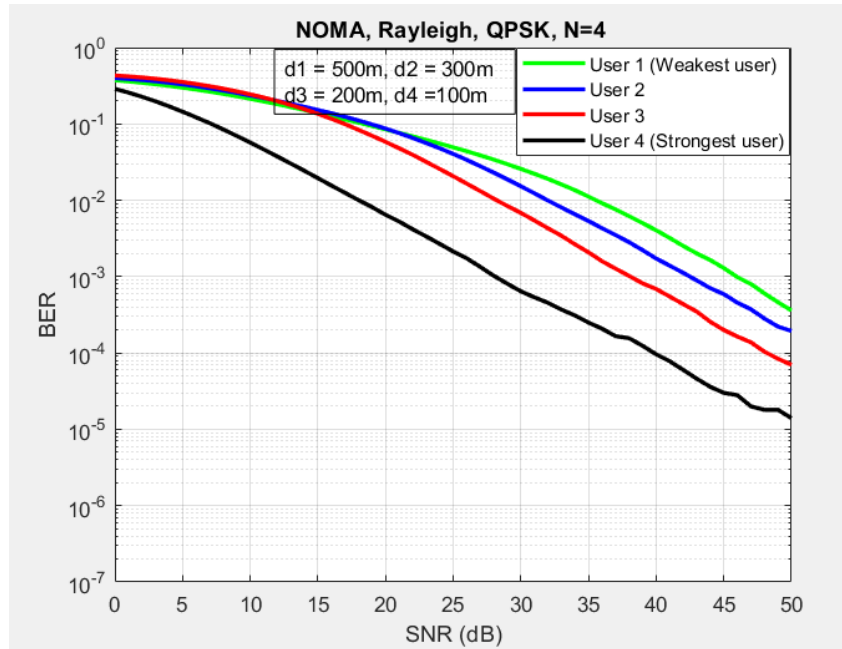


Figure 7. BER vs SNR for 4-UEs scenario over Rayleigh fading channel.

Fig. 8, shows the BER performance versus transmits power for the 2-UEs scenario. Same parameters are used for simulating Fig. 8, similar to Fig. 6, the red line represents the near user while the blue line is for the far user, as seen in Fig. 8, the amount of BER decreases by increasing the range of transmitted power until reaching the saturation region.

It could be said that the near user has lower BER compared with the far user, this is due to the distance of the users from the base station. The amount of BER for the 2-UEs scenario is shown in Table 2, at transmitting power which is equal to 25 dBm. As it is obvious from Table 2, the amount of BER for the near user at transmitting power = 25 dBm is 0.000016 while for the far user is 0.000052, the difference between BER of the near and the far user is due to the distances of the users from the base station.

Fig. 9, depicts the BER performance versus transmits power for the 4-UEs scenario by using the same parameters that are used for simulation of the BER versus the SNR, and the same distances are used, which is shown in Table 1.

Red line and blue line represent those two users, which were used in the 2-UEs scenario, while the black line and the green line represent the two new users, which were added to the 2-UEs scenario in order to become a multi-users scenario. These four users in 4-UEs scenario have a different amount of BER, which is shown in Table 2.

The amount of BER for the nearest user is 0.000028 at transmitting power = 25 dBm, while for the farthest user is 0.001738. In addition, the BER of the remaining two users is increased compared with the 2-UEs scenario. The difference between the amounts of BER of these users is due to the distances of the users from the base station. In addition, by increasing the power for the multi-users scenario the amount of BER will decrease.

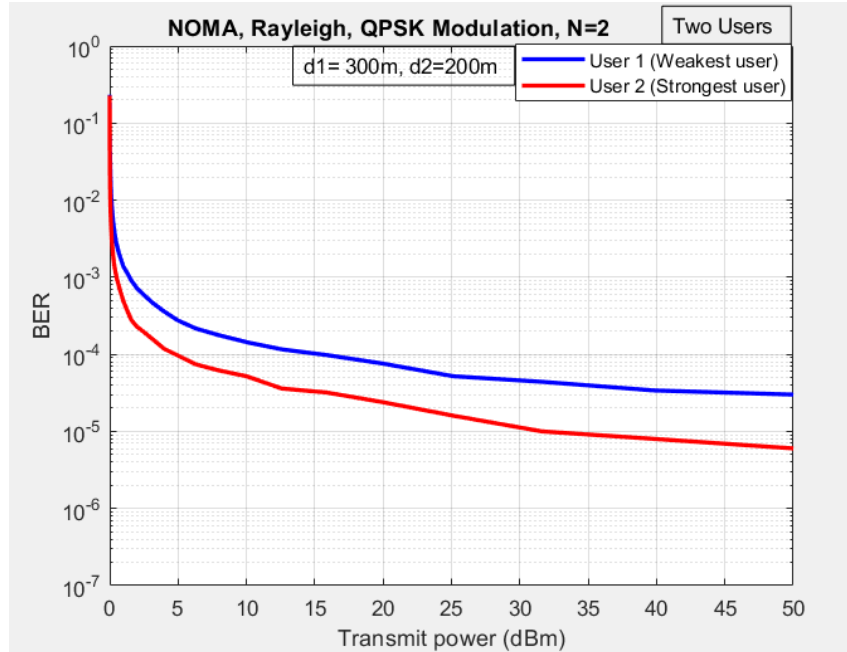


Figure 8: BER vs Transmit power for 2-UEs scenario over Rayleigh fading channel.

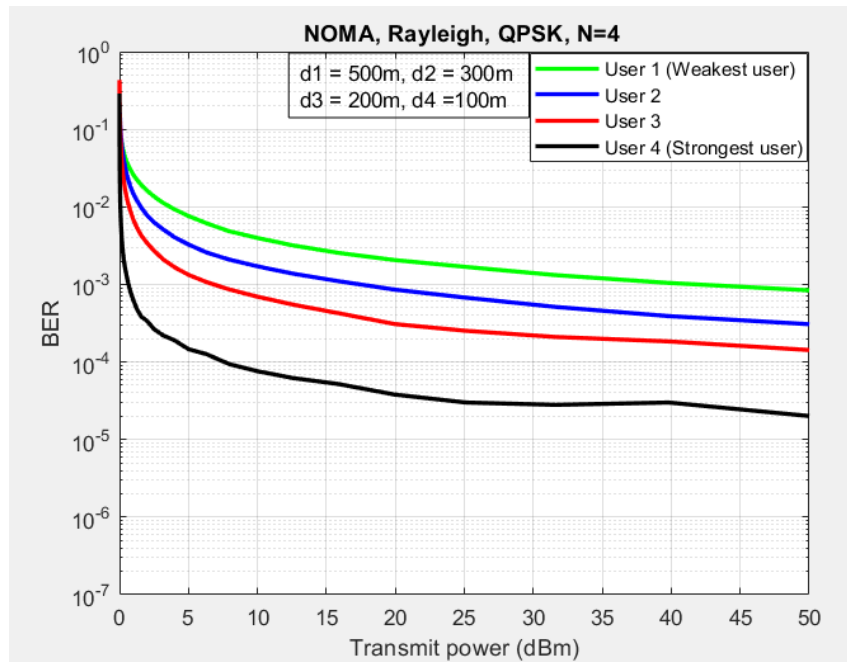


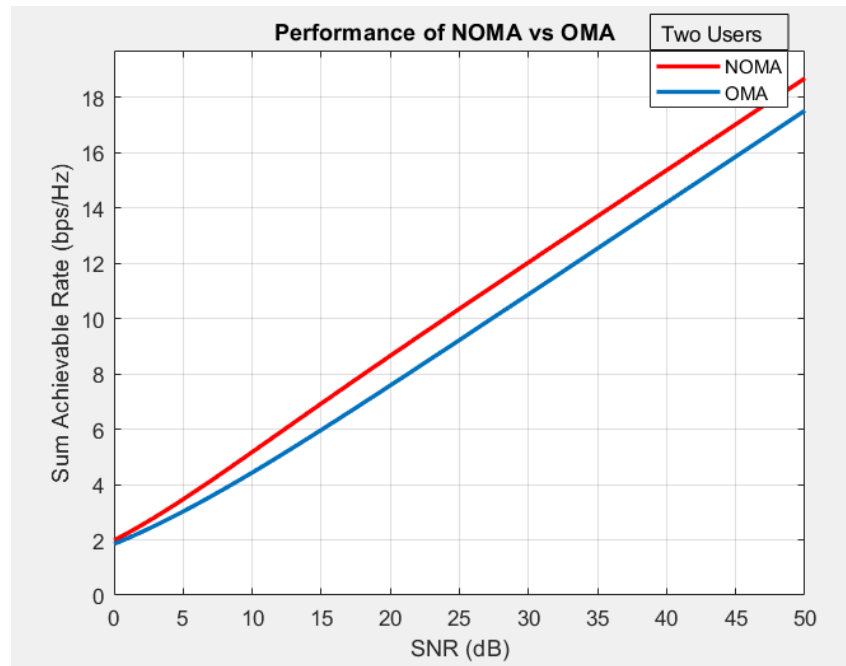
Figure 9. BER vs Transmit power for 4-UEs scenarios over Rayleigh fading channel.

From these compression results, it is indicated that, by increasing the number of users from two to four users, the amount of BER will be increased due to the power allocation coefficient problem, in addition, due to increasing system complexity. Since by increasing the number of users, the system complexity will be increased and cause error propagation.

In Fig. 10, the comparison of the NOMA and OMA system in terms of the achievable sum rate versus SNR is explained for the 2-UEs scenario.

Table 2. BER Comparison of 2-UEs and 4-UEs scenarios at P = 25dBm and SNR = 25dB.

SNR	Scenario		User 1	User 2	
	o				
= 25dB	2-Users	/	0.00420	0.00156	/
	Scenario	User 1	User 2	User 3	User 4
	o				
	4-Users	0.04939	0.04051	0.02069	0.00213
Power = 25 dBm	Scenario		User 1	User 2	
	o				
	2-Users	/	0.00005	0.00001	/
	Scenario	User 1	User 2	User 3	User 4
	o				
	4-Users	0.00173	0.00070	0.00028	0.00002
		8	6	6	8

**Figure10.** Capacity comparison of NOMA and OMA systems for 2-UEs scenario over Rayleigh fading channel.

For the comparison of NOMA and OMA systems for the 2-UEs scenario in **Fig. 10**, the same parameters are used according to **Table 1**. In **Fig. 10**, the red line indicates the NOMA system, while the blue line is for the 2-UEs OMA system. The simulation result for the normalized sum achievable data rate (bps/Hz) versus the SNR of NOMA and OMA systems depicts that NOMA outperforms OMA in the 2-UEs scenario. As it is indicated in **Fig. 10**, the amount of the achievable sum rate (bps/Hz) for both the

NOMA and OMA systems of the 2-UEs scenario is increased by increasing the range of the SNR more and more.

The amount of the achievable sum rate (bps/Hz) for the 2-UEs scenario at SNR = 25 dB, is shown in Table 3. The sum rate for NOMA and OMA systems is equal to 10.36 (bps/Hz) and 9.228(bps/Hz) respectively.

Fig. 11, shows the amount of the achievable sum rate for multi-users (4-UEs scenario). In Fig. 11, for the comparison of NOMA and OMA systems for the 4-UEs scenario same parameters are used according to Table 1. The red line in Fig. 11, indicates the NOMA system, while the blue line is for the 4-UEs OMA system. In the same of 2-UEs scenario, the simulation result for the normalized achievable sum data rate (bps/Hz) versus the SNR of NOMA and OMA systems depicts that NOMA outperforms OMA in the 4-UEs scenario.

As it is indicated in Fig. 11, the amount of the achievable sum rate (bps/Hz) for both the NOMA and OMA systems of the 4-UEs scenario is increased by increasing the range of the SNR more and more. The amount of the achievable sum rate (bps/Hz) for the 2-UEs scenario at SNR = 25 dB, is shown in Table 3. The sum rate for the NOMA system is 16.24 (bps/Hz) while for the OMA system is equal to 11.49 (bps/Hz).

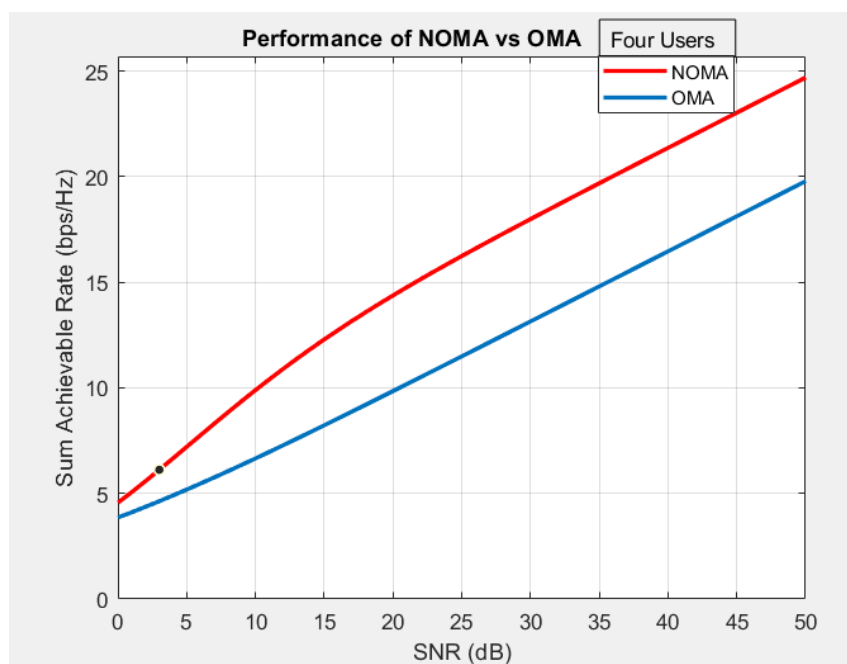


Figure 11. Capacity comparison of NOMA and OMA systems for 4-UEs scenario over Rayleigh fading channel.

Fig. 12, shows the performance of NOMA and OMA systems for the 2-UEs scenario in terms of the achievable sum rate versus transmit power. Performance comparison of NOMA and OMA systems for the 2-UEs scenario is shown in figure Fig. 12, and system parameters for achieving this result are shown in Table 1. Similar to Fig. 10, and Fig. 11, in Fig. 12, the red line indicates the NOMA system, while the blue line is for the 2-UEs OMA system.

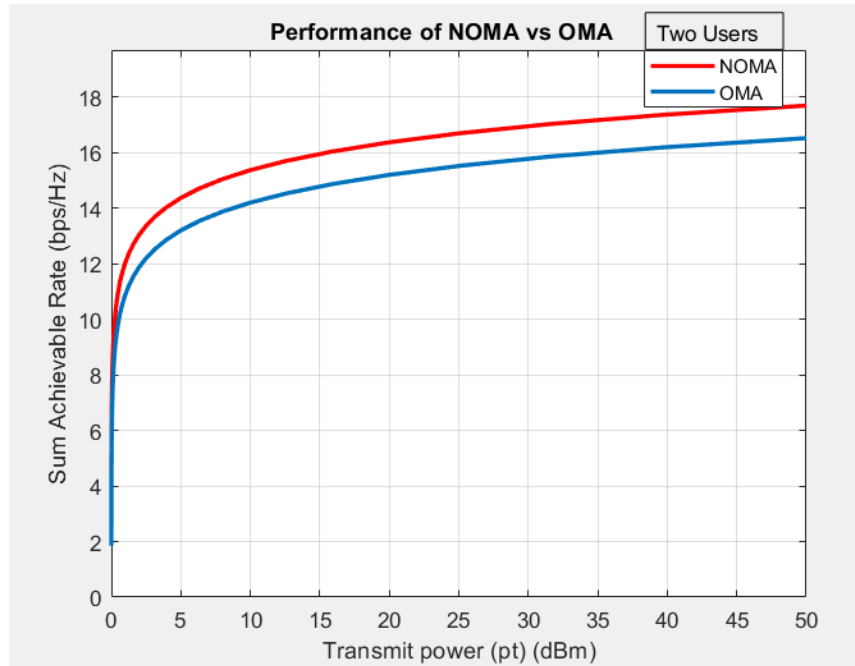


Figure 12. Performance comparison of NOMA and OMA for 2-UEs scenarios over Rayleigh fading channel.

The simulation result for the normalized achievable sum data rate (bps/Hz) versus the transmit power of NOMA and OMA systems depicts that NOMA outperforms OMA in the 2-UEs scenario. The amount of the achievable sum rate (bps/Hz) for the 2-UEs scenario at transmitting power = 25 dBm, is shown in Table 3.

The sum rate for the NOMA system is 16.7 (bps/Hz) but it is 15.53 (bps/Hz) for the OMA system. Fig. 13, shows the amount of throughput of NOMA and OMA systems for the 4-UEs scenario.

The amount of the throughput versus transmit power for multi-users NOMA depicts NOMA outperforming OMA such as in the previous results. In addition, red and blue lines are used to represent NOMA and OMA systems respectively by using the same parameters which are shown in Table 1.

As it is clear from Fig. 13, the amount of throughput of NOMA is improved more compare to the OMA system for the multi-users scenario. The amount of the throughput for the 4-UEs scenario is shown in Table 3, in which NOMA is 20.69 (bps/Hz) and OMA is 15.79 (bps/Hz).

As it is indicated in Table 3, by increasing the range of the transmitted power the amount of the throughput for both the NOMA and OMA systems and for both of the 2-UEs and the 4-UEs scenario are increased, until reach saturation after 50 dBm of the transmitted power.

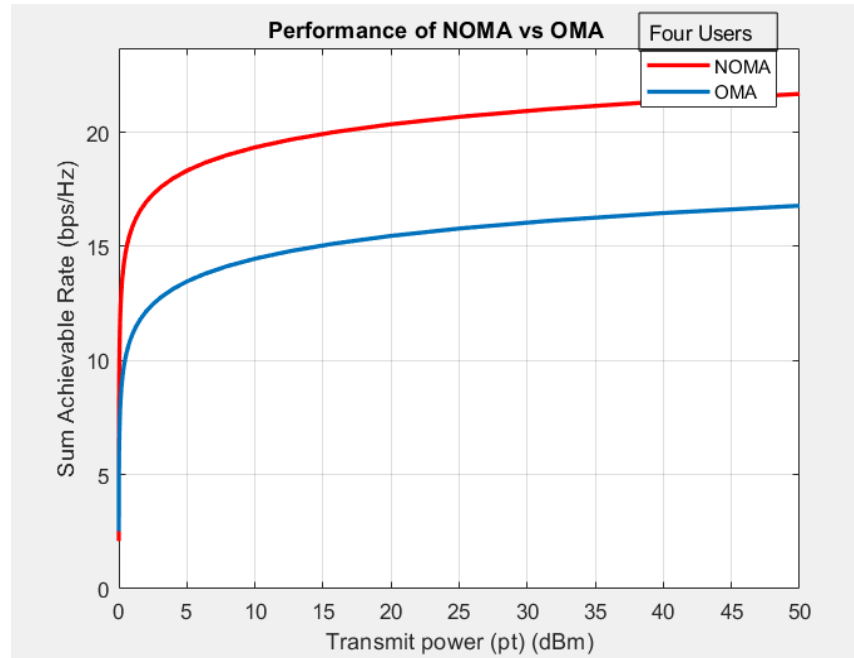


Figure 13. Performance comparison of NOMA and OMA for 4-UEs scenarios over Rayleigh fading channel.

Table 3. NOMA and OMA performance comparison in terms of system capacity.

Achievable sum rate (bps/Hz)	NOMA	OMA
SNR = 25 dB	2-UEs	2-UEs
	4-UEs	4-UEs
	10.36	9.228
Power = 25 dBm	2-UEs	2-UEs
	4-UEs	4-UEs
	16.7	15.53
	20.69	15.79

From these results, it is clear there is a capacity comparison between NOMA and OMA systems for 2-UEs and 4-UEs scenarios. According to the results, NOMA outperforms OMA. The amount of achievable sum rates for each of the systems for both of the scenarios is shown in **Table 3**, when SNR = 25 dB and at transmitted power = 25 dBm. From **Table 3**, it is indicated that by increasing the number of users, the capacity of the system is increased for both of the scenarios (2-UEs and 4-UEs scenario), and for both of the systems (NOMA and OMA systems).

However, for the multi-UEs scenario, the capacity is much more than in the 2-UEs scenario. In addition, by increasing the amount of transmitted power, the capacity will be increased, especially for the multi-UEs (4-UEs) scenario.

6. CONCLUSION

NOMA has been proposed as a possible solution to the problem of providing services to multiple users in future wireless networks. NOMA involves allowing multiple users to share the same time and frequency resources, which makes it more efficient than other multiple access schemes.

In this paper system, analysis for both NOMA and OMA has been expressed. According to the simulated results for the NOMA scheme, the 2-UEs scenario is better than the multi-UEs scenario in terms of BER and system complexity, while according to the system capacity, the multi-UEs scenario

outperforms the 2-UEs scenario. In addition, in terms of system capacity, overall, NOMA has seemed to be an effective technique compared to OMA for improving the performance of wireless networks. In particular, NOMA has been shown to improve the throughput spectral efficiency of wireless networks.

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