University of Baghdad
College of Engineering
JOURNAL OF ENGINEERING

Journal of Engineering

journal homepage: www.joe.uobaghdad.edu.iq

Volume 29 Number 4 April 2023

Modeling and Simulating NOMA Performance for Next Generations

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ABSTRACT

Non-orthogonal Multiple Access (NOMA) is a multiple-access technique allowing multiusers to share the same communication resources, increasing spectral efficiency and throughput. NOMA has been shown to provide significant performance gains over orthogonal multiple access (OMA) regarding spectral efficiency and throughput. In this paper, two scenarios of NOMA are analyzed and simulated, involving two users and multiple users (four users) to evaluate NOMA's performance. The simulated results indicate that the achievable sum rate for the two users' scenarios is 16.7 (bps/Hz), while for the multi-users scenario is 20.69 (bps/Hz) at transmitted power of 25 dBm. The BER for two users' scenarios is 0.004202 and 0.001564 for user 1 and user 2, respectively, while the BER for multi-users scenario are 0.001738, 0.000706, 0.000286, and 0.000028 for user 1, user 2, user 3, and user 4 respectively. In addition, this paper has compared 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 of 25 dBm.

Keywords: NOMA, BER NOMA, Achievable Rate, NOMA and OMA Capacity, SIC.

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Peer review under the responsibility of University of Baghdad.
https://doi.org/10.31026/j.eng.2023.04.11

Article received: 09/08/2022
Article accepted: 06/02/2023
Article published: 01/04/2023

نمذجة ومحاكاة أداء نوما للأجيال القادمة

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الخلاصة

الوصول المتعدد غير المتعامد (NOMA) هو أسلوب وصول متعدد يسمح لعدة مستخدمين بمشاركة نفس موارد الاتصال ، مما يؤدي إلى زيادة الكفاءة الطيفية والإنتاجية. لقد ثبت أن NOMA يوفر مكاسب كبيرة في الأداء على الوصول المتعدد المتعامد (OMA) من حيث الكفاءة الطيفية والإنتاجية. في هذه الورقة ، تم تحليل ومحاكاة سيناريوهين لـ NOMA ، بما في ذلك مستخدمين اثنين ومستخدمين متعددين (أربعة مستخدمين) من أجل تقييم أداء NOMA. تشير النتائج المحاكاة إلى أن معدل المجموع القابل للتحقيق لسيناريو المستخدمين الاثنين هو 16.7 (بت / هرتز) ، بينما بالنسبة لسيناريو المستخدمين المتعددين هو 20.69 (بت / هرتز) عند الطاقة المرسلة 25 ديسيبل ميلي واط. أن معدل BER لسيناريو مستخدمين هو 0.004202 و 0.001564 للمستخدم 1 والمستخدم 2 على التوالي ، بينما معدل BER لسيناريو المستخدمين المتعددين هو على التوالى 0.001738 و 0.000706 و 0.000286 و 0.000028 للمستخدم 1 والمستخدم 2 والمستخدم 3 والمستخدم 4. بالإضافة إلى ذلك ، فقد قارنت هذه الورقة NOMA مع OMA من حيث معدل المجموع القابل للتحقيق. تشير النتائج التي تم الحصول عليها إلى أنه تم تحقيق تحسن لمستخدمين NOMA (16.7 بت في الثانية / هرتز) مقارنة بـ OMA (15.53 بت في الثانية / هرتز) ، بينما بالنسبة للمستخدمين المتعددين NOMA(20.69 (بت / هرتز)) مقارنة مع OMA (15.79 (بت في الثانية / هرتز)) عند القدرة المرسلة تساوي 25 ديسيبل ميلي واط.

الكلمات الرئيسية: NOMA ، BER NOMA ، المعدل القابل للتحقيق ، NOMA و OMA السعة ، SIC.

1. INTRODUCTION

In the future, the mobile internet and the internet of things might be the main driving force for mobile communication development **(Omer et al., 2020)**. New multiple-access technologies will be needed to meet the requirements for future generations of wireless communication **(Mohammed, 2020)**. Non-orthogonal multiple access (NOMA) is an important enabling technology that can provide high system throughput, low latency, and massive connectivity **(Lu et al., 2017; Dai et al., 2018a).**

NOMA is a multiple access technique that allows users to share the same time-frequency resource using non-orthogonal signals. This makes it possible to increase the number of users that a given time-frequency resource can support. NOMA can provide significant performance gains over traditional orthogonal multiple access schemes (OMA) since orthogonality limits capacity. NOMA breaks this capacity limitation by allowing simultaneous transmission of multiple users in the same frequency carrier. **Fig. 1** shows the NOMA and OMA signals in the frequency domain **(Wu et al., 2018; Luo et al., 2021)**. 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 serve better cell edge users (users far from the base station) **(Luo et al., 2021; Dai et al., 2018)**.

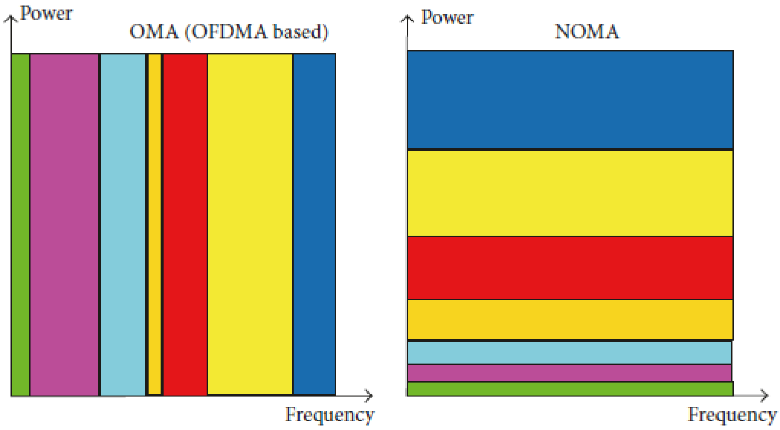

Figure 1. The NOMA and OMA signal in the frequency domain **(Hussain et al., 2020)**.

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 concerning the base station. Typically, users with poor channel conditions are allocated more power than those with good. 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 **(Zheng et al., 2020; Alqahtani et al., 2021)**.

The current studies on power domain-NOMA (PD-NOMA) performance mainly focus on the sum rate and BER performance. The BER of a digital communication system is an important metric used to quantify data quality transmitted through the Downlink NOMA system **(El-Mokadem et al., 2019)**. The authors **(Lee and Kim, 2019)** 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, they looked at the symbol error rate for NOMA under imperfect SIC using quadrature amplitude modulation (QAM). They came up with a 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. In **(Wang et al., 2017)**, an exact average BER expression of QPSK modulation for uplink PD-NOMA with SIC was obtained under the additive white Gaussian noise channel (AWGN). The BER performance for uplinking PD-NOMA in the presence of SIC error was also considered by **(Wang et al., 2017)** and **(Haci et al., 2017)**. Kara and Kaya examined the BER of downlink and uplink NOMA, where phase shift keying (PSK) modulation and exact closed-form BER expressions are used over Rayleigh fading channels are derived for the scenario of imperfect SIC **(Kara and Kaya, 2018)**. 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 by **(Emir et al., 2021)**. Closed-form BER expressions are composed for the ideal and practical scenarios of the SIC process. When considering perfect SIC, the results show that diversity and array gains can be achieved at high SNR. However, if SIC is imperfect, the system performance exhibits an error floor at high SNRs. The authors of **(Yeom et al., 2019)** 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 **(Assaf et al., 2019; Bariah et al., 2019)** have addressed the BER performance for various NOMA communication systems and modulation schemes. The study of **(Baidas et al., 2018)** 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, **(Yu et al., 2018)** investigated the effective capacity under the quality of service (QoS) requirements for multiple NOMA users and found that NOMA generally performs better than OMA.
This work aims 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 and multi-user scenarios. In addition, it compares NOMA and OMA performance according to their capacity (sum rates).

2. BASIC CONCEPT OF DOWNLINK NOMA SYSTEM

Fig. 2 shows a base station (BS), a far user (UE1), and a near user (UE2). The BS is selected to use the downlink NOMA technique to transmit signals to the UE1 and UE2 using the same frequency band.

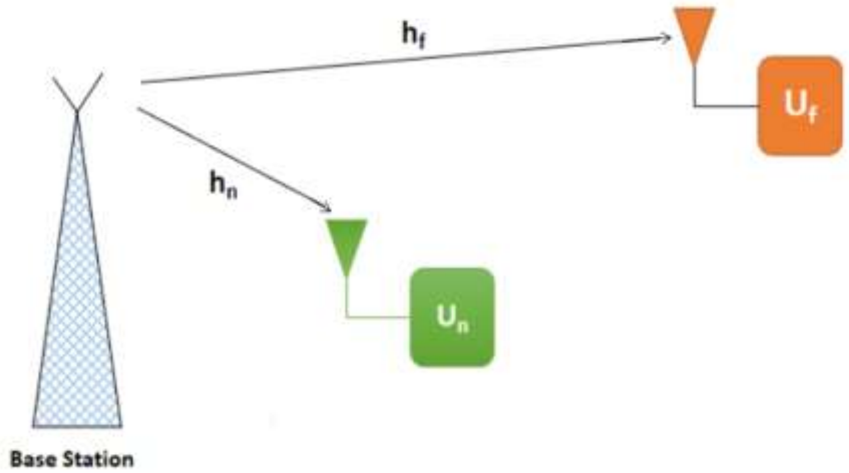

Figure 2. Downlink 2-UEs NOMA system **(Mouni et al., 2022)**.

Before transmission, the BS superimposes the UE1 and UE2 signals with different power levels to create a downlink NOMA signal. The received signal at the UE1 and UE2 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 of the near user signal to guarantee that both users can decode their desired signals. However, this means that the interference signal overcomes the desired signal at the near user.

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 can then decode the desired (far) signal from the received signal, as the desired signal is stronger than the interference signal (near-user signal). Similarly, the BS can simultaneously serve more than two users on a single frequency band, revealing a spectrum-sharing gain **(Liu et al., 2017; Baidas et al., 2018)**.

3. ANALYSIS OF SYSTEM PERFORMANCE

In this section, the system analysis for the NOMA system is illustrated and analyzing 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 a higher power than the near user. Thus, the far user is decoded firstly than that the decoded data which is combined with the corresponding channel link. Then it is 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 **(Ghosh et al., 2022)**. 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., 2019)** can be expressed as in Eq. (1) **(Kara and Kaya, 2020)**.

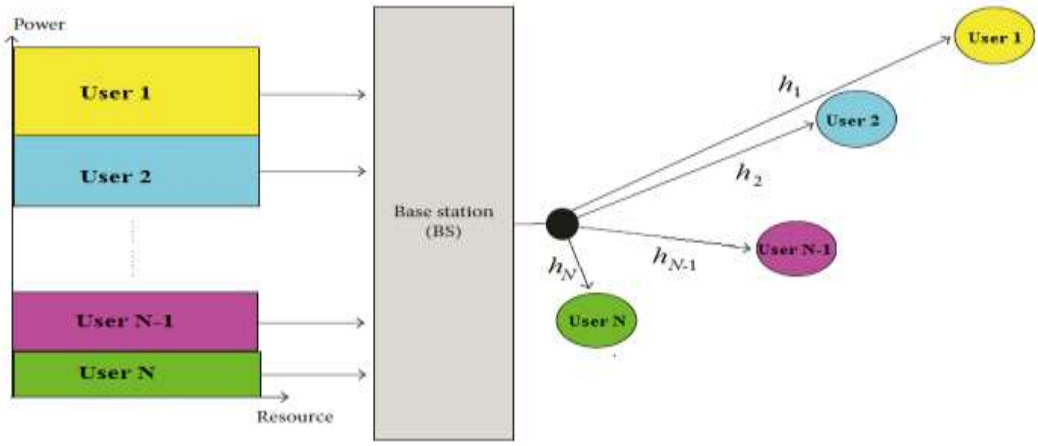

Figure 3. The downlink NOMA system model with N users **(Aldababsa et al., 2018)**.

$$X = \sum_{i=1}^{N} \sqrt{P_i}\ x_i \tag{1}$$

where; x_i are superposition-coded signals of the users and i ∈ [1,2,3,…,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) **(El-Mokadem et al., 2019)**.

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

where; $P_{BS} = P$ is the transmitted power from BS (total available power at the BS)

α_i are the power allocation Coefficient of the UEi , and the received signal for UEi is given by Eq. (3) **(Vaezi et al., 2019)**.

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

The channel coefficient between UEi and the base station is h_i , where w_i Additive White Gaussian Noise (AWGN) with zero mean and variance= σ^2.
The SIC process is implemented at the UEs receiver in the downlink NOMA. 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 $\frac{|h_i|^2}{\sigma_n{}^2} = \frac{|h_i|^2}{N} = \frac{|h_i|^2}{N_O BW}$ simply called the channel-to-noise ratio (CNR) of UEi. Where; No is the noise power, and BW is the system's bandwidth. In addition, hi = gi$*$ $d_i{}^{-p}$; where; gi follows Rayleigh distribution, di is the distance between the BS and UEi, and p is the pass loss exponent **(Vaezi et al., 2019)**. Based on channel gain order, assume each user can correctly decode the signals of other users whose decoding order comes before the corresponding user **(Ding et al., 2015)**. 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 $x_1, x_2, \ldots x_N$ denote the messages to be transmitted to the users based on **Fig. 3**, where $|h_1|^2 < |h_2|^2 < \cdots < |h_{N-1}|^2 < |h_N|^2$ Hence, the NOMA transmitted signal can be expressed by Eq. (4) **(Kara and Kaya, 2020).**

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

where; $\alpha_1 > \alpha_2 > \cdots > \alpha_N$, $\alpha_1 > \alpha_2 + \alpha_3 + \cdots + \alpha_N$, and $\alpha_1 + \alpha_2 + \cdots + \alpha_N = 1$.
Also, Eq. (4) can be re-expressed in Eq. (5) and the received signal at the ith user can be expressed as in Eq. (6) below.

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

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

In addition, substituting Eq. (5) into Eq. (6) the received signal can be re-expressed as: **(El-Mokadem et al., 2019)**.

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

At the first (far) user, the received vector is given by Eq. (8), and direct decoding is performed to estimate x1.

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

Thus the signal-to-interference plus noise ratio (SINR) for decoding the 1st user signal is given by **(Hussain et al., 2020)**:

$$SINR_{1,\ NOMA} = \frac{\alpha_1 P\,|h_1|^2}{\alpha_2 P\,|h_1|^2+\alpha_3 P\,|h_1|^2+\cdots+\alpha_N P\,|h_1|^2+\sigma^2} \tag{9}$$

For the second user, the received vector is given by Eq. (10), and the concept of the SIC is applied to achieve Eq. (11).

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

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

Direct decoding is performed to estimate x_2. Thus, the SINR for decoding the second user signal is given by Eq. (12):

$$\gamma_{2,\ NOMA} = \frac{\alpha_2 P\,|h_2|^2}{\alpha_3 P\,|h_2|^2+\alpha_4 P\,|h_2|^2+\cdots+\alpha_N P\,|h_2|^2+\sigma^2} \tag{12}$$

The same manner is up to the Nth user. In general, the ith SINR is given by Eq. (13) which can be re-expressed by Eq. (14)

$$SINR_{i,\ NOMA} = \frac{\alpha_i P\,|h_i|^2}{\alpha_{i+1} P\,|h_i|^2+\cdots+\alpha_N P\,|h_i|^2+\sigma^2} \tag{13}$$

$$SINR_{i,\ NOMA} = \frac{\alpha_i P\,|h_i|^2}{P\,|h_i|^2\sum_{j=i+1}^{N}\alpha_j+\sigma^2} \tag{14}$$

The achievable rate (bps/Hz) of the ith user can be given by Eq. (15) **(El-Mokadem et al., 2019)** and the sum rate of all the NOMA users is given by Eq. (16),.

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

$$R_{i,\ NOMA} = \sum_{i=1}^{N} R_{i,\ NOMA} \tag{16}$$

Eq. (16) can be re-expressed by Eq. (17) such that:

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

3.2 Analysis of Orthogonal Multiple Access Technique Performance

Per **(Manglayev et al., 2016)**, and referring to **Fig. 3**, the achievable rate for OMA could be analyzed; Let $x_1,\ x_2, \ldots x_N$ denote the messages to be transmitted to the users. Hence, the OMA signal can be expressed as**:**

$$X_{i,OMA} = \sqrt{P}x_i \tag{18}$$

at the i[th] user, the received vector is given by:

$$y_{i,\,OMA} = h_i\sqrt{P}x_{i,\,OMA} + w_i \tag{19}$$

The SINR for decoding the i[th] user signal is given as:

$$\gamma_{i,\ OMA} = \frac{P\,|h_i|^2}{\sigma^2} \tag{20}$$

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 the throughput achievable rate (bps/Hz) of the i[th] user is given by:

$$R_{i,\ OMA} = \frac{1}{N}log_2\left(1 + \gamma_{i,\ \ OMA}\right) \tag{21}$$

The sum rate of all the OMA users is given by Eq. (22).

$$R_{i,\ OMA} = \sum_{i=1}^{N} R_{i,\ \ OMA} \tag{22}$$

In the same manner, Eq. (22) can be re-expressed by Eq. (23)

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

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) and by Eq. (25) respectively.

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

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

In addition, in the case of four users, the achievable rates from first to fourth users can be expressed by Eq. (26), Eq. (27), Eq. (28), and Eq. (29) respectively.

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

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

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

$$R_{4\,,four-UEs4} = \frac{1}{4}\ log_2\left(1 + \frac{P\,|h_4|^2}{\sigma^2}\right) \tag{29}$$

4. SYSTEM MODEL

In this work, a downlink NOMA system's spectral efficiency is studied in two scenarios: a two-user scenario and a multi-user scenario. We assume that the transmitter and receiver channel are 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

For two users, the signal transmitted by the BS can be expressed through Eq. (30) **(El-Mokadem et al., 2019)**. The block diagram for this scenario is shown in **Fig. 4**.

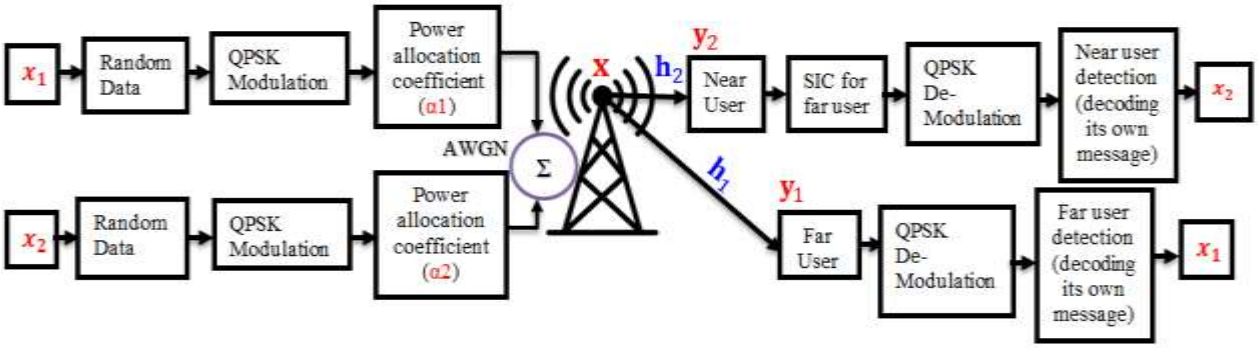

Figure 4. Block diagram of SISO-NOMA wireless communication system for two users over a Rayleigh fading channel.

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

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) **(El-Mokadem et al., 2019)**.

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

This vector can be used to directly decode and estimatex_1. Eq. (31) can be rewritten as:

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

The SINR for decoding the first user's signal is given by Eq. (33) **(Hussain et al., 2020)**.

$$SINR_1 = \frac{\alpha_1 P\,|h_1|^2}{\alpha_2 P\,|h_1|^2 + \sigma^2} \tag{33}$$

The achievable rate for the first user is given by:

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

The second (near) user receives the signal vector given by Eq. (35). First, the signal x_1 is decoded directly.

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

Then, the SIC is applied through Eq. (36) to decode the signal x_2 from the near user.

$$y_2' = h_2\sqrt{P}\sqrt{\alpha_1}x_1 + h_2\sqrt{P}\sqrt{\alpha_2}x_2 + w_2 - h_2\sqrt{P}\sqrt{\alpha_1}\hat{x}_1 \quad (36)$$

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) **(Hussain et al., 2020)**.

$$SINR_2 = \frac{\alpha_2 P\,|h_2|^2}{\sigma^2} \quad (37)$$

The corresponding achievable rate (bps/Hz) for the second user is given by Eq. (38).

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

4.2 Multiusers (4-UEs NOMA) Scenario

In the second scenario, Multi-Users NOMA, the block diagram is used for four users NOMA system, as 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) **(El-Mokadem et al., 2019)**.

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

The signal received by the first (farthest) user can be expressed by Eq. (40).

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

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:,

$$SINR_1 = \frac{\alpha_1 P\,|h_1|^2}{\alpha_2 P\,|h_1|^2 + \alpha_3 P\,|h_1|^2 + \alpha_4 P\,|h_1|^2 + \sigma^2} \quad (41)$$

and the achievable rate of the first user (bps/Hz) is given by:

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

The received vector at the second (second farthest) user is given by: **(El-Mokadem et al., 2019)**.

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

Because 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 are considered interference. Thus, the SINR for decoding the second user's signal is given by:**(Hussain et al., 2020)**

$$SINR_2 = \frac{\alpha_2 P\,|h_2|^2}{\alpha_3 P\,|h_2|^2 + \alpha_4 P\,|h_2|^2 + \sigma^2} \tag{44}$$

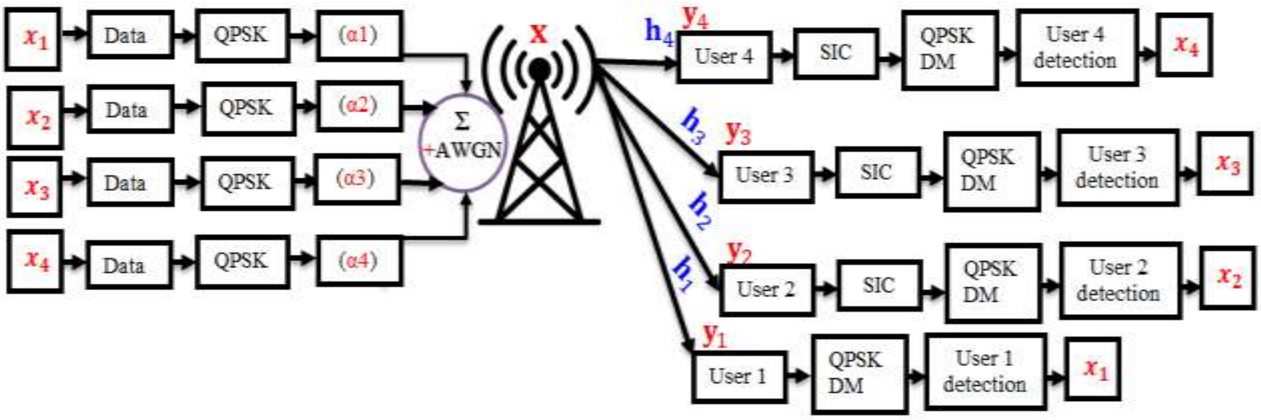

Figure 5. Block diagram of SISO-NOMA wireless communication system for four users over a Rayleigh fading channel.

The achievable rate (bps/Hz) of the second farthest user can be expressed by **(El-Mokadem et al., 2019)**:

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

At the third (third farthest = second near) user, the received vector is given by Eq. (46), 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.

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

Thus the SINR for decoding the user 3 signal is given by:

$$SINR_3 = \frac{\alpha_3 P\,|h_3|^2}{\alpha_4 P\,|h_3|^2 + \sigma^2} \tag{47}$$

and the achievable rate (bps/Hz) of the third (third farthest = second near) user is given by:

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

The received vector at the nearest user is given by Eq. (49). User 4 is the nearest, 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, 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 then SIC for user 3 is performed.

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

Finally, direct decoding for user 4 data is performed to recover its own data. Thus the SINR for decoding the user 4 (nearest user) signal is given by:

$$SINR_4 = \frac{\alpha_4 P\,|h_4|^2}{\sigma^2} \quad (50)$$

The achievable rate (bps/Hz) of the nearest user is given by:

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

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 power of 1:50 dBm to all users. The parameters for both scenarios are shown in **Table 1**.

The simulated BER performance of 2-UEs scenario, N = 2, is shown in **Fig. 6**, with power allocation coefficients α_1 = 0.75 and α_2 = 0.25.

Table 1. System parameters.

Parameters	Values
Bandwidth (BW)	20 x 10^6 Hz = 20 MHz
Noise power (No)	8.23 x 10^{-14}
Path loss exponent (p)	4
Channel Realization	5 x 10^5
Transmit power (Pt)	0:1:50 (dBm)
Power allocation coefficients (α) for 2-UEs scenario	α_1= 0.75 α_2= 0.25
Power allocation coefficients (α) for 4-UEs scenario	α_1= 0.75, α_2= 0.1875 α_3= 0.046875, α_4= 0.015625
Distances for two users scenario	d_{near} = 200 m d_{far} = 300 m
Distances for four users scenario	$d_{nearest}$ = 100 m, d_{near} = 200 m d_{far} = 300 m, $d_{fartherst}$ = 500 m

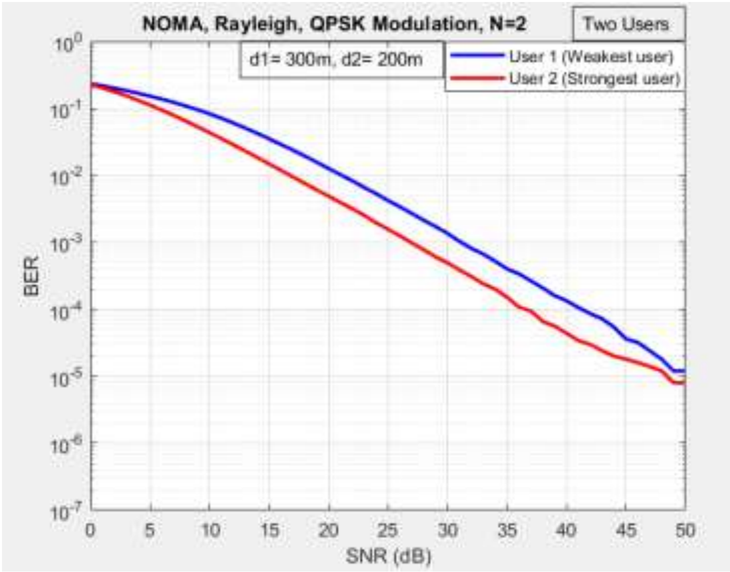

Figure 6. BER vs. SNR for 2-UEs scenario over Rayleigh fading channel.

Fig. 6 presents 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 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 user's distance 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 = 0.75, = 0.1875, = 0.046875, and = 0.015625. Four users are used in multiusers NOMA by distances shown in **Table 1**. It is worth saying that two new users are increased for the 2-UEs scenario to become multi-users NOMA. One user in increased, the nearest user from the base station, is represented by black color. Another new user is increased, which is the farthest user from the base station is represented by green color in **Fig. 7**.

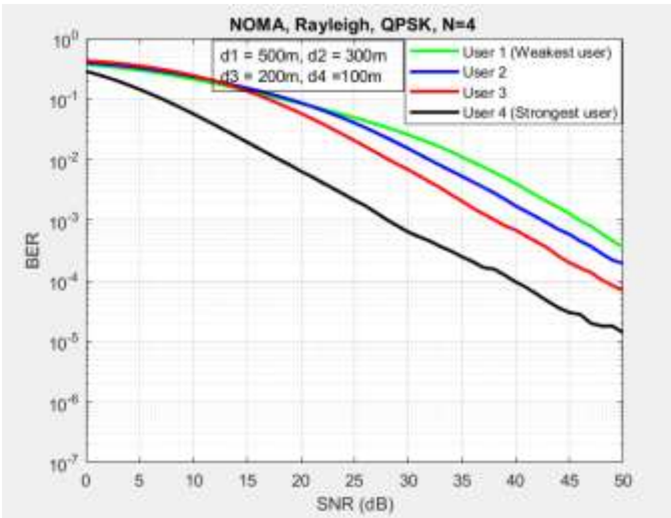

Figure 7. BER vs. SNR for 4-UEs scenario over Rayleigh fading channel.

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. At the same time, the BER is equal to 0.001738, 0.000706, 0.000286, and 0.000028 from the weakest toward the strongest user, respectively, for multiusers (4-UEs) scenario as shown in **Table 2**.

Fig. 8 shows the BER performance versus transmits power for the 2-UEs scenario. The same parameters are used for simulating; **Fig. 8** is similar to **Fig. 6**. The red line represents the near user while the blue line is for the far user; as can be 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 than the far user 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, equal to 25 dBm. As it is obvious from **Table 2**, BER amount of 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 using the same parameters to simulate the BER versus the SNR. The same distances are used, shown in **Table 1**. The red and blue lines represent those two users. In comparison, 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 the 4-UEs scenario have a different amount of BER, 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 decrease the amount of BER.

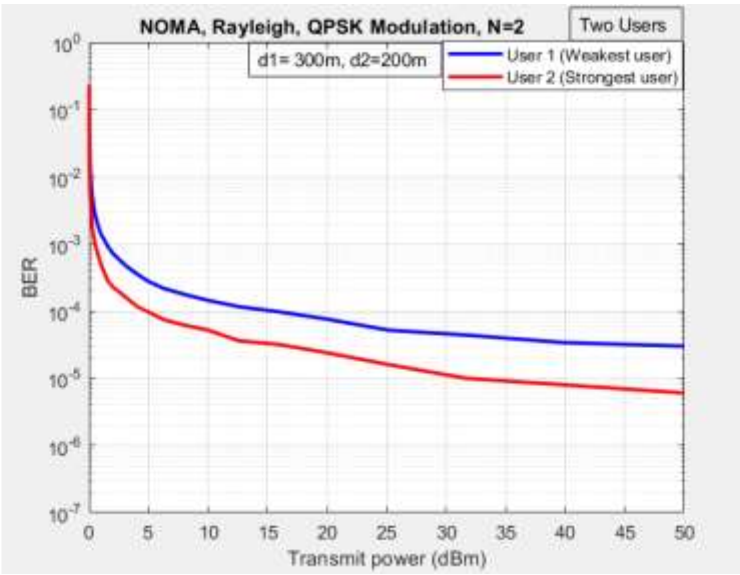

Figure 8. BER vs. Transmit power for 2-UEs scenario over Rayleigh fading channel.

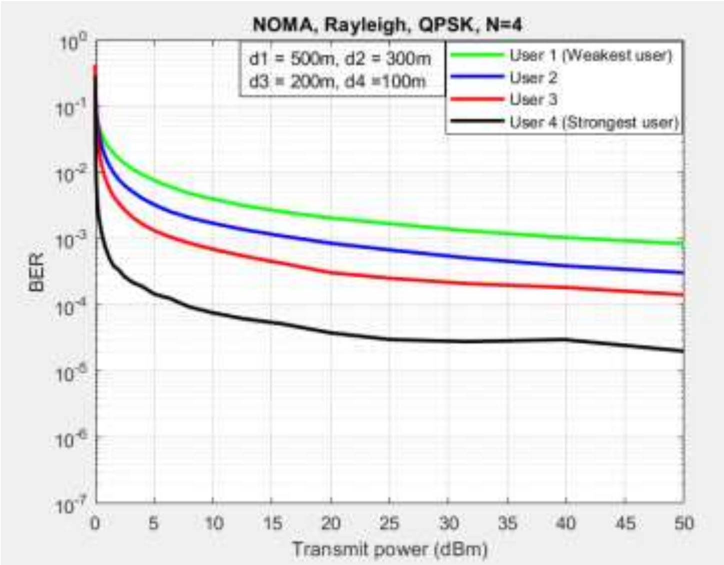

Figure 9. BER vs Transmit power for 4-UEs scenarios over Rayleigh fading channel.

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

SNR = 25dB	Scenario		User 1	User 2	
	2-Users	/	0.004202	0.001564	/
	Scenario	User 1	User 2	User 3	User 4
	4-Users	0.04939	0.04051	0.02069	0.002134
Power = 25 dBm	Scenario		User 1	User 2	
	2-Users	/	0.000052	0.000016	/
	Scenario	User 1	User 2	User 3	User 4
	4-Users	0.001738	0.000706	0.000286	0.000028

These compression results indicate that, by increasing the number of users from two to four users, the amount of BER increases due to the power allocation coefficient problem and increasing system complexity. Since increasing the number of users, the system complexity increases and causes error propagation. **Fig. 10** shows a comparison of NOMA and OMA systems in terms of the achievable sum rate versus SNR which is explained for the 2-UEs scenario.

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 indicates 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 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 equals 10.36 (bps/Hz) and 9.228(bps/Hz), respectively. **Fig. 11** shows the amount of the achievable sum rate for multiusers (4-UEs scenario).

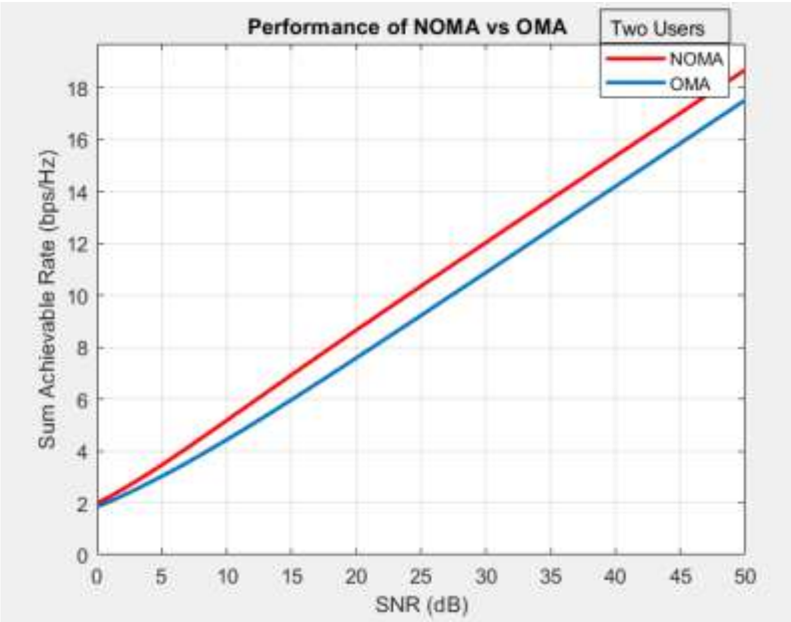

Figure 10. Capacity comparison of NOMA and OMA systems for 2-UEs scenario over Rayleigh fading channel.

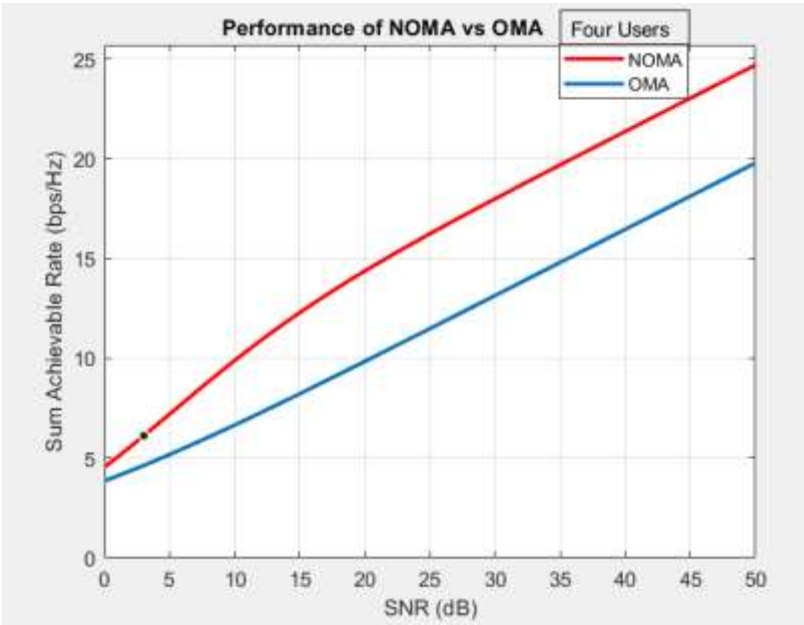

Figure 11. Capacity comparison of NOMA and OMA systems for 4-UEs scenario over Rayleigh fading channel.

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 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 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). **Fig. 12** shows the performance of NOMA and OMA systems for the 2-UEs scenario regarding the achievable sum rate versus transmit power.

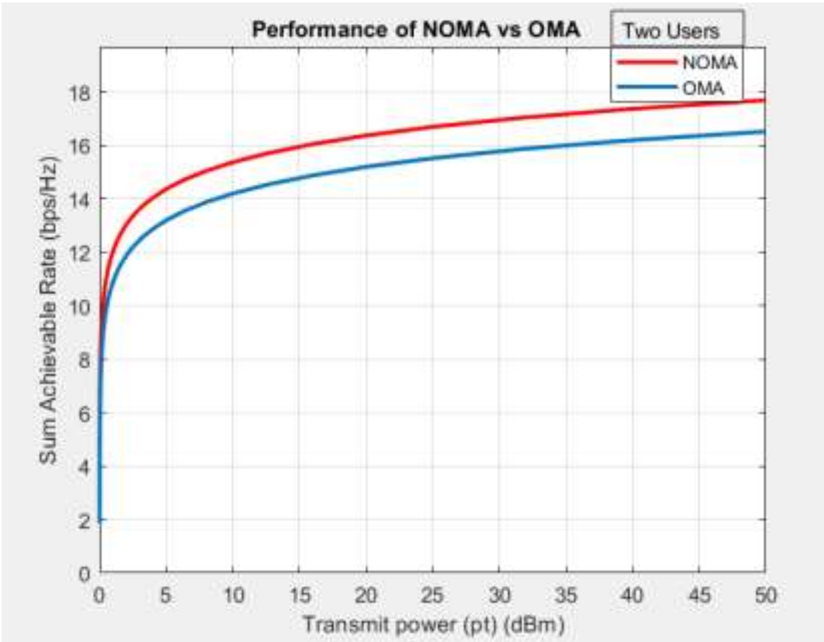

Figure 12. Performance comparison of NOMA and OMA for 2-UEs scenarios over Rayleigh fading channel.

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. 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 15.53 (bps/Hz) for the OMA system.
Fig. 13 shows the amount of NOMA and OMA systems throughput for the 4-UEs scenario. The amount of the throughput versus transmit power for multiusers NOMA depicts NOMA outperforming OMA, as in the previous results. In addition, red and blue lines represent NOMA and OMA systems respectively by using the same parameters shown in **Table 1**.

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

Achievable sum rate (bps/Hz)	NOMA		OMA	
SNR = 25 dB	2-UEs	4-UEs	2-UEs	4-UEs
	10.36	16.24	9.228	11.49
Power = 25 dBm	2-UEs	4-UEs	2-UEs	4-UEs
	16.7	20.69	15.53	15.79

As it is clear from **Fig. 13**, the amount of NOMA's throughput is improved more compared to the OMA system for the multi-users scenario. The amount of throughput for the 4-UEs scenario is presented in **Table 3**, in which NOMA is 20.69 (bps/Hz), and OMA is 15.79 (bps/Hz). The amount of throughput for both the NOMA and OMA systems and for both the 2- UEs and the 4-UEs scenario is increased with increasing the range of transmitted power, until reach saturation after 50 dBm of the transmitted power.

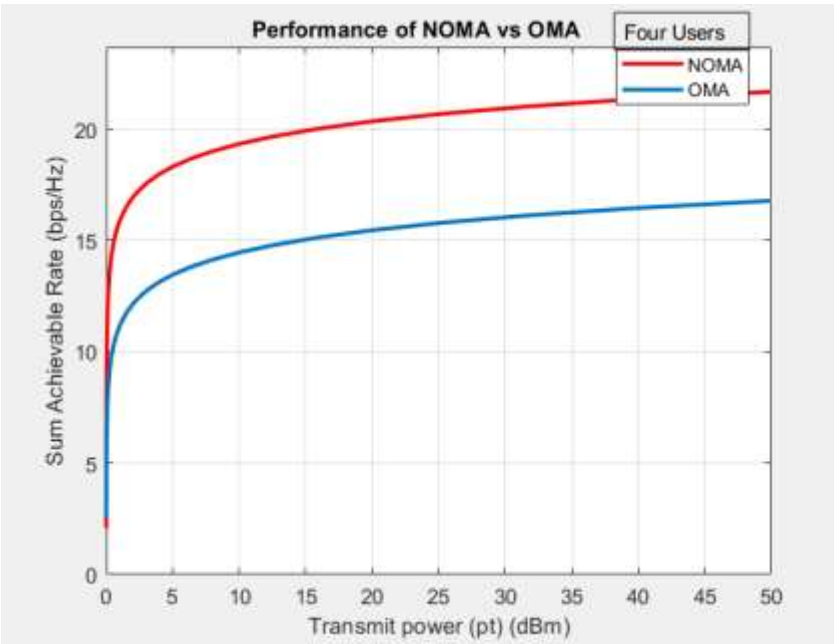

Figure 13. Performance comparison of NOMA and OMA for 4-UEs scenarios over Rayleigh fading channel.

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 number of achievable sum rates for each of the systems for both scenarios is shown in **Table 3**, when SNR is equal to 25 dB and at transmitted power of 25 dBm. From **Table 3**, it is indicated that by increasing the number of users, the system's capacity is increased for both scenarios (2-UEs and 4-UEs scenario), and for both systems (NOMA and OMA systems). However, for the multi-UEs scenario, the capacity is much more than in the 2-UEs scenario.

In addition, the capacity can be increased by increasing the amount of transmitted power, especially for the multi-UEs (4-UEs) scenario.

6. CONCLUSION

NOMA allows multiple users to share the same time and frequency resources, making 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 spectral throughput efficiency of wireless networks.

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