Performance Analysis of MIMO NOMA based Wireless Network for 5G and beyond under Rayleigh Fading Channel

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***Abstract*— In this research endeavor, the amalgamation of two cutting-edge technologies, Multiple-Input Multiple-Output (MIMO) and Non-Orthogonal Multiple Access (NOMA), offers a solution to the challenges posed by the 5G cellular system and its futuristic counterparts. The study focuses on wireless networks operating in Rayleigh fading channels, which are challenging conditions. The main objectives of the research are to derive closed-form expressions for Bit Error Rate (BER) and the outage probability equation for Downlink (DL) NOMA. Additionally, the investigation extends beyond 5G into the unexplored territory of 6G wireless technology, where the impact of dynamic bandwidth variations is explored. Furthermore, the study evaluates the system's performance by examining the BER, shedding light on the capabilities of 5G and its evolutionary successors. The findings from this research could significantly contribute to advancements in wireless communication technologies.**

Keywords—MIMO, NOMA, Rayleigh fading channels, Down Link, 5G, BER.

I. INTRODUCTION

The demand for higher data rate is the main focus behind the evolution of next generation wireless network. To fulfil these demands of wireless systems, researchers are always looking into better communication technologies and more effective system design.

With an aura of innovation and boundless possibilities, the fifth-generation (5G) wireless network emerges as a transformative force, captivating the world of wireless communications with its groundbreaking advancements. In the realm of 5G wireless communication networks, a grand symphony of challenges awaits, demanding harmonious solutions. Embracing the cacophony of demands, we strive to support a staggering multitude of interconnected devices, orchestrating low latency, unfathomable data throughput, unwavering reliability, and an artful balance of energy efficiency. Together, we weave a tapestry of possibilities, uniting the intricate threads of the Internet of Things (IoT) into a harmonious ensemble [1]. In order to fulfill these challenges, researchers are always investigating new and better communication technologies as well as system designs that are more effective. NOMA has emerged as a promising multiple access strategy for both 5G and future 6G networks [2], due to its ability to address certain limitations.

In the ever-evolving landscape of modern times, Non-Orthogonal Multiple Access (NOMA) emerges as the epitome of reliability, surpassing its counterparts in the realm of 5G and future networks.

As the pages of progress turn, NOMA stands as a testament to the relentless pursuit of efficiency and connectivity [3]-[5]. Diverging from conventional OMA techniques such as TDMA, FDMA, CDMA, and OFDMA, where users contend for separate radio resources in domains of time, frequency, or code, NOMA takes a distinct path. By harnessing the power domain and code domain, NOMA revolutionizes the concept of multiple access, offering a novel approach that opens up new vistas for seamless connectivity [6]. In NOMA, based on the channel circumstances, various users are given different power coefficients from transmitter. More precisely, multiple users' information signals are skillfully intertwined during transmission, while a sophisticated technique called successive interference cancellation (SIC) is skillfully utilized to untangle and decode the signals individually by skillfully eliminating interference from other users. This intricate process strikes a harmonious balance between maximizing system throughput and ensuring fairness among users [7]. With its ingenuity, NOMA employs an ingenious strategy to disentangle the overlapping signals and eliminate inter-user interference. This involves the implementation of a superposition code at the transmitter and the skillful application of SIC at each user, resulting in a remarkable separation of signals and a significant reduction in interference. Since a result, NOMA systems benefit users by providing more equitable resource allocation, even for those with modest channel gains, as NOMA systems distribute less transmission power to users with favorable channel conditions and more to those with unfavorable ones [8]. By harnessing the power of multiple antennas at both the transmitter and the receiver, the capacity of a radio communication channel can be dramatically amplified, unlocking new levels of performance and efficiency. By leveraging multiple-input multiple-output (MIMO) technology with these antennas, it becomes feasible to accommodate numerous independent channels within the given bandwidth. However, this capability is contingent on the availability of a diverse propagation environment [9]. Research into the combination of MIMO and NOMA has lately garnered a lot of attention. This is despite the fact that the use of MIMO methods provides an additional dimension to the enhancement of efficiency [10]. In [11], a new MIMO-NOMA transmission framework based on the idea of signal alignment is introduced. During the performance evaluation of the MIMO NOMA system, particular attention was given to assessing the system's effectiveness under two distinct

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power allocation strategies: fixed power allocation and power allocation influenced by cognitive radio. This comprehensive evaluation sheds light on the system's adaptability and performance under different power allocation schemes. To learn more about how MIMO may be used in NOMA systems, check out [12]. A groundbreaking architecture for precoding and detection matrices in MIMO-NOMA was introduced, revolutionizing the field and sparking extensive investigations into its potential. The novel architecture offered a fresh perspective and opened up exciting possibilities for optimizing the performance of MIMO-NOMA systems.

Some of the important factors in NOMA are channel fading, BER, channel capacity or outage capacity, outage probability, etc., which can be seen by looking at many previous research works. In the study presented in [13], a cellular DL scenario is considered where users are randomly distributed and the Rayleigh fading channel is employed. The performance evaluation of NOMA in terms of outage performance and ergodic sum rate is conducted to assess its effectiveness in this scenario. This investigation provides valuable insights into the performance characteristics of NOMA in realistic cellular environments. The data unequivocally demonstrate that NOMA outperforms the OMA scheme. The BER and outage measurements of DL NOMA are integrated with the Nakagami-m fading channel in [14]. Reference [15] presents a comprehensive analysis of the outage probability for both DL and uplink communication systems employing NOMA. This research looked at a variety of fading channels, including Rayleigh, Rician, Nakagami-m, Nakagami-q, $\kappa - \mu$, $\eta - \mu$, and Nakagami-lognormal. In the paper [16], an analysis and evaluation are conducted to assess the extent to which MIMO can improve the reliability of a 5G network, focusing on metrics such as BER, DL Spectrum Efficiency (SE), average capacity rate (ACR), and Uplink (UL) Outage Probability (OP). Yang et al., in reference [17], have published a study on the performance of Outage Probability (OP) and sum rate in a NOMA DL system. The study focuses on the utilization of partially Channel State Information (CSI)-based user ordering for uniformly dispersed users across Rayleigh fading channel connections. Partially coincident nearby user NOMA is proposed in [18].

This paper makes notable contributions in the following aspects: it presents a derived closed-form equation for the BER and outage probability of a MIMO NOMA wireless communication system.

In the subsequent sections, we shall provide an overview of the paper's organization. Commencing with Section-II, we will introduce the system scenario, accompanied by a detailed description. Moving on to Section-III, we will mathematically derive the closed-form expressions for both the outage probability and the BER. In Section-IV, the results will be presented, showcasing the effectiveness of the proposed scheme. Lastly, Section-V will serve as the conclusion, summarizing the key findings of this paper.

II. SYSTEM SCENARIO WITH DESCRIPTION

A. System Model

In this study, we examine a DL MIMO NOMA wireless network, as depicted in Fig. 1. We analyze a non-orthogonal communication system in a single cell configuration, consisting of i^{th} users and a Base Station (BS). Both the users and the BS are equipped with $N \times M$ multiple antennas. The wireless channel between the BS and all the users is modeled as a frequency-selective fading environment, following the Rayleigh fading assumption.

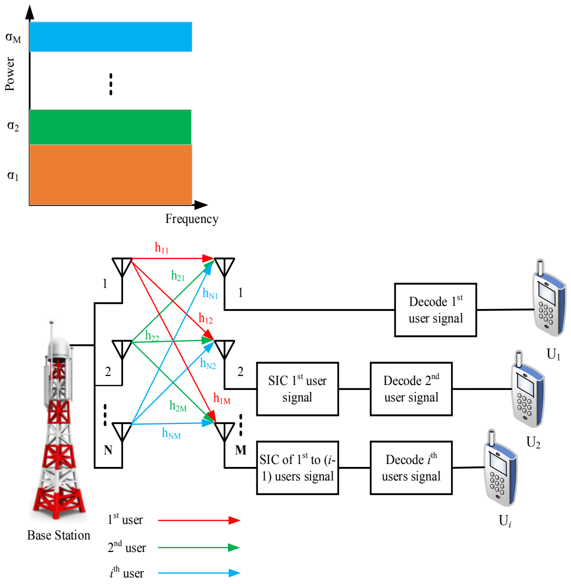

Fig. 1. Proposed DL MIMO NOMA based wireless network

In the depicted Fig. 1, the BS in the DL NOMA network acts as the transmitter, transmitting a composite signal to all mobile users. In a remarkable feat, the composite signal formed at the transmitter is ingeniously crafted by superimposing the intended signals from multiple users, each assigned distinct power coefficients. At the receiver, a sequential process of SIC is astutely employed for each user, enabling the successful retrieval of their respective intended signals. The power coefficients assigned to the users are distributed in an inversely proportional manner, determined by the characteristics of their individual channel conditions. As a consequence, the user endowed with the highest transmission power adeptly treats the signals from other users as interference, swiftly recovering its own signal without the need for undergoing any SIC procedure.

B. Channel Model

In Fig. 1, the channel fading coefficients $h_{i,j}$ between the Base Station (BS) and the users (U_i) are considered to be independent and potentially distributed differently. Here, i ranges from 1 *to* N and j ranges from 1 *to* M. The total transmission power at the BS is denoted as P_s, while α_{11}, $\alpha_{12}, \ldots\ldots,$ α_{NM} represent the power coefficients assigned to each user.

User 1 is positioned at the farthest distance from the transmission side. If this is the case, then user 2 is located quite near to the transmission side of user 1, and other users are also located relatively close to the transmission side. So it can be written that, $U_1 > U_2 \ldots \ldots \ldots .. > U_N$. So the highest power goes to the U_1 and the lowest power goes to the U_N. It is clear from the information presented that User 1 has gone the most distance; hence, User 1 ought to be granted a greater degree of autonomy. Therefore, the cost for each user is determined by their total distance covered. From the above text, it can be understood that user 1 is the farthest away, so user 1 should be given more power.

Thus, all users have to pay according to their distance, so it can be written that $\alpha_{11} > \alpha_{12} > \ldots\ldots \alpha_{NM}$. Since without loss of generality the channel gains are assumed to be ordered as $|h_{11}|^2 \geq |h_{12}|^2 \geq \cdots |h_{NM}|^2$.

The channel is the physical path used by the BS to communicate with the receiving antenna. Rayleigh fading models presume that the amplitude of a signal from the BS to users passing via a wireless communication channel which will fluctuate randomly, or fade, according to a Rayleigh distribution. We assume that all connections experience Rayleigh flat fading, accompanied by additive white Gaussian noise (AWGN). While large-scale fading can be mitigated over an extended period through power regulation, small-scale fading remains constant and cannot be reduced.

The link gains of Rayleigh fading channel over M transmitter to N receiver is given below.

$$\alpha_{N,M} = \begin{vmatrix} \alpha_{1,1} & \alpha_{1,2} & \cdots & \alpha_{1,M} \\ \alpha_{2,1} & \alpha_{2,2} & \cdots & \alpha_{2,M} \\ \vdots & \vdots & \vdots & \vdots \\ \alpha_{N,1} & \alpha_{N,2} & \cdots & \alpha_{N,M} \end{vmatrix} \tag{1}$$

Similarly, all the channels coefficient of DL NOMA proposed scenario over M transmitter to N receiver is

$$h_{N,M} = \begin{vmatrix} h_{1,1} & h_{1,2} & \cdots & h_{1,M} \\ h_{2,1} & h_{2,2} & \cdots & h_{2,M} \\ \vdots & \vdots & \vdots & \vdots \\ h_{N,1} & h_{N,2} & \cdots & h_{N,M} \end{vmatrix} \tag{2}$$

and these are distributed in complex Gaussian distribution with zero mean and variance of

$$\lambda_{N,M} = \begin{vmatrix} \lambda_{1,1} & \lambda_{1,2} & \cdots & \lambda_{1,M} \\ \lambda_{2,1} & \lambda_{2,2} & \cdots & \lambda_{2,M} \\ \vdots & \vdots & \vdots & \vdots \\ \lambda_{N,1} & \lambda_{N,2} & \cdots & \lambda_{N,M} \end{vmatrix} \tag{3}$$

Therefore, the link gains with the channel coefficient can be written as

$$\alpha_{N,M} = \begin{vmatrix} |h_{1,1}|^2 & |h_{1,2}|^2 & \cdots & |h_{1,M}|^2 \\ |h_{2,1}|^2 & |h_{2,2}|^2 & \cdots & |h_{2,M}|^2 \\ \vdots & \vdots & \vdots & \vdots \\ |h_{N,1}|^2 & |h_{N,2}|^2 & \cdots & |h_{N,M}|^2 \end{vmatrix} \tag{4}$$

III. PROBLEM FORMULATIONS

Embracing the principles of power domain allocation, NOMA ensures that lower-ranking users are bestowed with higher power while higher-ranking users receive relatively lower power. In the DL, the Base Station (BS) performs a linear combination of the information symbols $x_1, x_2, \ldots x_k$ to generate a superposed encoded signal x, which encompasses the symbols of all users involved, as illustrated below:

$$x = \sqrt{p}\left(\sqrt{\alpha_1}x_1 + \sqrt{\alpha_2}x_2 + \cdots + \sqrt{\alpha_k}x_k\right) \tag{5}$$

$$x = \sqrt{p}\sum_{i=1}^{k}\sqrt{\alpha_i}x_i \tag{6}$$

The total Rayleigh fading channel for every user may be calculated as follows:

$$h_{T_i} = \sum_{i=1}^{M} h_{T_i} \tag{7}$$

When it has its full strength, the power domain NOMA immediately decodes the distant user's data y_1, which causes interference with the signals of the second, third, and subsequent user.

$$y_1 = h_{T_1} \cdot \left[\sum_{i=1}^{M}\sqrt{P_i} \cdot x_i\right] + \omega_1 \tag{8}$$

$$y_1 = h_{T_1} \cdot \sqrt{P_1} \cdot x_1 + h_{T_1} \cdot \left[\sum_{i=2}^{M}\sqrt{P_i} \cdot x_i\right] + \omega_1 \tag{9}$$

$$y_1 = h_{T_1} \cdot \sqrt{P_1} \cdot x_1 + \varrho_1 \tag{10}$$

Where, $\varrho_1 = h_{T_1} \cdot \left[\sum_{i=2}^{M}\sqrt{P_i} \cdot x_i\right] + \omega_1$ seems to be random noise in the context of the NOMA system being presented.

$$y_2 = h_{T_2} \cdot \left[\sum_{i=1}^{M}\sqrt{P_i} \cdot x_i\right] + \omega_2 \tag{11}$$

$$\begin{gathered} y_2 = h_{T_2} \cdot \sqrt{P_2} \cdot x_2 + h_{T_2} \cdot \sqrt{P_1} \cdot x_1 + \\ h_{T_2} \cdot \left[\sum_{i=3}^{M}\sqrt{P_i} \cdot x_i\right] + \omega_2 \end{gathered} \tag{12}$$

$$y_2 = h_{T_2} \cdot \sqrt{P_2} \cdot x_2 + h_{T_2} \cdot \sqrt{P_1} \cdot x_1 + \varrho_2 \tag{13}$$

$$\begin{gathered} y_2 = h_{T_2} \cdot \sqrt{P_2} \cdot x_2 + h_{T_2} \cdot \sqrt{P_1} \cdot x_1 \\ + \varrho_2 - h_{T_2} \cdot \sqrt{P_1} \cdot \widehat{x_1} \end{gathered} \tag{14}$$

$$\varrho_2 = h_{T_2} \cdot \left[\sum_{i=3}^{M}\sqrt{P_i} \cdot x_i\right] + \omega_2 \tag{15}$$

Similarly, for M^{th} user's data can be decoded using power domain NOMA at receiver side,

$$y_M = h_{T_M} \cdot \left[\sum_{i=1}^{M}\sqrt{P_i} \cdot x_i\right] + \omega_M \tag{16}$$

$$\begin{gathered} y_M = h_{T_M} \cdot \sqrt{P_M} \cdot x_M + h_{T_M} \cdot \left[\sum_{i=1}^{M-1}\sqrt{P_i} \cdot x_i\right] \\ + \omega_M \end{gathered} \tag{17}$$

The Signal-to-Interference-plus-Noise Ratio (SINR) can be expressed as follows [19-20]:

$$SINR_i = \frac{P \cdot \alpha_i \cdot |h_{T_i}|^2}{P \cdot \left|h_{T_i}\right|^2 \cdot \sum_{l=i}^{M-1}\alpha_{i+1} + \sigma_n^2} \tag{18}$$

$$SINR_i = \frac{\frac{P\alpha_i|h_{Ti}|^2}{\sigma^2}}{\frac{P|h_{Ti}|^2\sum_{l=i}^{M-1}\alpha_{i+1} + \sigma^2}{\sigma^2}}$$

$$SINR_i = \frac{\frac{P}{\sigma^2}\alpha_i |h_{Ti}|^2}{\frac{P}{\sigma^2}|h_{Ti}|^2 \sum_{l=i}^{M-1}\alpha_{i+1} + 1}$$

$$SINR_i = \frac{\rho\alpha_i |h_{Ti}|^2}{\rho|h_{Ti}|^2 \sum_{l=i}^{M-1}\alpha_{i+1} + 1} \tag{19}$$

Where, $\rho = \frac{P}{\sigma^2}$, denotes the transmission SNR.

$$SINR_i = \frac{\alpha_i \rho\gamma_i}{\rho\gamma_i \sum_{l=i}^{M-1}\alpha_{i+1} + 1} \tag{20}$$

Where, link gain $\gamma_i = |h_{T_i}|^2$ and $i = 1, 2, 3 \dots M$ is the number user for M number of wireless channels of MIMO NOMA based proposed scenario.

Thus, the closed form BER can be calculated as follows:

$$BER = \int_0^\infty \frac{1}{2} erfc\left[\frac{\sqrt{SINR_i}}{2}\right] \times \frac{1}{\delta_i^2} e^{-\frac{\gamma_i}{\delta i}} d\gamma_i$$

$$= \int_0^\infty \frac{1}{2} erfc\left[\frac{\sqrt{\frac{\alpha_i\rho\gamma_i}{\rho\gamma_i \sum_{l=i}^{M-1}\alpha_{i+1}+1}}}{\sqrt{2}}\right] \times \frac{1}{\delta_i^2} e^{-\frac{\gamma_i}{\delta i}} d\gamma_i \tag{21}$$

The achievable data rate can be written as

$$R_i = log_2(1 + SINR_i) \tag{22}$$

$$2^{R_i} = 1 + \frac{\alpha_i\rho\gamma_i}{\rho\gamma_i \sum_{l=i}^{M-1}\alpha_{i+1} + 1}$$

$$2^{R_i} - 1 = \frac{\alpha_i\rho\gamma_i}{\rho\gamma_i \sum_{l=i}^{M-1}\alpha_{i+1} + 1}$$

$$(2^{R_i} - 1)(\rho\gamma_i \textstyle\sum_{l=i}^{M-1}\alpha_{i+1} + 1) = \alpha_i\rho\gamma_i$$

$$2^{R_i}\rho\gamma_i \textstyle\sum_{l=i}^{M-1}\alpha_{i+1} + 2^{R_i} - \rho\gamma_i \sum_{l=i}^{M-1}\alpha_{i+1} - 1 = \alpha_i\rho\gamma_i$$

$$\gamma_i\{2^{R_i}\rho \textstyle\sum_{l=i}^{M-1}\alpha_{i+1} - \rho\sum_{l=i}^{M-1}\alpha_{i+1} - \alpha_i\rho\} = (2^{R_i} - 1)$$

$$\gamma_i = \frac{(2^{R_i} - 1)}{(2^{R_i}\rho\sum_{l=i}^{M-1}\alpha_{i+1} - \rho\sum_{l=i}^{M-1}\alpha_{i+1} - \alpha_i\rho)} = \varphi \tag{23}$$

Let, $E(\gamma_i) = \delta_i^2$, Probability Density Function (PDF) of Rayleigh fading channel [21] is given by

$$f(\gamma_i) = \frac{1}{\delta_i^2} e^{-\frac{\gamma_i}{\delta_i^2}} \tag{24}$$

Outage Probability,

$$P_{outage} = \int_0^\varphi \frac{1}{\delta_i^2} e^{-\frac{\gamma_i}{\delta_i^2}} d\gamma_i \tag{25}$$

$$P_{outage} = -\left[e^{-\frac{\gamma_i}{\delta_i^2}}\right]_0^\varphi$$

$$P_{outage} = 1 - e^{-\frac{1}{\delta_i^2}\cdot\frac{(2^{R_i}-1)}{(2^{R_i}\rho\sum_{l=i}^{M-1}\alpha_{i+1} - \rho\sum_{l=i}^{M-1}\alpha_{i+1} - \alpha_i\rho)}} \tag{26}$$

IV. RESULTS & DISCUSSION

In this section, simulation results have been presented to validate the derived equations for the outage probability, and BER of the DL NOMA system. The MATLAB program was used in order to acquire each one of the results shown in this section. The DL system is configured with M = 5 users. The variances of AWGNs are $\sigma^2 = 1$. Power allocation factors for NOMA $\alpha_5 = 0.75$, $\alpha_4 = 0.17$, $\alpha_3 = 0.05$, $\alpha_2 = 0.02$, $\alpha_1 = 0.01$ except to specific simulation results.

A. Performance Results over Rayleigh Fading Environment

Fig. 2 illustrates the performance of outage probability versus SINR for a DL NOMA system with M = 5 users. The plot considers the channel between the BS and the users, denoted as k_1, k_2, k_3, *and* k_4, following a Rayleigh fading distribution. According to Fig. 2, the user who is located the furthest away from the transmission side is user 4. If this is the case, then user 2 is located quite near to the transmission side of user 1, and other users are also located relatively close to the transmission side. So, it can be written that, $k_4 > k_3 > k_2 > k_1$. From the analysis of Fig. 2, it is evident that the outage probability for user 1, who is in close proximity, is relatively higher at SINR 10 dB compared to other users. This can be attributed to the fact that user 1 is situated closest to the BS. Conversely, user 4 exhibits a lower outage probability compared to other users in Fig. 2 as user 4 is situated at the farthest distance from the BS.

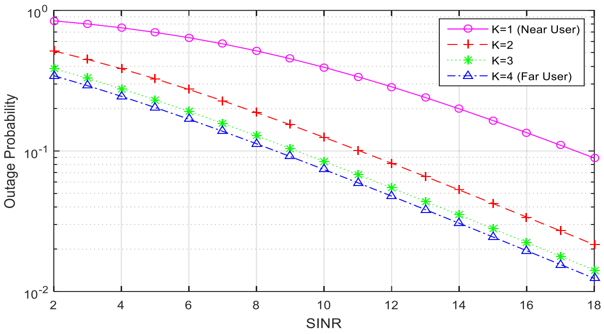

Fig. 2. Outage Probability Analysis of Massive MIMO NOMA beyond under Rayleigh Fading Channel

Fig. 3 depicts the BER of a 5-user SIMO NOMA network versus the SINR. User 5 is situated the farthest away from the transmission side, as seen in "Fig. 3". If this is the case, user 2 and other users are situated quite close to user 1's transmission side, as well as other users. Fig. 3 shows that distant user 5 has a significantly low BER compared to other users, falling below 10^{-4} at an SNR of 10 dB. In contrast, the BER of other users might reach up to 10^{-4}.

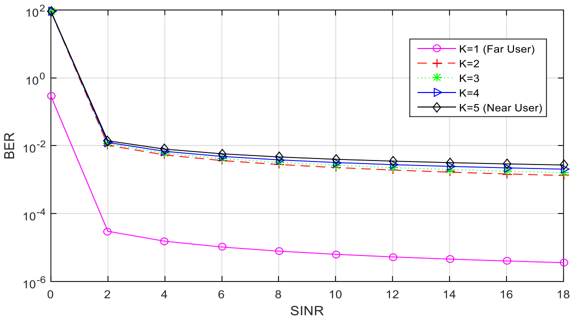

Fig. 3. The BER of SIMO NOMA network versus the SINR

Fig. 4 shows the BER vs SINR for a MIMO NOMA with perfect SIC. The BER performance of the users is also differentiated, with $P_1 > P_2 > P_3 > P_4 > P_5$ being the order since user 1 is affected by interference from all four users (k_2, k_3, k_4, k_5). User 2 by interference from three users (k_3, k_4, k_5), user 3 by interference from two user (k_4, k_5), user 4 by interference from two user (k_5) and user by no interference at all.

Fig. 4 also shows that distant user 1 has a significantly low BER compared to other users. Observing Fig. 4 it can be interpreted that MIMO NOMA shows the better BER than SIMO NOMA. However, when compared with MIMO NOMA, the BER of SIMO NOMA is high, because SIMO has single transmitter or receiver but MIMO has multiple transmitter or receiver.

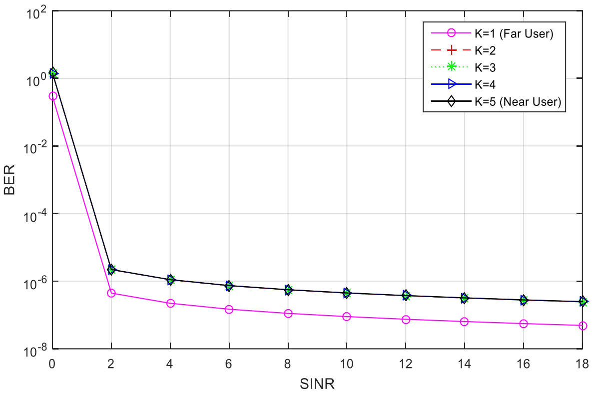

Fig. 4. The BER of MIMO NOMA network versus the SINR

V. CONCLUSION

NOMA schemes have emerged as a promising solution to optimize limited network resources, surpassing the limitations of traditional OMA methods. By employing power-domain-based multiple access, MIMO NOMA techniques effectively exploit radio resources, leading to significant improvements in throughput. In this study, we developed a rigorous analytical framework to assess the performance of a MIMO NOMA system operating in a Rayleigh fading environment, focusing on important metrics such as BER and outage probability. In future, the capacity of the system can be expanded by increasing the number of receiving antennas and utilizing longer code lengths. Moreover, we provided a comprehensive review of the current state of the art in this field, offering valuable insights into the existing literature. Through continued research and innovation, MIMO NOMA holds great potential for enhancing multiple access efficiency and revolutionizing wireless communication networks.

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