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Comparative Performance Analysis of Orthogonal and Non-Orthogonal Multiple Access Schemes in 5G Systems

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Abstract*:* This paper presents a comparative performance analysis of Orthogonal Multiple Access (OMA) and Non-Orthogonal Multiple Access (NOMA) techniques for 5G wireless communication systems. The OMA performance is modelled using OFDM and MIMO-OFDM under single-user and multi-user scenarios, while NOMA is implemented as a two-user power-domain system with Successive Interference Cancellation (SIC). Bit Error Rate (BER) and system throughput (sum rate) are evaluated through MATLAB-based simulations against varying levels of transmit power under identical channel conditions. The results reveal that although OMA schemes provide simpler implementation and effective interference management, NOMA achieves significantly higher sum rate while maintaining acceptable BER performance, especially at higher transmit power levels. These findings underscore NOMA's potential to meet the growing spectral efficiency and user connectivity requirements of future 5G networks.

Keywords: OMA, NOMA, OFDM, MIMO-OFDM, Bit Error Rate (BER), Sum Rate, Transmit Power, 5G, Spectral Efficiency, SIC (Successive Interference Cancellation)

I. INTRODUCTION

The explosive growth in wireless data demand and the need for ultra-reliable, high-speed communication have driven the development of advanced access schemes for fifth-generation (5G) networks. Efficient resource sharing, higher spectral efficiency, and support for massive connectivity are central goals in the design of radio access techniques. Multiple Access (MA) schemes—responsible for how users share the radio spectrum—play a critical role in achieving these objectives.

Orthogonal Multiple Access (OMA) techniques, such as Orthogonal Frequency Division Multiplexing (OFDM) and Multiple-Input Multiple-Output OFDM (MIMO-OFDM), have been widely used in existing wireless standards like LTE and Wi-Fi. These methods allocate non-overlapping time-frequency resources to users, ensuring low interference and simple receiver design. However, OMA systems face limitations in user scalability and spectral efficiency, particularly in multi-user scenarios.

To overcome these limitations, Non-Orthogonal Multiple Access (NOMA) has emerged as a promising candidate for 5G and beyond. NOMA allows multiple users to simultaneously access the same frequency-time resources using power-domain multiplexing. Signals are superimposed at different power levels and separated at the receiver using Successive Interference Cancellation (SIC), significantly improving user connectivity and spectrum utilization.

This paper provides a comprehensive comparative analysis of OMA and NOMA systems under identical channel conditions. The OMA systems are simulated using OFDM and MIMO-OFDM architectures for both single-user and four-user configurations, with performance metrics evaluated as functions of Signal-to-Noise Ratio (SNR). For the NOMA system, a two-user power-domain configuration is used, and Bit Error Rate (BER) and throughput are analysed as functions of transmit power.

Furthermore, a direct comparison between OMA and NOMA is conducted based on BER and sum rate (system throughput) performance with respect to varying transmit power levels. All simulations are carried out under Rayleigh fading conditions using MATLAB. The objective of this work is to analyse the performance trade-offs between OMA

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and NOMA in terms of error performance, spectral efficiency, and power utilization, thereby guiding the selection of appropriate access strategies for future wireless networks.

II. FUNDAMENTALS OF MULTIPLE ACCESS TECHNIQUES

2.1 *Orthogonal Multiple Access (OMA)*

Orthogonal Multiple Access (OMA) techniques ensure minimal intra-user interference by assigning orthogonal resources—time, frequency, or code—to different users. These methods are foundational in traditional wireless systems, providing simple and effective user separation.

- **OFDM (Orthogonal Frequency Division Multiplexing):** OFDM is a multicarrier modulation technique that divides the available spectrum into a large number of orthogonal subcarriers. It transforms a frequency-selective fading channel into a set of flat-fading subchannels, thereby enhancing robustness and simplifying equalization. It is widely used in 4G LTE and Wi-Fi due to its ability to handle multipath propagation effectively.
- **MIMO-OFDM (Multiple Input Multiple Output - OFDM):** MIMO-OFDM combines the spectral efficiency of OFDM with the spatial diversity of MIMO systems. This allows simultaneous transmission of multiple data streams across different antennas, significantly increasing capacity and reliability. Techniques such as spatial multiplexing and diversity coding improve both BER and throughput performance in fading environments.

However, OMA techniques allocate orthogonal resources per user, which inherently limits the number of users that can be served simultaneously. As the number of users increases, spectral efficiency decreases, particularly under high-load conditions. Additionally, the separation of resources among users restricts the full utilization of available bandwidth.

2.2 *Non-Orthogonal Multiple Access (NOMA)*

Non-Orthogonal Multiple Access (NOMA) has been introduced as a more spectrum-efficient alternative, allowing multiple users to share the same frequency-time resources. Unlike OMA, NOMA utilizes the power domain for multiplexing, where users' signals are superimposed with different power levels. At the receiver end, Successive Interference Cancellation (SIC) is used to detect and subtract the stronger signals before decoding the weaker ones. This hierarchical decoding enables multiple signals to coexist in the same spectrum without orthogonal separation.

- **In a typical power-domain NOMA system:**
- Users with weaker channel gains (far users) are allocated more power.
- Users with stronger channel gains (near users) receive less power.
- This strategy enhances fairness and ensures that both users meet their Quality of Service (QoS) requirements. The main advantages of NOMA include:
- Enhanced spectral efficiency
- Increased number of simultaneous users
- Better user fairness in heterogeneous network scenarios

Despite its advantages, NOMA introduces challenges in terms of SIC implementation, increased receiver complexity, and sensitivity to imperfect channel knowledge. Nonetheless, it is a strong candidate for addressing the high-density connectivity and throughput demands of 5G and beyond.

III. SYSTEM SETUP FOR OMA AND NOMA PERFORMANCE ANALYSIS

3.1 *OMA System (OFDM and MIMO-OFDM)*

The OMA system considered in this study includes both OFDM and MIMO-OFDM configurations. In the single-user OFDM case, the entire bandwidth is allocated to one user using orthogonal subcarriers. In the multi-user OFDM configuration, four users are served by dividing the available spectrum into non-overlapping sub-bands, with each user assigned a distinct set of subcarriers to ensure orthogonality and eliminate interference.

MIMO-OFDM is implemented with a 2x2 antenna configuration. For the single-user case, spatial multiplexing is utilized to transmit independent data streams, boosting throughput and diversity gain. In the four-user MIMO-OFDM scenario, each user is assigned unique orthogonal spatial and spectral resources. Although spatial diversity enhances the reliability of the transmission, the system still adheres to the principle of orthogonal resource allocation among users, limiting simultaneous access.

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In both OFDM and MIMO-OFDM systems, throughput is calculated based on modulation efficiency, bandwidth allocation, and user configurations. In the case of MIMO-OFDM, spatial multiplexing gain contributes to increased throughput compared to conventional OFDM, especially under single-user scenarios. For multi-user configurations, throughput is normalized per user to reflect spectral sharing and assess scalability.

Both OFDM and MIMO-OFDM are simulated under Rayleigh fading conditions using BPSK modulation. Bit Error Rate (BER) and throughput performance are evaluated as functions of Signal-to-Noise Ratio (SNR), with emphasis on comparing single-user and multi-user configurations within the OMA framework.

3.2 *NOMA System*

The NOMA system is modelled for a downlink two-user scenario operating in the power domain. In this configuration, both users are allowed to transmit simultaneously over the same time-frequency resources. Users are differentiated based on their channel conditions, where the user with the poorer channel (far user) is allocated a higher power share, and the user with a better channel (near user) receives a lower power level.

The superimposed signal is transmitted from the base station, and the receiver applies Successive Interference Cancellation (SIC) to decode the signals. The near user decodes and subtracts the far user's signal before retrieving its own data, while the far user directly decodes its signal assuming interference from the near user.

The NOMA system assumes ideal conditions such as perfect channel state information (CSI) and fixed power allocation coefficients. The channel is modelled using Rayleigh fading, and BPSK modulation is employed. Performance evaluation is carried out in terms of BER and sum rate as functions of increasing transmit power. This setup is particularly focused on analysing how well NOMA scales with power and how it compares to traditional OMA techniques under similar conditions.

IV. SIMULATION PARAMETERS

The simulation parameters outlined in Tables below provides a standardized configuration for evaluating the performance of OMA (OFDM and MIMO-OFDM) and NOMA systems. These settings ensure fair comparison under identical channel conditions, enabling consistent analysis of BER and throughput across different access techniques. MATLAB was used to simulate all scenarios using BPSK modulation over Rayleigh fading channels.

TABLE I Main Simulation parameters for OFDM system for single and multiple users for BER and Throughput calculation

Parameter	**Value**
Number of subcarriers (N)	128, 64
Cyclic prefix length (Ncp)	16
Number of pilot symbols (Np)	4
Modulation order (M)	2 (BPSK)
Eb/No range (EbNo)	0 to 30 (in steps of 5) dB
Data rate (bits per symbol)	1
No. of users	1, 4

TABLE II Main Simulation parameters for MIMO-OFDM system for single and multiple users for BER and Throughput calculation

Parameter	**Value**
Number of subcarriers (N)	128
Length of cyclic prefix (Ncp)	16
Modulation order (M)	2 (BPSK)
SNR range (EbNo)	0 to 30 dB (step of 5 dB)
MIMO configuration	2x2 Alamouti scheme
Channel type	Frequency-selective Rayleigh fading

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TABLE III Main Simulation parameters for NOMA system for BER and Throughput calculation

Parameter	Value
Number of bits	10^6
User distance from Base station	d1 = 1000m, d2 = 500m
Power allocation factors	a1 = 0.75, a2 = 0.25
Modulation (M)	2 (BPSK)
Channel type	Rayleigh fading

TABLE IV Main Simulation parameters for Comparison between OMA system vs NOMA system for BER and Sum Rate calculation

Parameter	Value
Number of Bits (N)	10^6
Modulation Scheme	BPSK
Power Allocation	a1=0.75, a2=0.25
Distance from BS	User 1: 1000 m, User 2: 500 m
Channel Model	Rayleigh fading

V. RESULTS AND DISCUSSION

To evaluate the relative performance of OFDM and MIMO-OFDM systems, simulations were conducted under a frequency-selective Rayleigh fading environment using BPSK modulation. Both single-user and multi-user scenarios were considered, with 2×2 MIMO antenna configurations used for MIMO-OFDM. The key metrics analysed were Bit Error Rate (BER) and throughput across SNR values ranging from 0 dB to 30 dB.

5.1 *BER Performance of OMA Systems*

The Bit Error Rate (BER) for both systems was plotted against Signal-to-Noise Ratio (SNR) ranging from 0 dB to 30 dB. The modulation scheme used was BPSK, and 64 subcarriers were employed.

Figures 5.1 and 5.2 show BER performance of OFDM for single and multiple users, respectively. As the SNR increases, the BER decreases exponentially in both scenarios. With four users, BER slightly degrades due to shared spectral resources. MIMO-OFDM performance is illustrated in Figures 5.3 and 5.4. In the single-user case (Fig. 5.3), BER falls sharply, achieving around 10^{-5} at 30 dB SNR. In the multi-user case (Fig. 5.4), all four users achieve a BER near or below 10^{-3} for SNR > 20 dB, showing excellent performance even under user multiplexing.

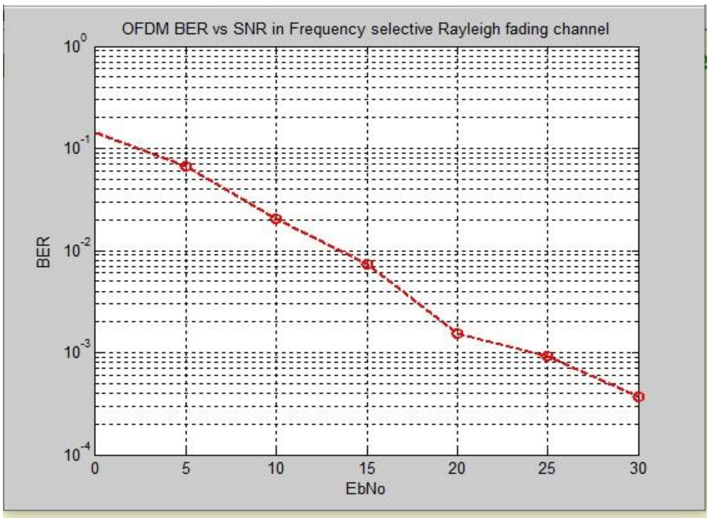

Fig 5.1 BER vs SNR in OFDM for single user

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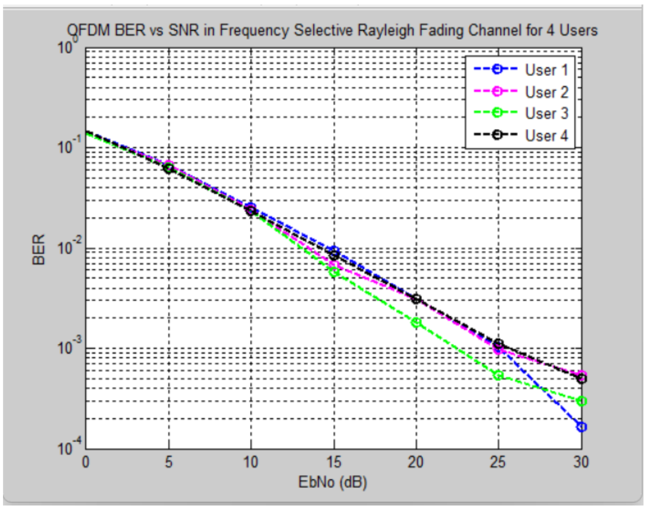

Fig 5.2 BER vs SNR in OFDM for multiple users (4 users)

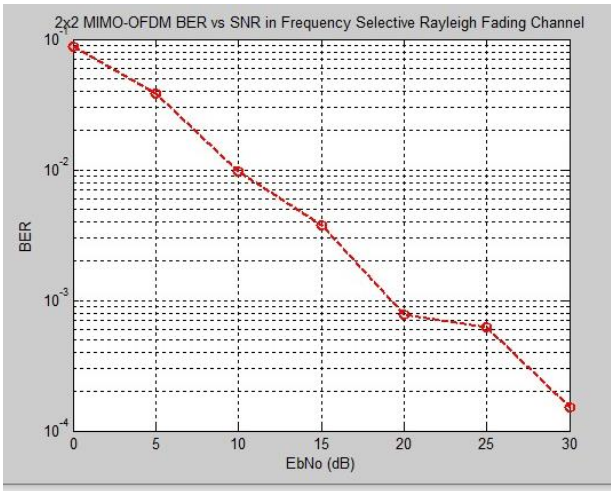

Fig. 5.3 BER vs SNR in MIMO-OFDM for single user

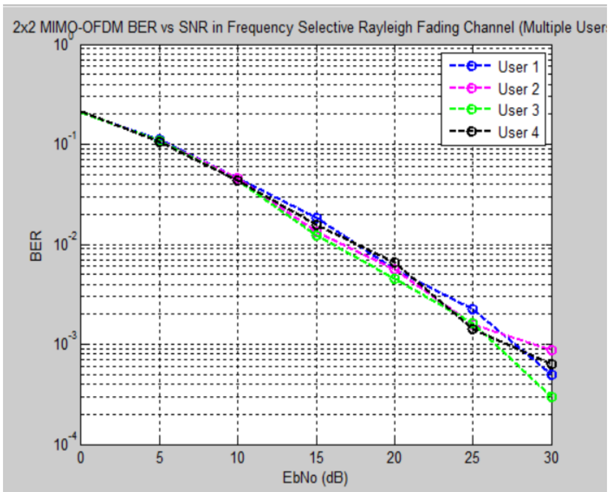

Fig 5.4 BER vs SNR in MIMO-OFDM for multiple users

Observations:

- MIMO-OFDM outperforms OFDM at all SNR levels in terms of BER.
- BER improvement is more significant in low to mid SNR ranges (0–20 dB) due to spatial diversity.
- Multi-user MIMO-OFDM still maintains acceptable BER, suggesting its viability in dense networks.

5.2 *Throughput Performance Comparison*

Figures 5.5 illustrate OFDM throughput for single and multi-user settings. In comparison, Figure 5.6 presents MIMO-OFDM throughput over a Rayleigh channel. While the throughput gain is relatively modest due to the use of BPSK modulation, MIMO-OFDM achieves consistently higher throughput per user than single-antenna OFDM.

At 30 dB SNR, the MIMO-OFDM system reaches a throughput of approximately 0.507 bits/symbol, compared to 0.509 bits/symbol in single-user OFDM. However, this does not account for spatial multiplexing gain, which can become significant when higher-order modulation and multiple streams are employed.

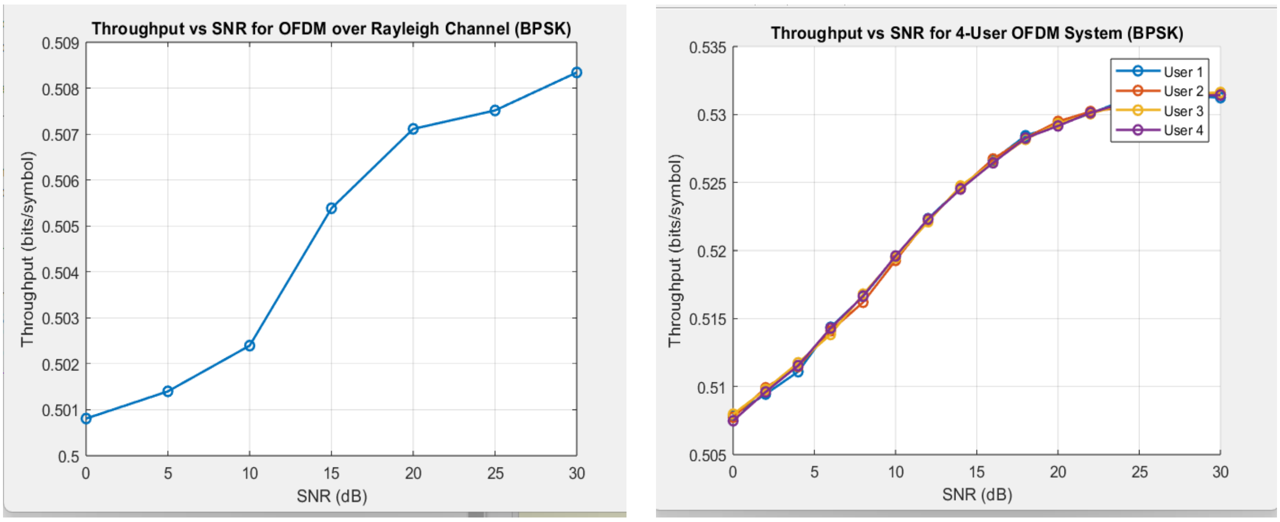

Fig 5.5 Throughput vs SNR in OFDM for multiple users (2 and 4 users)

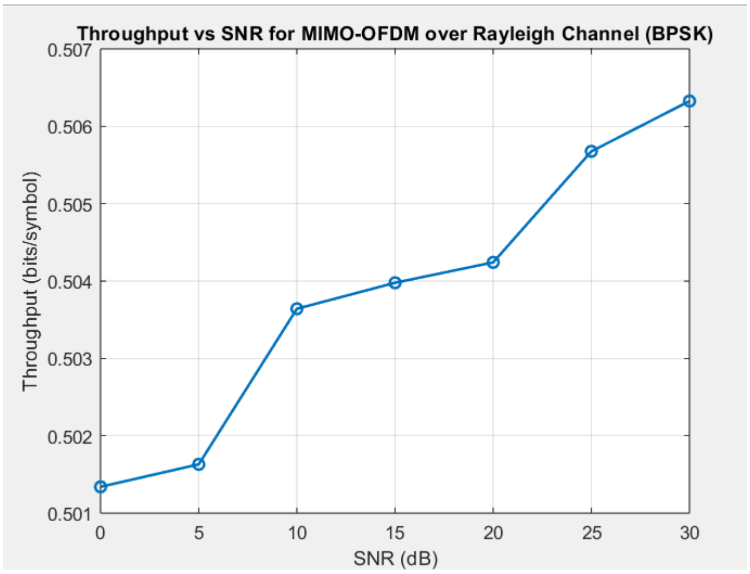

Fig 5.6 Throughput vs SNR in MIMO-OFDM

Observations:

- MIMO-OFDM provides better throughput scaling with SNR than traditional OFDM.
- Although both systems are BPSK-limited, MIMO architecture offers latent capacity for higher data rates through parallel streams.
- In real-world applications, the combination of spatial multiplexing and adaptive modulation would show greater throughput benefits.

5.3 *Performance of NOMA System*

The performance of the two-user power-domain NOMA system was evaluated with respect to transmit power ranging from 0 dBm to 40 dBm. Two key performance indicators were analyzed: Bit Error Rate (BER) and system throughput (bps/Hz), as shown in **Figures 5.7 and 5.8**.

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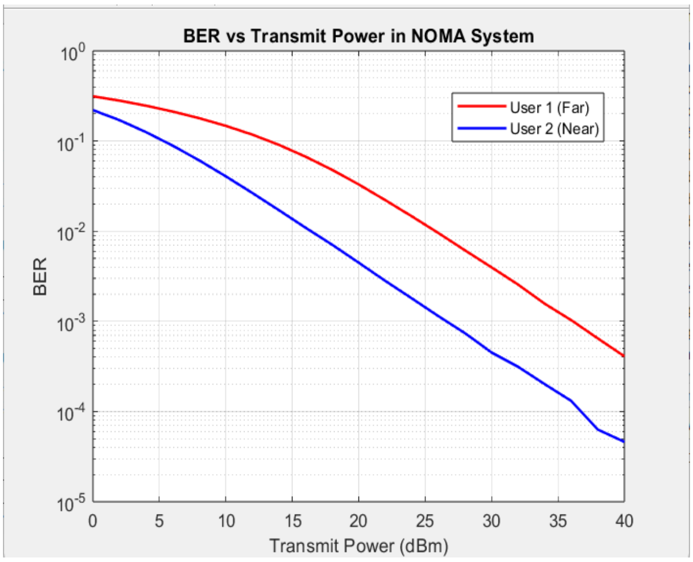

Fig 5.7 BER vs Transmit power in NOMA

Figure 5.7 shows the variation of BER with transmit power for both users in the NOMA system:

- **User 1 (Far User)** experiences higher BER due to lower signal quality and higher power allocation. Despite receiving more power, the far user suffers from significant interference, especially at lower transmit power levels.
- **User 2 (Near User)** consistently achieves better BER performance due to stronger channel conditions and the use of SIC (Successive Interference Cancellation) to decode and remove the far user's signal before decoding its own.

As transmit power increases, the BER for both users drops significantly. At 40 dBm, BER values fall below 10−410^{-4}10−4 for both users, indicating improved reliability of the system with higher power budgets.

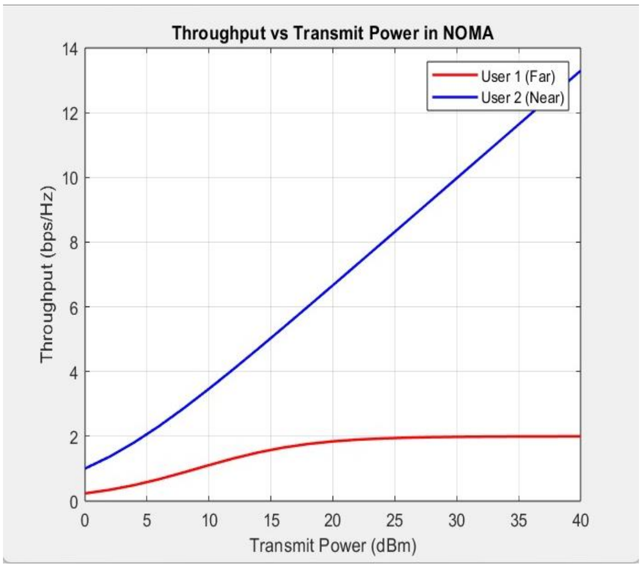

Fig 5.8 Throughput vs Transmit power in NOMA

Figure 5.8 illustrates throughput versus transmit power for the same two-user NOMA configuration:

- **User 2 (Near User)** achieves significantly higher throughput than the far user due to superior channel quality and efficient interference cancellation.
- **User 1 (Far User)** shows only marginal throughput improvements with increasing transmit power, primarily because of higher interference and lower SINR.

Overall, the total system throughput increases with transmit power, showcasing NOMA's ability to scale well with available power. The performance gap between the near and far user, however, highlights the importance of optimal power allocation and fairness mechanisms in practical deployments.

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These results demonstrate that NOMA enhances spectral efficiency by allowing simultaneous access to resources, albeit with a need for balancing user fairness and decoding complexity.

5.4 *OMA vs NOMA Comparison*

To assess the practical benefits of NOMA over traditional OMA, both techniques were directly compared under identical channel and power conditions. The evaluation focused on **Bit Error Rate (BER)** and **Sum Rate (System Throughput)** as functions of **transmit power**, as shown in **Figures 5.9 and 5.10**.

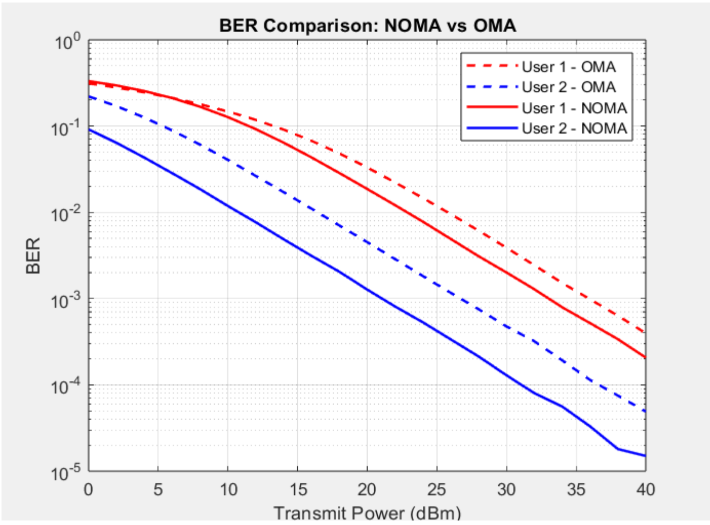

Fig 5.9 NOMA vs OMA: BER

Figure 5.9 presents a detailed BER comparison for both User 1 (Far) and User 2 (Near) under OMA and NOMA schemes:

- **NOMA outperforms OMA** in terms of BER across the entire transmit power range for both users.
- The BER curves for NOMA decline more sharply with increasing power, especially for the near user, benefiting from **Successive Interference Cancellation (SIC)**.
- In contrast, OMA users experience higher BER due to strict resource partitioning, which limits their ability to exploit power and frequency diversity.

This comparison highlights NOMA's **superior error performance** and ability to provide better reliability at lower power thresholds, even in multi-user scenarios.

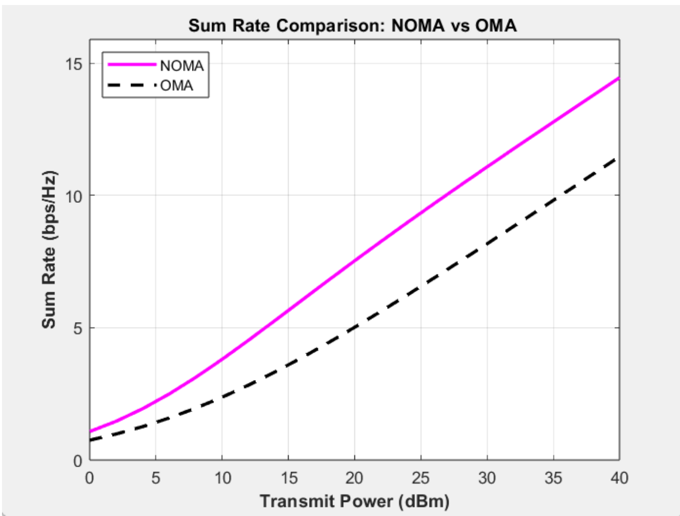

Fig 5.10 NOMA vs OMA: Sum Rate

Figure 5.10 compares the **sum rate performance** of OMA and NOMA:

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- NOMA achieves a **significantly higher sum rate** across all transmit power levels, due to its ability to **superimpose multiple user signals** over the same time-frequency resources.
- The performance gap widens with increasing power, reaching over **4 bps/Hz higher** at 40 dBm compared to OMA.
- OMA's sum rate grows more slowly due to orthogonal resource division, which limits its spectral efficiency.

This result confirms NOMA's capability to **serve multiple users simultaneously without compromising throughput**, making it a highly efficient solution for next-generation high-capacity wireless systems.

5.5 *Summary of OMA vs NOMA Performance*

TABLE V comparative analysis of OMA and NOMA system performance

Parameter	OMA (OFDM/MIMO-OFDM)	NOMA (2-User Power Domain)
Access Strategy	Orthogonal resource allocation (time/frequency/space)	Power-domain multiplexing with SIC
User Support	Limited simultaneous users	Multiple users on same resources
Spectral Efficiency	Moderate; decreases with more users	High; better spectrum utilization
BER (Near User)	Higher than NOMA at high transmit power	Lower due to SIC and favourable channel
BER (Far User)	Slightly better than NOMA at low power	Improves with higher transmit power
Sum Rate	Limited; scales slowly with power	Significantly higher, increases rapidly with power
Complexity	Lower implementation complexity	Higher due to SIC requirements
Fairness	Depends on resource allocation scheme	Better fairness through power allocation
Use Case Suitability	Best for low-to-moderate user density	Ideal for dense 5G/IoT scenarios

VI. CONCLUSION

This paper presented a comparative performance analysis between Orthogonal Multiple Access (OMA) techniques—specifically OFDM and MIMO-OFDM—and Non-Orthogonal Multiple Access (NOMA) systems in the context of 5G wireless communication. Using MATLAB simulations, we evaluated system performance in terms of Bit Error Rate (BER) and sum rate (throughput) under identical channel conditions and varying transmit power levels.

The results for OMA systems showed that while MIMO-OFDM outperforms conventional OFDM in both BER and throughput due to spatial diversity, their performance is limited by resource orthogonality and scalability in multi-user scenarios.

NOMA, on the other hand, achieved significantly improved sum rate performance and lower BER for both users—particularly the near user—thanks to power-domain multiplexing and successive interference cancellation. Moreover, when directly compared, NOMA outperformed OMA in terms of throughput efficiency and reliability across the entire transmit power range.

These findings confirm the effectiveness of NOMA in enhancing spectral efficiency, user connectivity, and overall throughput, making it a promising candidate for future high-capacity 5G and beyond communication systems.

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