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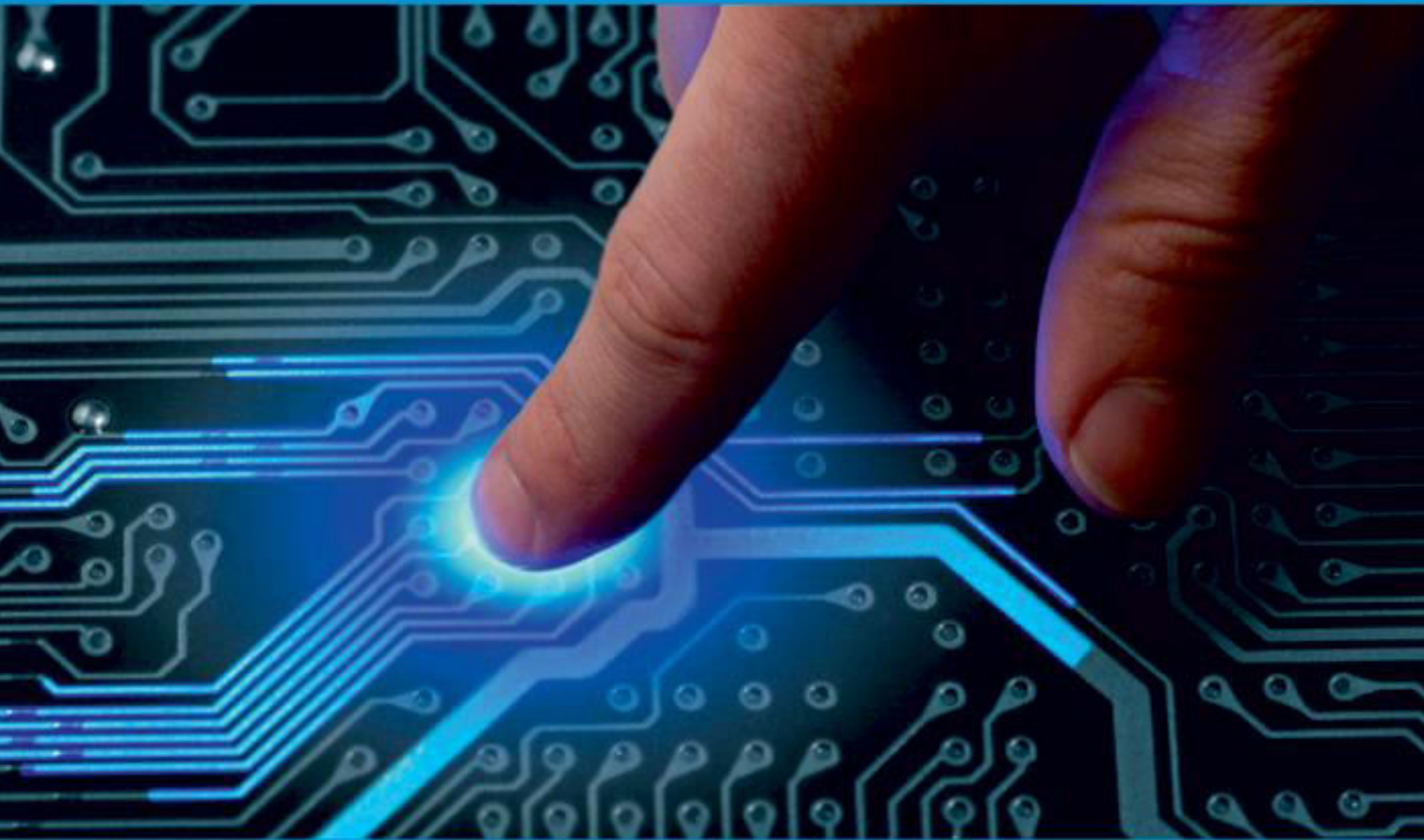

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Performance Analysis of Single Cluster NOMA

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ABSTRACT: Non orthogonal multiple access (NOMA), as the newest member of the multiple access family isenvisioned to be an essential component of 5G mobile networks. Multiple inputs MultipleOutput is a technology in which more than one antenna are used at transmitter and receiver.The combination of MIMO NOMA technologies exhibits a significant potential in improving spectral efficiency and providing better wireless services to more users. This abstract introduce the basic concepts of MIMO NOMA and explores the beamforming, user clustering and power allocation of single / multi cluster MIMO NOMA. Furthermore, the concept of superposition coding (SC) and successive interference cancellation (SIC) are explained. Finally incorporating NOMA with MIMO. In this paper, we present a comprehensive performance analysis of single-cluster Non-Orthogonal Multiple Access (NOMA) networks, demonstrating significant performance gains over both user-paired NOMA and Orthogonal Multiple Access (OMA) systems. By deriving exact closed-form expressions and approximate closed-form expressions at high signal-to-noise ratios (SNRs) for the total effective capacity (EC) or spectral efficiency of single-cluster NOMA networks, we provide a robust framework for understanding the superior efficiency of this communication strategy. Our findings indicate that, at high SNRs, the total EC is primarily influenced by the statistical delay requirement of the strongest user, while remaining independent of the delay requirements of other users in the cluster. In addition to this, we conduct a theoretical analysis comparing the total throughput of single-cluster NOMA with user-paired NOMA and OMA, focusing on the impact of transmit SNR. Through rigorous simulation results, we confirm the accuracy of our analytical models. The results reveal that single-cluster NOMA networks consistently achieve a significantly higher total throughput compared to conventional OMA, particularly as the number of users in the network increases.

KEYWORDS: Non-Orthogonal Multiple Access (NOMA), single-cluster NOMA, effective capacity (EC), signal-to-noise ratio (SNR), orthogonal multiple access (OMA), user-paired NOMA, delay requirements, channel conditions, transmit SNR, performance analysis.

I. INTRODUCTION

Non-Orthogonal Multiple Access (NOMA) technology enhances connectivity, boosts spectral efficiency, and realizes low transmission latency, making it one of the most promising techniques for next-generation cellular networks. With the rise of diverse Quality of Service (QoS) requirements in the beyond 5G era, it's crucial for future networks to flexibly schedule resources to support differentiated services such as massive connectivity and low-latency transmissions. NOMA has shown potential in addressing these needs. This paper focuses on single-class traffic regarding delay QoS, exploring NOMA's performance in supporting delay-sensitive services.

Previous investigations into multi-user NOMA systems have covered various aspects. For instance, the authors in one study analyzed the outage probability and capacity for a downlink NOMA network, highlighting the ability to meet target data rates rather than users' delay requirements. Another study considered the joint optimization of user clustering and power allocation to maximize the sum rate of NOMA systems. Additionally, research has examined the impact of imperfect successive interference cancellation (SIC) in downlink NOMA networks, supporting massive access with optimized transmit beams and powers. However, these studies did not focus on users' delay requirements.

Considering delay-sensitive applications, one author investigated power control in a downlink NOMA network by maximizing the sum effective capacity (EC). Similarly, another study characterized the delay constraint by the delay QoS exponent, studying power allocation based on the max-min EC criterion. However, these works focused on designing power control policies without analyzing delay-constrained achievable rates. Analytical expressions for EC in downlink and uplink NOMA transmissions have been provided, but these studies considered user-paired NOMA, where users are separated into clusters of two. The performance of EC for single-cluster NOMA, where all users share the same resource, has not been explored.

Motivated by these observations, this paper focuses on the EC analysis for single-cluster NOMA networks, providing a quantitative performance comparison among single-cluster NOMA, user-paired NOMA, and Orthogonal Multiple

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Access (OMA). We derive exact closed-form expressions for the total EC of single-cluster NOMA and approximate expressions at high SNRs. For the first time, it is found that at high SNRs, the total EC of single-cluster NOMA is independent of power coefficients, relying solely on the delay requirement of the user with the best channel quality. The total EC differences between single-cluster NOMA and user-paired NOMA/OMA are analyzed theoretically and validated via simulations.

Our findings reveal that the performance gain of single-cluster NOMA over user-paired NOMA/OMA remains stable at high SNRs. Numerical results indicate that in both loose and strict latency scenarios, single-cluster NOMA outperforms the other two models at high SNRs, with the performance gain independent of users' power coefficients. Simulation results further demonstrate that increasing the number of users enhances this performance advantage.

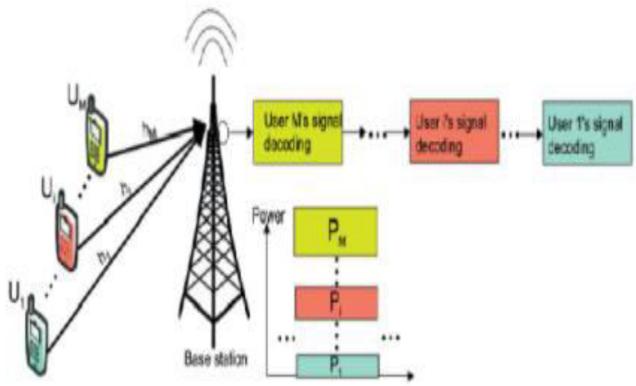

Figure 1: An illustration of Block Diagram of Uplink NOMA and Power Levels of Users.

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II. LITERATURE REVIEW

Non-Orthogonal Multiple Access (NOMA) has emerged as a promising technology for enhancing connectivity, boosting spectral efficiency, and achieving low transmission latency in next-generation cellular networks. Several key studies have explored the potential and challenges of NOMA in various contexts:

Overview of NOMA in 5G and Beyond:
Liu et al. [1] provide a comprehensive review of NOMA for 5G and beyond, discussing its fundamental principles, potential benefits, and implementation challenges. This work emphasizes the importance of NOMA in meeting the diverse requirements of future wireless networks.

Information-Theoretic Perspective:
Vaezi and Poor [2] present an information-theoretic analysis of NOMA, highlighting its capacity and performance limits. This study offers deep insights into the theoretical underpinnings of NOMA and its potential advantages over traditional multiple access techniques.

NOMA in Multi-Cell Networks:
Shin et al. [3] investigate the application of NOMA in multi-cell networks, addressing theoretical performance and practical challenges. Their work underscores the complexities of implementing NOMA in real-world multi-cell environments and proposes solutions to enhance its effectiveness.

5G Network Slicing:
Popovski et al. [4] discuss the role of NOMA in supporting 5G network slicing for enhanced Mobile Broadband (eMBB), Ultra-Reliable Low-Latency Communications (URLLC), and massive Machine-Type Communications (mMTC). Their communication-theoretic view highlights how NOMA can facilitate diverse QoS requirements in future networks.

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Massive NOMA with Imperfect SIC:
Chen et al. [5] design massive NOMA systems considering imperfect successive interference cancellation (SIC). This study provides insights into the practical limitations of NOMA and suggests design strategies to mitigate the impact of imperfect SIC.

Effective Capacity and Power Control:
Choi [6] explores the effective capacity of NOMA and proposes a suboptimal power control policy to meet delay QoS requirements. This research highlights the importance of power allocation in maximizing the performance of NOMA under QoS constraints.

Cross-Layer Power Allocation:
Liu et al. [7] propose a cross-layer power allocation scheme for NOMA systems to ensure statistical QoS provisioning. Their work demonstrates the effectiveness of cross-layer optimization in enhancing the performance of NOMA networks.

Link-Layer Capacity under QoS Guarantees:
Yu, Musavian, and Ni [8] analyze the link-layer capacity of NOMA under statistical delay QoS guarantees. This study provides a detailed examination of the capacity and delay trade-offs in NOMA systems.

Delay Guarantee and Effective Capacity:
Xiao et al. [9] investigate the delay guarantee and effective capacity of downlink NOMA fading channels. Their findings emphasize the importance of considering delay constraints in the design and analysis of NOMA systems.

Asymptotic Performance under QoS Constraints:
Bello et al. [10] provide an asymptotic performance analysis of NOMA uplink networks under statistical QoS delay constraints. This research offers valuable insights into the long-term performance and reliability of NOMA systems in meeting stringent delay requirements.

Research Gap
Despite the advancements in Non-Orthogonal Multiple Access (NOMA) technology, several aspects remain under-explored. These include the focus on multi-user NOMA systems, the impact of delay requirements, high SNR analysis, comparison with user-paired NOMA and OMA, scalability with number of users, and the impact of channel quality variations on single-cluster NOMA performance. Most existing literature focuses on multi-user NOMA systems, emphasizing user-paired configurations. However, there is a lack of comprehensive analysis on how delay requirements specifically influence the effective capacity (EC) in single-cluster NOMA networks. High SNR analysis is limited, with studies focusing on power control policies and delay QoS guarantees. Comparisons with user-paired NOMA and OMA are common, but there is a need for a more detailed theoretical and simulation-based comparison. Scalability with number of users is also under-explored, with studies addressing the scalability of NOMA in multi-cell and massive access scenarios but not the impact of increasing the number of users on EC and latency. Channel quality variations on single-cluster NOMA performance have not been extensively studied, and there is a gap in understanding how EC and overall network performance adapt to changes in channel conditions, especially under high SNRs.

This research aims to fill these gaps by providing a detailed analysis of the effective capacity of single-cluster NOMA networks, exploring their performance under various SNR conditions, and comparing them with user-paired NOMA and OMA systems.

III. PROPOSED SYSTEM

Single-cluster Non-Orthogonal Multiple Access (NOMA) is a technique used in wireless communication to enhance connectivity, boost spectral efficiency, and minimize transmission latency. In a single-cluster NOMA system, all users share the same frequency, time, and code resources, distinguishing themselves by their power levels. This approach contrasts with traditional Orthogonal Multiple Access (OMA) methods, where each user is allocated a unique resource block. The primary advantage of single-cluster NOMA lies in its ability to serve multiple users simultaneously within the same cluster, leading to more efficient utilization of available resources. By employing power domain multiplexing, single-cluster NOMA can accommodate users with different channel conditions, improving the overall system capacity and ensuring that high-priority users receive the required Quality of Service (QoS). This makes single-cluster NOMA a

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promising solution for next-generation cellular networks, particularly in scenarios demanding massive connectivity and low-latency transmissions.

The NOMA is a multiple access technique employed in 5G cellular wireless network. The main function of NOMA is to serve multiple UEs (User Equipments) using single 5G-NB (Node B or Base Station). It serves multiple users on same time/frequency resources.

There are two main techniques employed in NOMA for multiple access.
• Power domain: Here NOMA achieves multiplexing based on different power levels.
• Code domain: Here NOMA achieves multiplexing based on different codes. .

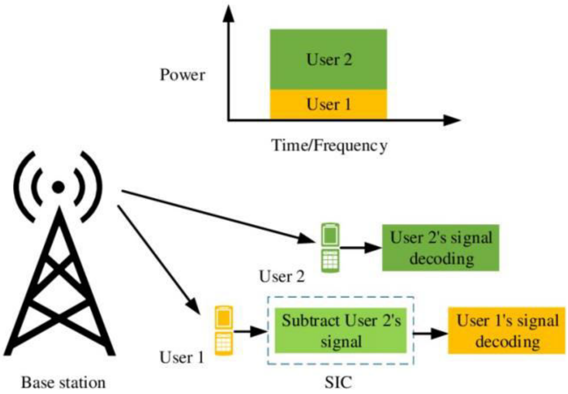

Figure.2 Downlink NOMA in a single cell with one BS and two users.

Transmit side: NOMA uses superposition coding at the transmitter end. The different power levels have been assigned to users. As shown in the figure-1, Base Station transmits superposed signals to User#1 and User#2. Here User#2 uses high gain and User#1 uses low gain as shown.

Receive side: NOMA uses SIC (Successive interference cancellation) technique to retrieve data of both the users. At receiver, User#2 (Strong User) subtracts signal of user#1 through SIC and later decodes its own signal. User#1 (Weak User) treats signal of User#2 as noise and decodes its own signal directly.

Single-cluster Non-Orthogonal Multiple Access (NOMA) is a wireless communication technique that enhances connectivity, boosts spectral efficiency, and reduces transmission latency. In a single-cluster NOMA system, multiple users share the same frequency, time, and code resources simultaneously, differentiating themselves by their power levels. This method stands in contrast to traditional Orthogonal Multiple Access (OMA), where each user is assigned a distinct resource block. The key advantage of single-cluster NOMA is its ability to serve multiple users within the same cluster concurrently, leading to more efficient resource utilization. By employing power domain multiplexing, single-cluster NOMA can effectively manage users with varying channel conditions, thereby enhancing overall system capacity and ensuring that high-priority users meet their Quality of Service (QoS) requirements. This makes single-cluster NOMA particularly suitable for next-generation cellular networks, especially in scenarios requiring massive connectivity and low-latency transmissions. Additionally, single-cluster NOMA systems demonstrate resilience against environmental factors and disasters, maintaining operational integrity even when traditional wired infrastructures are compromised. This robustness makes NOMA an attractive solution for diverse and demanding communication environments.

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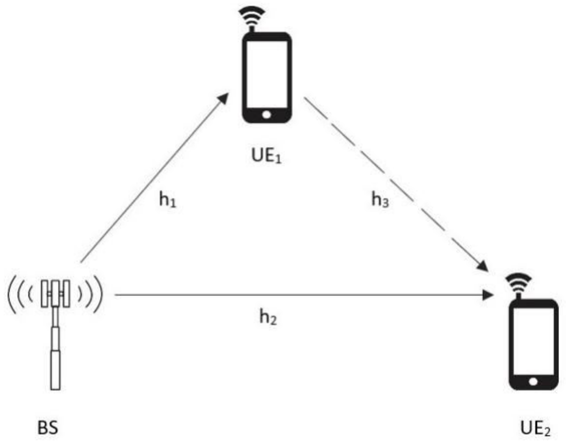

Figure 3: System Model Using NOMA

In our research, we employ a MATLAB simulator to gauge how network parameters and fading environments influence the outage probability of a Non-Orthogonal Multiple Access (NOMA) system using full duplex relaying over Nakagami-m fading channels. This simulator helps us grasp how different factors affect the reliability and performance of NOMA systems in practical settings. To simulate outage probability, we start by deriving mathematical expressions representing outage probability under varied network conditions and fading environments. These expressions establish the connection between outage probability and parameters like transmit power, channel conditions, user locations, and interference levels. We integrate Nakagami-m fading channel characteristics into our simulation model for its adaptability in modeling fading phenomena. In MATLAB, we implement these expressions to generate realistic scenarios and mirror NOMA system behavior.

By adjusting network parameters and environmental conditions, we explore diverse scenarios to thoroughly assess system performance. Our extensive simulations reveal how alterations in these parameters influence outage probability, offering valuable insights into NOMA system robustness and reliability. Moreover, we analyze simulation results to comprehend the factors contributing to outage events in NOMA systems. We pinpoint critical parameters that notably affect outage probability and explore strategies to mitigate outage occurrences. This analysis aids in optimizing system design and deployment strategies, enhancing NOMA-based communication system reliability and efficiency.

Overall, our MATLAB simulation acts as a potent tool for examining NOMA system outage probability in varied network conditions and fading environments. By accurately representing real-world complexities, our simulation findings contribute to designing and optimizing reliable and high-performance NOMA communication systems for future wireless networks.

In the system model we're examining, there's a Base Station (BS) communicating with two User Equipment (UE1 and UE2) simultaneously using power domain NOMA. At the Base Station, a technique called superposition coding is employed. This technique combines the signals intended for UE1 and UE2 into a single composite signal.

$$x(t)= \sqrt{\rho\beta_1 b x_1}(t) + \sqrt{\rho\beta_2 x_2}(t) \qquad (1)$$

To explain further, let's consider the signals intended for UE1 and UE2, denoted as $X_1(t)$ and $X_2(t)$ respectively. These signals are combined at the Base Station using superposition coding. We assume that both signals have the same power, let's say, unit power.

$$E|x_1(t)|^2 = E|x_2(t)|^2 = 1 \qquad (2)$$

So, in simpler terms, the Base Station is combining the signals meant for UE1 and UE2 into one signal, ensuring that each signal has equal power. This combined signal is then transmitted to both UE1 and UE2, allowing them to decode their respective signals from the composite transmission.

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Simulation parameters for conventional NOMA in downlink and uplink transmissions.

Investigate the throughput performances of downlink and uplink NOMA systems in LTE/LTE-Advanced systems using my proposed suboptimal user grouping and optimal power allocation solutions. In these simulations, resource blocks are allocated as follows: 2 units for 2-user NOMA clusters, 3 units for 3-user clusters, 4 units for 4-user clusters, and 6 units for 6-user clusters. Both uplink and downlink NOMA systems are compared with OFDMA-based LTE/LTE-Advanced systems. Additionally, the total downlink transmission power is evenly distributed among the available resource blocks. The main simulation parameters are shown in Table 1.

Parameter	Value
Unit resource bandwidth, B	180 kHz
Downlink Transmit power budget, P_T	46 dBm
Uplink Transmit power budget, P_t	24 dBm
SIC receiver's detection threshold, P_{tol}	20 dBm
Number of transmit antenna at both of BS and UE end	1
Number of receive antenna at both of BS and UE end	1

Table No 1. Parameters for Conventional NOMA in Downlink and Uplink Transmissions

IV. RESULTS AND DISCUSSION

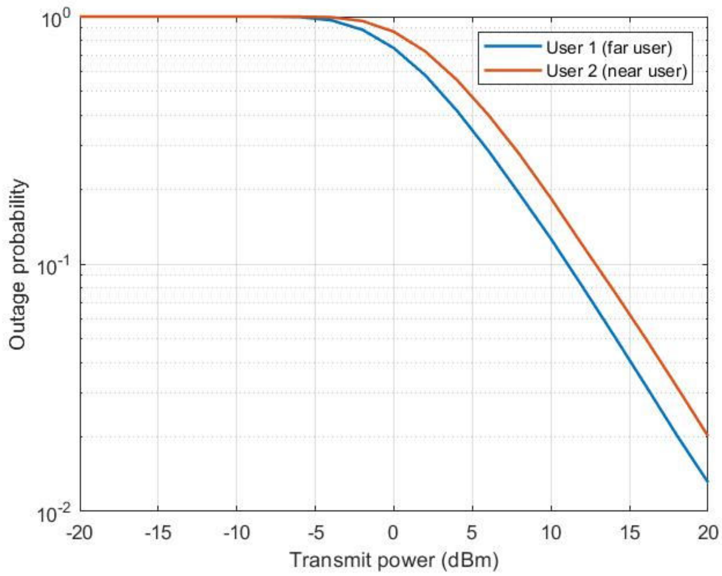

Figure 4 Single Cluster Noma (2 User) Outage Probability

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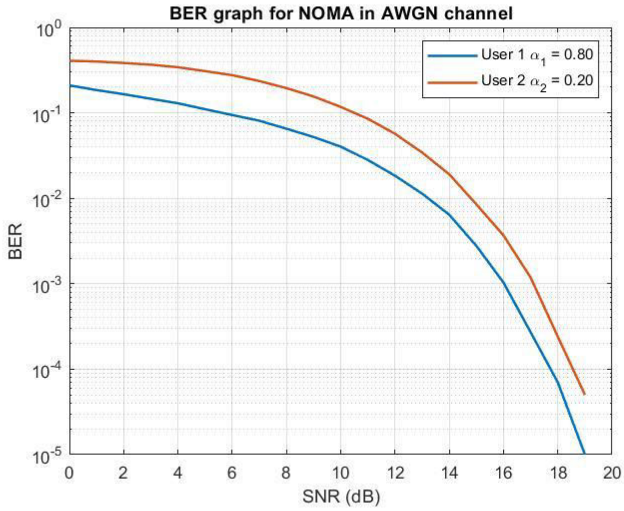

Figure 5 BER of Single Cluster Noma (2 User)

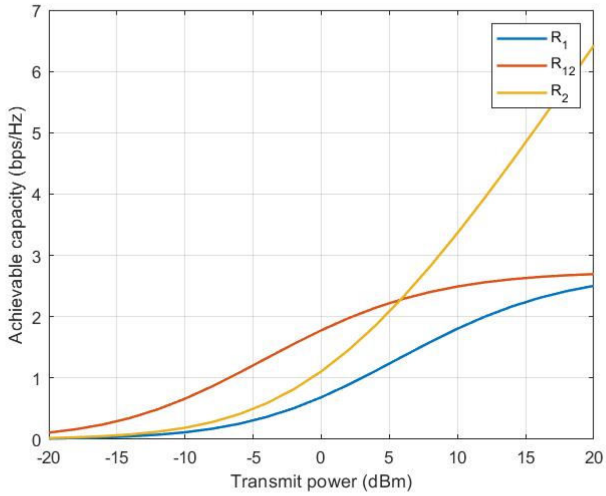

Figure 6 Achievable Capacity of Single Cluster Noma (2 User)

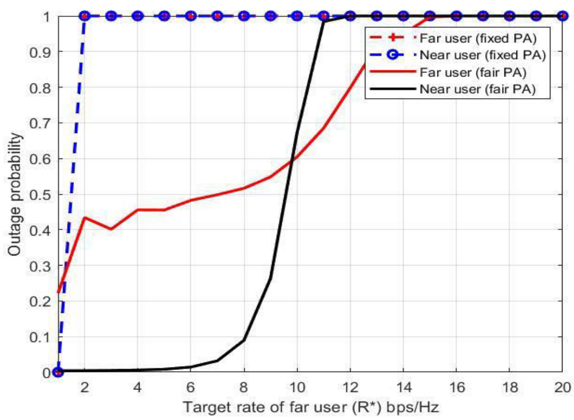

Figure 7 Power Allocation in Noma (2User)

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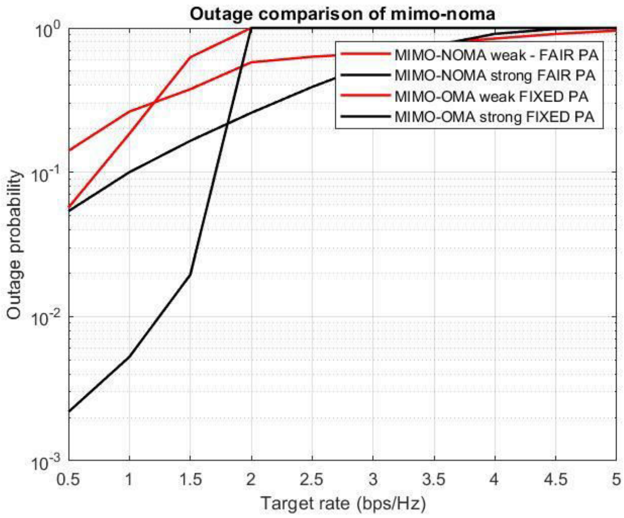

Figure 8 Mimo-Noma Fair PA Outage comparison

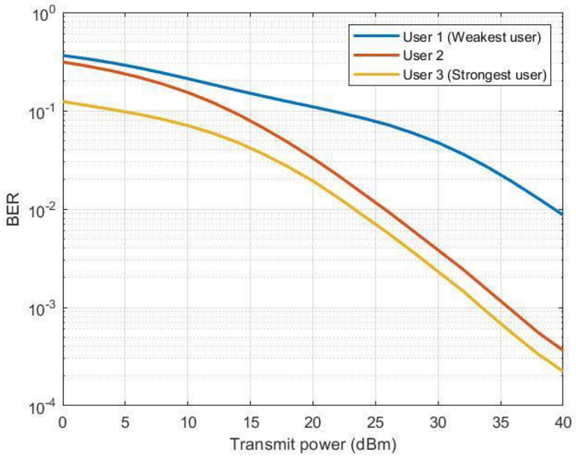

Figure 9 BER of Noma (3 User)

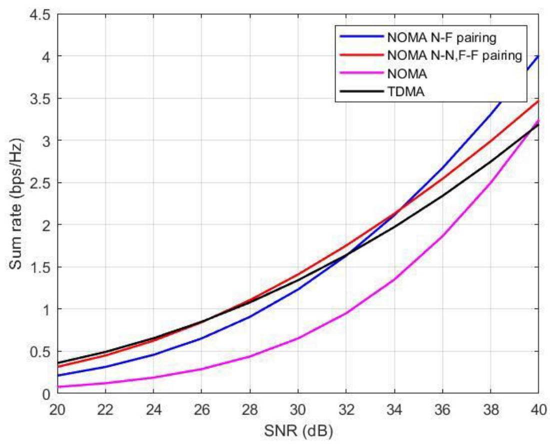

Figure 10 User Pairing in Single Cluster Noma (4User)

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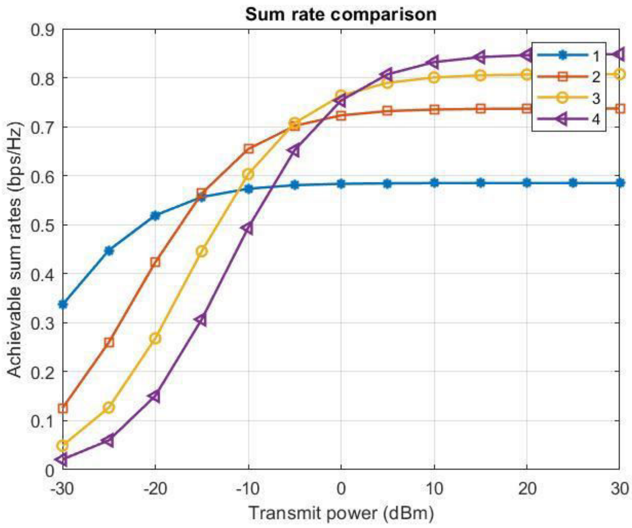

Figure 11 Sum Rate of Single Cluster Noma (4 User)

The above fig.4, shows the outage probability of near user and far user. In general, near users are more stronger and have a lower outage probability than far users which have higher outage probability due to weaker signal strength and high susceptability to interference and noise. In fig.5, we observe that user2 has greater BER than user1, specifically in the low SNR region. Because, user2 must perform SIC. While implementing SIC, user2 must first find user1's data from y. If this y value is incorrect, then this will result error in the decodinh of its own information because the wrong data will be subtracted from y. It means that, user2 must decode both user1's and its own data perfectly. Any of the error in decode operation will result in an impact on BER. Fig.6 shows the achievable capacity of two users in which one is near and another is far user. It is clear that the user which is near to the base station is having high capacity than the user which is far. In figures 7 & 8, for the power allocation in NOMA, the total transmit power is fixed as 40dBm. To get the outage, the same target rates are set for both the near and far users. Here, it is seen that fixed power allocation results in poor outage and saturates to 1 when rate is greater than 0.2bps/Hz. In the fig.9, user1(weaker user) is having the highest BER of all. Because, user1 suffers from high interference due to user2 and user3. User2 is effected by moderate interference due to user3. And lastly, user3 is not at all effected by any interference and it has low BER. Fig.10. shows that the result of just NOMA is poor when it is compared to TDMA. This is because, the overloading of the users creates interference. This is why, we cannot increase the number of users which share the same carrier. Fig.11. shows the sum rate comparison of four users present in the single cluster. The users which are near to base station are allocated with less power but they can achieve higher sum rates.

V. CONCLUSION

In this paper, we have undertaken a comprehensive performance analysis of single-cluster Non-Orthogonal Multiple Access (NOMA) networks, illustrating substantial performance enhancements over both user-paired NOMA and Orthogonal Multiple Access (OMA) systems. By deriving exact closed-form expressions and approximate closed-form expressions at high signal-to-noise ratios (SNRs) for the total effective capacity (EC) of single-cluster NOMA networks, we have established a robust framework for understanding the superior efficiency of this communication strategy. Our findings reveal that, at high SNRs, the total EC is predominantly influenced by the statistical delay requirement of the strongest user, while remaining unaffected by the delay requirements of other users in the cluster. This underscores the effectiveness of single-cluster NOMA in capitalizing on the channel conditions of the most advantageous users. Furthermore, we have conducted a theoretical analysis comparing the total EC of single-cluster NOMA with user-paired NOMA and OMA, with a specific focus on the impact of transmit SNR. Through rigorous simulation results, we have verified the accuracy of our analytical models. The outcomes indicate that single-cluster NOMA networks consistently achieve significantly higher total EC compared to conventional OMA, particularly as the number of users in the network increases. In conclusion, our study highlights the substantial performance gains offered by single-cluster NOMA networks and underscores their potential as an efficient communication strategy, especially in scenarios with diverse user requirements and varying channel conditions. These insights contribute to the advancement of future wireless communication systems, emphasizing the importance of embracing NOMA techniques for enhancing network efficiency and capacity.

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