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Performance Enhancement Using NOMA-MIMO for 5G Networks

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Abstract

The integration of MIMO and NOMA technologies addresses key challenges in 5G and beyond, such as connectivity, latency, and dependability. However, resolving these issues, especially in MIMO-enabled 5G networks, required additional research. This involved optimizing parameters like bit error rate, downlink spectrum efficiency, average capacity rate, and uplink transmission outage probability. The model employed Quadrature Phase Shift Keying modulation on selected frequency channels, accommodating diverse user characteristics. Evaluation showed that MIMO-NOMA significantly improved bit error rate and transmitting power for the best user in download transmission. For uplink transmission, there was an increase in the average capacity rate and a decrease in outage probability for the best user. Closed-form formulas for various parameters in both downlink and uplink NOMA, with and without MIMO, were derived. Overall, adopting MIMO-NOMA led to a remarkable performance improvement for all users, even in challenging conditions like interference or fading channels.

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1. Background

In recent decades, wireless communication has undergone a substantial technological shift, evolving from basic voice communication to highly interactive data exchange, driven by the need for high data rates and continuous connectivity. The growing demand for mobile devices has further fueled this evolution. To meet future requirements, researchers are actively developing fifth-generation (5G) and beyond-fifth-generation (B5G) wireless communication networks. Non-orthogonal multiple access (NOMA) emerges as a promising solution, addressing the increasing needs of a vast user base, connectivity demands, cost-effectiveness, limited bandwidth, and extensive coverage. However, implementing NOMA in wireless networks presents both challenges and advantages.

In order to overcome the limitations of 5G and beyond fifth-generation technologies and establish innovative technological pathways for spectrum efficiency and energy efficiency at minimal costs, exploring multiple-access systems becomes imperative to partially mitigate these challenges. Conventional orthogonal multiple access (OMA) schemes employed in 1G through 4G cellular networks, which allocate different frequencies, resource blocks, time slots, or codes to individual users, prove insufficient to handle the anticipated high demands for network traffic and user density in the future. The fundamental advantage of orthogonality lies in assigning various resources to users, ensuring zero interference while accessing network resources (Kalra and Chauhan, 2014) [1].

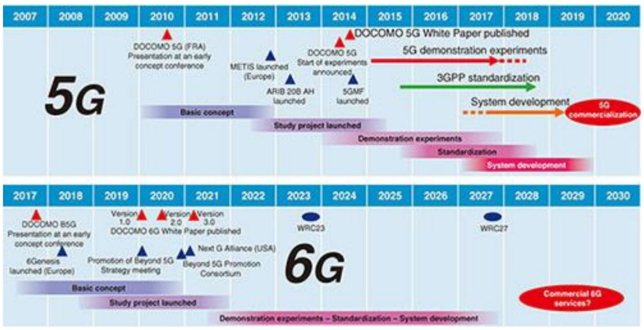

Figure 1: Evolution from 1G to 6G (B5G)

NOMA, on the other hand, allows numerous users within the same cell to simultaneously share a single frequency channel, providing advantages such as improved cell-edge throughput, enhanced spectrum efficiency, loose channel feedback, and reduced transmission delay. NOMA outperforms conventional OMA by servicing multiple users simultaneously, using the same frequency resource and employing successive interference cancellation to reduce interference and achieve superior spectral efficiency. It facilitates large-scale connectivity, accommodating a vast number of users. The simultaneous transmission nature of NOMA enforces a set time period for information delivery, reducing latency. NOMA's flexible power control between strong and weak users ensures user fairness and accommodates different quality of service (QoS) requirements (Ahmad, 2016) [2], ultimately leading to a superior user experience and enhanced cell-edge throughput. (Figure 2 illustrates the evolution from 1G to 6G (B5G).)

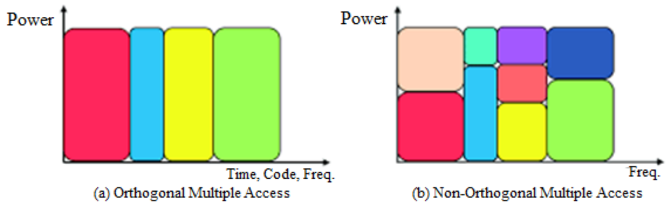

Figure 2: Comparison of OMA and NOMA

NOMA, a prominent multiple access method for LTE systems, is extensively examined within the 3GPP for various applications. In LTE Release 12, NOMA was integrated to mitigate inter-cell-interference (ICI) as an extension of NAICS. NOMA achieves goals such as user connections, system capacity, and service latency, with ongoing 3GPP research focusing on downlink transmission in LTE Release-13 and shifting to uplink transmissions in Release-15, emphasizing grant-free processes for reliability, low latency, and extensive connectivity (Chen and his colleagues., 2018) [3].Despite the benefits, challenges in NOMA-assisted wireless communication, highlighted by Vaezi and his colleagues. (2019b) [4], include receiver complexity and the need for sufficient channel gain differences among users for power domain functionality. Researchers, such as Dai and his colleagues. (2018a) [5], Islam and his colleagues. (2018) [6], Lu and his colleagues. (2017) [7], and Vaezi and his colleagues. (2019a) [8], provide comprehensive reviews and insights into NOMA fundamentals, downlink PD-NOMA, and its flexible integration with various technologies.NOMA, or Non-Orthogonal Multiple Access, is poised to shape the future of network technology, particularly in 5G and beyond, surpassing OMA in serving more clients through power and code domain multiplexing. Techniques like SC and CIC in the receiver facilitate power-domain multiplexing in the transmitter. NOMA aims to enhance spectrum efficiency while ensuring fairness for all users. The grant-free NOMA uplink holds promise for reducing latency, communication overhead, and terminal power consumption, contributing to increasing 5G capacity alongside tiny cells as a key player in future network evolution [10].

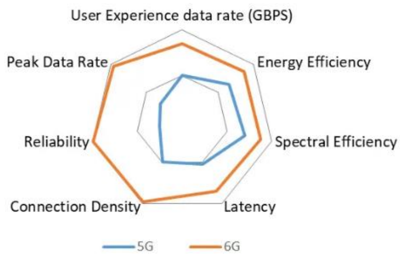

Figure 3: Performance requirements between 5G and 6G [24]

The deployment of small cells plays a crucial role in managing network traffic load and improving Quality of Service (QoS) in power regulation and allocation mechanisms [11]. Additionally, the introduction of the "New Radio" (NR) principle in new radio access technologies addresses challenges related to 5G. 5G incorporates enhancements like new operational frequency bands, Multiple Input Multiple Output (MIMO), Millimeter Wave (mmWave), and Non-Orthogonal Multiple Access (NOMA), which is preferred over Orthogonal Multiple Access (OMA) for its ability to handle a higher number of subscribers [11]. The categorization of NOMA under multiple access schemes is detailed below:

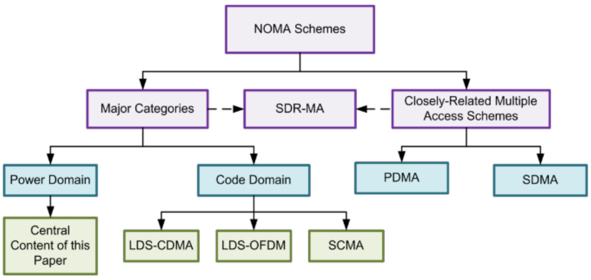

Figure 4: NOMA Classification Schemes

NOMA B5G (Beyond 5G)/6G Systems Applications

The profound impact of technology on human lifestyle is evident, with wireless technologies transforming businesses, infrastructure, and living conditions. The evolution of wireless communication from 1G to 5G, and ongoing efforts towards 5G and Beyond 5G (B5G) by dedicated researchers, reflects the constant search for innovative solutions and progress. In the span of five years (2016-2021), mobile data traffic has surged sevenfold, highlighting rapid development (Benisha and his colleagues., 2019) [12]. However, the increasing congestion daily underscores the inadequacy of available spectrum to meet these demands, prompting exploration of innovative approaches like Non-Orthogonal Multiple Access (NOMA). Various NOMA schemes have emerged in recent decades, addressing diverse applications and promising enhanced Energy Efficiency (EE) and spectral efficiency in upcoming 5G and B5G wireless communication networks.

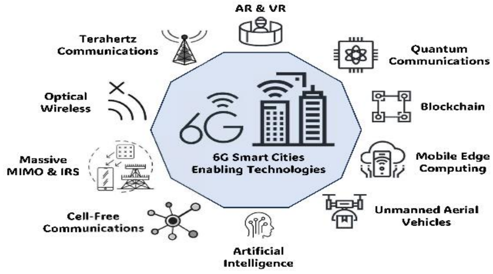

Figure 5: Enabling Technologies for 6G and beyond wireless communications systems [25]

The escalating demand for data rates and connectivity due to exponential user growth can be addressed through advanced technological trends like NOMA-assisted Base Stations (BS) [13]. With the widespread availability of fifth-generation (5G) mobile communication technology, attention is shifting towards the next generation, Beyond 5G (B5G). Anticipating additional demands and larger network capacity in B5G applications compared to current 5G networks, future wireless networks, especially in the form of sixth-generation (6G) applications, are expected to play a pivotal role in various aspects of lifestyle, economic sectors, and social structures [13]. These networks will serve as communication channels between people and intelligent machines, emphasizing the necessity for enhancement and collaboration between the scientific community and industry [13]. By 2030, wireless networks are projected to meet increased needs, supporting demanding applications such as virtual, augmented, and mixed reality, as well as remote control of delicate operations.

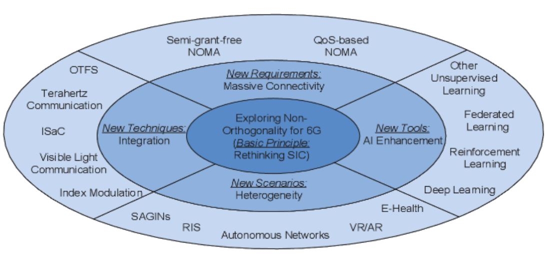

Figure 6: Application of NOMA in B5G Networks [26]

New application possibilities are expected to emerge until 2030, categorized into three groups: intelligent production, intelligent life, and intelligent society [14]. These categories help organize diverse scenarios, with post-2030 use cases highlighted by Sodhro and his colleagues. (2020) and Khan and his colleagues. (2020).

- ***Smart Production***
- ***Smart Life***
- ***Smart Society***

By 2030, the expansive network coverage is anticipated to significantly expand public service availability, eliminating regional digital disparities. The introduction of a 6G network is set to improve overall social governance, laying the groundwork for a more stable society. Detailed applications of Beyond 5G (B5G) are provided in the accompanying table.

Table 1: Beyond 5G/6G Applications [15]

	5G	Use Cases	6G	Use Cases
Data Rate	1 – 10 Gb/s	Telemedicine	100 GB/s – 1Tb/s	3D holographic AR/VR Robotics Arm
Coverage Extension	0.1 Km	The limited scale of IoT network	3D coverage scenarios (100000 m (Sky, 200NM (sea)	Terrerstrial, aerial, space and sea domain, massive-scale IoT Network
Power Comsumption	10 years battery life	IoT devices	50 times improvements compared to 5G, nearly (1 Tb/J)	Wearable user devices Zero energy devices
End-to-End Latency	1-5 ms	Vehicular Networks Military Services	< 1ms	Healthcare Network AR/VR Unmanned Ariel Vehicle (UAV) Robotics Arm
Reliable Communication	99.9%	Vehicular Netwkrs Telemedicine	~99.9999%	Healthcare Network AR/VR Unmanned Ariel Vehicle (UAV) Robotics Arm
Massive Connectivity and Sensing	1 milliondevice / km^2	IoT devices	10 milliondevice / km^2	Wearable user devices AR/VR IoE
Frequency Extension and Improves Spectrum	3-300 Ghz	mmWave for fixed access	Up to 1 Thz	mmWave Sub-6 GHz Exploration of THz bands (above 300GHz) High-defination imaging and frequency Non-RF (e.g., Optical, VC) Spectroscopy localization
Mobility and Speed Supportive	500 km / hr	Vehicular Networks	1000 km / hr	Terrestrial, space, sea, aerial, and airline

NOMA-MIMO Technologies

To advance the development of intelligent wireless systems, designing an energy-efficient Massive multiple-input-multiple-output (MIMO)-non-orthogonal multiple access (NOMA)-aided Internet of Things (IoT) network is crucial. This network should accommodate numerous distributed users and IoT devices to ensure seamless data transfer and connectivity. Massive MIMO, with its use of a substantial number of antennas, is a fitting technology for an energy-efficient IoT network in beyond 5G (B5G) communications. However, the challenge lies in achieving swift data transfer and maintaining hyper-connectivity among IoT devices in B5G communications, posing an energy challenge.

Numerous studies have shown that Non-Orthogonal Multiple Access (NOMA) outperforms Orthogonal Multiple Access (OMA) in various performance aspects. NOMA excels in meeting high-demand requirements, including extremely low latency, high spectral efficiency, increased network capacity, and elevated connectivity demand. Additionally, MIMO is recognized as a highly adaptable technology capable of enhancing capacity by increasing potential data rates. When compared to the combination of MIMO and OMA, MIMO and NOMA (MIMO-NOMA) are anticipated to achieve a higher capacity than MIMO and OMA (MIMO-OMA) [27].

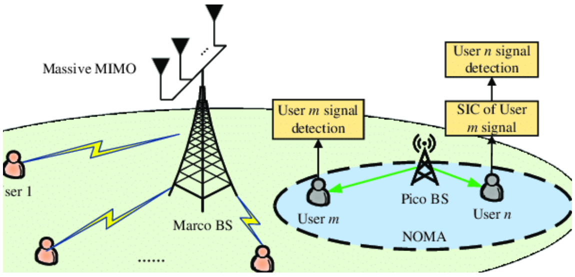

Figure 7: NOMA in Massive MIMO System [30]

The requirements for next-generation technology include high data rates, substantial spectrum efficiency, successive interference cancellation (SIC), and ultra-reliable low latency (URLL). In the realm of next-generation technologies, non-orthogonal multiple access (NOMA) is preferred over orthogonal multiple access (OMA), offering advantages such as multi-user scaling, optimal spectral efficiency (SE), significant user-pairing improvement, and the capability for multiple users to share a single resource block. Researchers conducted comparative analyses of various power allocation algorithms to identify the optimal one for multiple-input multiple-output-NOMA (MIMO-NOMA) technology [28].

A multiple-input multiple-output (MIMO) structure enhances the overall capacity of modern communication networks without excessive power or bandwidth requirements. To meet the demands for higher user data rates and improved spectrum efficiency, the non-orthogonal multiple access (NOMA) configuration is a suitable candidate for integration with the MIMO structure. The dynamic uniform channel gain difference (DUCGD) user pairing technique plays a significant role in maximizing the capacity of all paired and served users [29]. In summary, the depiction of NOMA in B5G Systems using the MIMO Technique is presented in the figure below.

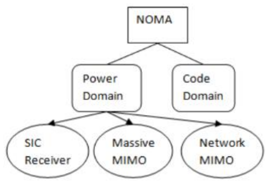

Figure 8: NOMA in B5G Systems using MIMO Technique [31]

Researchers have primarily classified NOMA technology into two types: the power domain and the code domain. In the power domain, subcategories include the SIC Receiver and Massive MIMO. Massive MIMO involves using multiple antennas at both the source and destination points of wireless communication [31].

Artificial Intelligence application to NOMA implementation

Cellular The proliferation of cellular devices and emerging wireless applications has led to explosive growth within wireless systems. To support extensive connectivity and high data speeds in constrained environments, research into advanced multiple access technologies, including next-generation multiple access (NGMA), is crucial [16]. Non-orthogonal multiple access (NOMA) is identified as a key component of NGMA, especially when integrated with multiple-antenna technology, revealing substantial connectivity potential [17,18].Despite the promise of NGMA, the intricate multi-domain multiplexing presents challenges in interference suppression and system optimization. The communication design of next-generation NOMA systems often involves highly complex nonconvex mixed-integer nonlinear programming (MINLP) problems, where obtaining a globally optimal solution is extremely difficult. Recent advances in AI offer opportunities to address these challenges, providing automated communication designs to handle overwhelming complexities [19,22]. This has prompted investigations into promising and advanced machine learning (ML) methods to enhance NGMA through AI, as illustrated in the integration of AI/ML in the planning process of mobile networks.

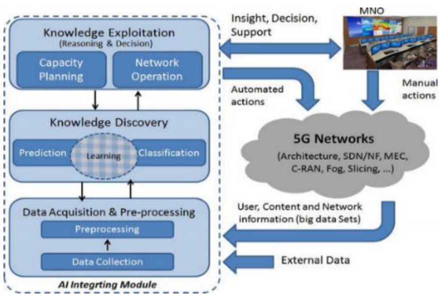

Figure 9: Integrating AI/ML in the planning process of mobile networks [32]

AI harnesses the power of deep neural networks (DNNs) to approximate optimal solutions for complex problems, utilizing deep models' exceptional ability to fit arbitrary functions. AI can automatically learn optimal solutions, eliminating the need for expert knowledge and hand-engineered parameter initialization required by traditional optimization methods [23].Supervised learning, which focuses on approximating pre-labeled solutions, and unsupervised learning, which directly minimizes unsupervised variables, are the two main approaches. Common machine learning models in wireless communications include the multi-layer perceptron (MLP) and convolutional neural network (CNN). Reinforcement learning is typically applied to long-term optimization problems modeled using the Markov decision process (MDP). Each base station (BS) is treated as an autonomous agent, interacting with its environment to continually enhance decisions through trial and error, observing the system state at each time slot to determine optimization variables (actions) and maximize the accumulated discount reward.The emerging AutoML paradigm [23], encompassing hyper-parameter optimization (HO), neural architecture search (NAS), and meta-learning, can be combined to automate the configuration of learning models, significantly reducing human interventions and improving performance. NAS can automatically optimize hyperparameters and neural architecture, while meta-learning aims to create a general initial model that quickly adapts to previously unseen communication scenarios. These AutoML techniques can serve as add-on modules to assist Next-Generation Multiple Access (NGMA) communications based on the requirements of different application scenarios. The figure below illustrates the applications of AI (deep learning) in various layers of B5G Systems.

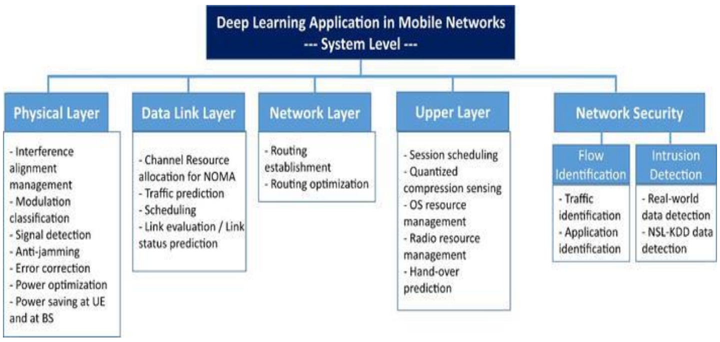

Figure 10: Applications of AI (deep learning) in different layers of B5G Systems [33]

Researchers propose a novel AI-powered cluster-free Non-Orthogonal Multiple Access (NOMA) framework to expand the scope of current multiple-antenna NOMA schemes. This framework enables highly flexible Successive Interference Cancellation (SIC) operations. However, the exploration of AI-enabled Next-Generation Multiple Access (NGMA) is in its early stages.

Model-based constrained ML for NGMA

The design of Next-Generation Multiple Access (NGMA) communication often deals with complex non-convex, coupled, and mixed-integer constraints. Learning algorithms typically handle constraint violations by converting them into loss functions or utilizing projection operations to find feasible solutions, although their ability to strictly enforce constraints is limited. Recently, the integration of the Lagrangian dual method and the interior point method into model-based machine learning has shown promise in guiding machine learning with constrained optimization theory. This has generated interest among researchers in exploring model-based constrained machine learning for NGMA communication design.

ML empowered dynamic multi-objective optimization for NGMA

In the context of next-generation wireless systems with time-variant and heterogeneous characteristics, communication design faces multiple competing optimizations, including system rate objectives, energy consumption, traffic latency, outage probability, and more. The dynamic nature of wireless environments introduces challenges in predicting the evolving Pareto optimal front for these competing objectives and constraints over time. To address this, efficient multitask machine learning methods are crucial for facilitating dynamic multi-objective optimization.

Accelerating AutoML for NGMA

While machine learning efficiently predicts favorable solutions through low-complexity forward propagation, the training phase, usually conducted through back-propagation, requires substantial datasets and imposes significant computational demands. Integrating AutoML techniques like meta-learning and NAS can further increase the time and computational intensity of the training process. The challenge is to address the research problem of constructing high-performance lightweight models and improving AutoML to reduce training costs for Next-Generation Multiple Access (NGMA).

Problem Statement

In the hybrid technology environment, the integration of Multiple Input Multiple Output (MIMO) and Non-Orthogonal Multiple Access (NOMA) technologies is crucial for addressing challenges in 5G and Beyond 5G

(B5G) cellular systems, specifically related to massive connectivity, low latency, and high dependability. User performance is significantly impacted by interference and fading in channels, posing challenges to seamless connections. However, enhancing the number of antennas and bandwidth in a 5G network without concurrent improvements in fading characteristics may result in performance degradation. This degradation can manifest as a higher bit error rate (BER) and lower spectrum efficiency (SE) for the downlink, along with reduced average capacity rate and increased outage probability (OP) for the uplink.

Purpose of the Study

The existing research is focused on achieving improvements in these parameters, and the study will address these objectives.

• Developing an integrated network architecture that combines multiple-input multiple-output (MIMO) and non-orthogonal multiple access (NOMA) technologies in a hybrid configuration.

• Creating a network model focused on achieving massive connectivity, low latency, and high dependability by implementing MIMO-NOMA to address challenges related to near/far user scenarios.

• Enhancing the performance of a B5G network by addressing bit error rate, spectrum efficiency (downlink), average capacity rate, and outage probability (uplink) through the utilization of MIMO technology.

• Analyzing the performance of downlink NOMA in terms of bit error rate and spectral efficiency for different distances, power location coefficients, transmitted power, and bandwidths.

• Analyzing the performance of uplink NOMA in terms of average capacity rate and outage probability for various distances, signal-to-noise ratio, and bandwidth.

2. Background Literature

Wireless Communication

In the past decade, wireless communication has experienced rapid advancement fueled by the widespread adoption of smart mobile devices and engaging multimedia applications [34,35]. An approach to achieve enhanced performance is non-orthogonal multiple access (NOMA), which aims to preserve spectral efficiency and ensure widespread accessibility [36,37]. NOMA utilizes successive interference cancellation (SIC) in receivers with noise, enabling signal reception while adjusting power levels of overlay user signals at the transmitter. This strategy minimizes bandwidth usage for undesired channels and optimizes user rates for desirable channels [38-41].

Non-orthogonal multiple access (NOMA)

NOMA incorporates successive interference cancellation (SIC) at the power user level, enabling the detection and exclusion of users with stronger channel conditions, prioritizing data extraction from users with superior channels and weaker interfering users [42]. In NOMA's downlink (DL) system, multiple users share the same time, coding, and frequency resources, receiving an overlay signal from the base station (BS) encompassing signals for all users [43]. This eliminates the need for users to wait for an orthogonal resource block, supporting extensive connections and reducing transmission delay [44].

In the next-generation communication system, NOMA with SIC emerges as a promising multiple-access strategy [45], meeting the demands of the current wireless environment [46]. As the assessment of various access technologies continues to evolve [47], the primary research focus is on determining spectrum efficiency [48,49].In NOMA's uplink (UL), multiple users simultaneously transmit signals to their respective BS [50,51]. Intra-cluster interference impacts a user's received signal, influenced by other users' channel data. Minimizing interference is crucial, and the BS decodes communications via SIC. Successful SIC application requires separate message signals with sufficient strength variance, typically managed by using various scales at the transmitter in the DL. However, in the UL, channel gains already provide adequate signal separation, making such adjustments unnecessary. The UL standard emphasizes power control, which is not recommended for UL NOMA broadcasts, as it could compromise channel distinctness in balancing received signal levels of users [53,57].

Multiple-input multiple-output (MIMO)

The Deploying multiple antennas in both the transmitter and receiver, known as multiple-input multiple-output (MIMO) technology, significantly enhances the capacity of a radio communication channel, allowing the management of numerous independent channels within the same bandwidth. However, this is effective only in a sufficiently rich propagation environment and with specific antennas [58,59]. Recent research has shown significant interest in integrating MIMO and non-orthogonal multiple access (NOMA) to improve efficiency [59,60].

Exploring the downlink (DL) NOMA network's bit error rate (BER) in both perfect and deficient successive interference cancellation (SIC) states, the study utilized additive white Gaussian noise (AWGN) and Rayleigh fading channels, with a focus on BPSK modulation. Notably, the exploration did not include BER-influencing variables such as distance and power location coefficients [61]. Three power assignment algorithms to maximize the power allocated to each NOMA are proposed in [62,63].

Bandwidth, Average Capacity Rate, Outage Probability, Bit Error Rate & Spectrum Efficiency

Researchers delved into the impact of varying bandwidth and the number of antennas in a 5G network on key performance metrics. The study explored the uplink's average capacity rate, outage probability (OP), and the downlink's bit error rate (BER) and spectrum efficiency (SE), considering the influence of Rayleigh fading. Analytical processes generated integral expressions for BER, SE, capacity rate, and OP, while modeling was used to explore diverse system configurations.

The study focused on the NOMA approach, a fundamental element of 5G technology, and proposed a novel NOMA-MIMO power domain architecture. By integrating NOMA and MIMO to support users, system enhancements were observed. The central idea behind the research was to redesign NOMA-MIMO in the power domain to improve data rate, capacity, and throughput in a 5G network.

Proposed Research Literature

According to the author in [65], NOMA systems utilize multiple beams forming with a single carrier to accommodate multiple users. This involves a two-stage beamforming solution with modular beamforming vectors. The design specifically addresses the challenge of shaping transmission packets, focusing on identifying the power and packet-shaping vectors of users.

MIMO-NOMA Performance

The potential of NOMA is demonstrated in [66], where effective precoding and detection processes create a significant difference in users' effective channel gains, even when users have comparable initial channel conditions. MIMO-NOMA outperforms MIMO-OMA in total channel capacity and practical capacity when multiple users are combined into a single group [67,63] addresses the ergodic capacity maximization problem for selective

Rayleigh fading MIMO-NOMA systems, indicating superior performance compared to traditional OMA schemes. An experimental evaluation in [68] explores NOMA downlink integrated with MIMO in real-world scenarios. [69] demonstrates that NOMA with a proposed user pair strategy performs better than NOMA with a signal realignment method. [70] examines multiple NOMA downlink and uplink user power field-based communication systems with various fading conditions. Analytical formulations of outage probability (OP) for NOMA downlink and uplink systems are developed, particularly for high signal-to-noise ratios (SNRs) [71,72] investigates an unmanned aerial vehicle-assisted NOMA network with uplink and downlink transmissions, emphasizing fairness and application enhancement using statistical channel state information in a unique NOMA system.

Correlation Similarity for NOMA Effectiveness

In [73], a strategy for identifying correlation similarity is proposed, examining the effectiveness of various NOMA schemes over the tapping delay line channel, considering regular and high-speed user equipment (UE) mobility, and exploring correlation-level modeling [73,75]. NOMA's potential for 5G networks, initially discovered by Saito and his colleagues. [76], outperforms OMA in capacity and user fairness. Early NOMA research focused on single-input single-output (SISO), emphasizing user fairness and power allocation. NOMA's power distribution strategy, considering fairness and sum rate while maximizing the sum rate, ensures a balanced approach. The dynamic power allocation scheme in [77] guarantees higher individual rates for both strong and weak users in NOMA compared to OMA. [78] considers max-min data rate and min-max outage probability, focusing on user fairness.

Combining MIMO and NOMA

The swift progress in wireless communication, driven by the widespread use of smart mobile devices and multimedia applications, has led to the exploration of non-orthogonal multiple access (NOMA) with successive interference cancellation (SIC) as a promising strategy for next-generation communication systems. Ongoing evaluations of various access technologies aim to determine the most efficient spectrum utilization, especially as new features emerge.The combination of NOMA with multi-input multi-output (MIMO) technology, known as MIMO-NOMA, enhances performance by grouping users into clusters. Despite the challenge of finding optimal user pairings, random and greedy pairing methods have been proposed to reduce computational costs. Users within the same cluster share a common precoding vector, effectively converting the MIMO channel into parallel single-input single-output (SISO) channels and maintaining NOMA's superiority over orthogonal multiple access (OMA). A comprehensive MIMO-NOMA framework utilizing zero-forcing precoding and signal alignment-based detection has been explored to eliminate inter-cluster interference, albeit assuming perfect instantaneous channel state information (CSI). Sun and his colleagues. investigate power distribution strategies for enhanced power efficiency, and the ergodic capacity of a two-user MIMO-NOMA system is analyzed with considerations for total transmit power and the minimum rate constraint of the weaker user. Additionally, a NOMA strategy for large MIMO systems and its performance in multi-cell networks, addressing inter-cell interference (ICI) through synchronized beamforming strategies, have been explored.Researchers are extending NOMA applications to communication using visible light and millimeter-wave (mmWave) technologies, showcasing the versatility of NOMA in diverse communication scenarios.

3. Research Methodology

The research methodology follows a systematic approach, encompassing the formulation of research questions, development of a research design, data analysis through diverse methods, and drawing conclusions. The primary goal is to integrate multiple-input multiple-output (MIMO) and non-orthogonal multiple access (NOMA) technologies to address challenges in B5G cellular systems. A literature gap exists regarding the impact of MIMO on parameters like bit error rate (BER), downlink spectrum efficiency (SE), average capacity rate, and uplink outage probability (OP) for B5G, and the current research focuses on enhancing these parameters. The study aims to design an integrated network architecture based on MIMO and NOMA, improving BER, downlink SE, average capacity rate, and uplink OP in B5G networks. The researcher evaluates the performance of downlink (DL) and uplink (UL) NOMA power domain (PD) in a 5G network with and without 64 x 64 MIMO technologies. The introduction of 64 x 64 MIMO technology enhances DL NOMA performance, addressing near-far user issues. NOMA systems using multiple beams and a two-stage beamforming solution are described, and effective precoding and detecting techniques are developed to create a significant gap in effective channel gains for optimal NOMA performance. Studies on MIMO-NOMA reveal superior performance compared to MIMO-OMA. Ergodic capacity maximization for selective Rayleigh fading MIMO-NOMA systems and experiments evaluating NOMA DL integrated with MIMO are explored. The research also covers UL NOMA with various power allocation techniques, unmanned aerial vehicle-assisted NOMA networks, and a novel UL/DL NOMA system, along with proposing a method for finding correlation similarity and exploring NOMA plots under diverse user equipment speeds and correlation-level modeling.

In this research, the researcher came up with two scenarios.

- Downlink (DL) Scenario
- Uplink (UL) Scenario

- ***Data Collection - Downlink (DL) Scenario***

Shown below is the Downlink (DL) Design.

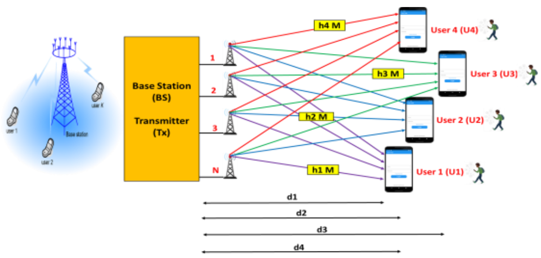

Figure 11: Wireless Network - 4 Users (64 × 64 MIMO-DL-NOMA) Power Domain

The table below shows various parameters of the conceptualized design. h_{T1}

Table 2: Design Parameters

S/No	Design Parameters	Notation
1	Bandwidth	80 MHz, 200 MHz
2	Users (4 Users)	U1, U2, U3, U4
3	Distance of Users from the Base Station (BS)	d1, d2, d3, d4
4	Rayleigh Fading Coefficients	$h_{T1}, h_{T2}, h_{T3}, h_{T4}$

The distances from the base station vary, with users positioned at different proximities to the base station. The formulas employed for these calculations are presented below, along with references indicating their sources or utilization:

Table 3: Design Formulas (DL)

S/No	Description	Formula	Reference
1	* Total Rayleigh fading channel (each user)	$hT = \sum_{i=1}^{M} h_{Ti}$	[87]
2	* Base Stations Encoded Overlay Signal	$x = \sqrt{P}(\sqrt{\alpha_1}x_1 + \sqrt{\alpha_2}x_2 + \sqrt{\alpha_3}x_3 + \sqrt{\alpha_4}x_4)$	[88 - 89]
3	* U Rate R1	$R_1 = \log_2\left(1 + \frac{\alpha_1 P\|h_{T1}\|^2}{\alpha_2 P\|h_{T1}\|^2 + \alpha_3 P\|h_{T1}\|^2 + \alpha_4 P\|h_{T1}\|^2 + \sigma^2}\right)$	[88]
4	* U Rate R2	$R_2 = \log_2\left(1 + \frac{\alpha_2 P\|h_{T2}\|^2}{\alpha_3 P\|h_{T2}\|^2 + \alpha_4 P\|h_{T2}\|^2 + \sigma^2}\right)$	[88]
5	* U Rate R3	$R_3 = \log_2\left(1 + \frac{\alpha_3 P\|h_{T3}\|^2}{\alpha_4 P\|h_{T3}\|^2 + \sigma^2}\right)$	[88]
6	* U Rate R4	$R_4 = \log_2\left(1 + \frac{\alpha_4 P\|h_{T4}\|^2}{\sigma^2}\right)$	[88]
7	* Spectrum Efficiency	$SE = \frac{Th}{BW}$	[88]

*Where;

i = 1, 2, 3, 4

M (No of Channels) = 64

Power Coefficients = α_1, α_2, α_3, α_4 where $\alpha_1 > \alpha_2 > \alpha_3 > \alpha_4$

QPSK Formed Messages = x_1, x_2, x_3, x_4

R = U Rate

P = Maximum Power

SIC = Successive Interference Cancellation

SE = Spectrum Efficiency

Th = Throughput

BW = Bandwidth

Conceptualized wireless network consists of a 64 x 64 MIMO system and four DL NOMA users, namely U1, U2, U3, and U4, each with different bandwidths of 80 and 200 MHz. Various distances of the users from the base station are represented by d1, d2, d3, and d4, where d1 > d2 > d3 > d4, indicating the preferred order.

Depending on the distance, U1 is considered the weak/far user, while U4 is regarded as the strong/near user from the base station. The selective Rayleigh fading coefficients are identified as h_{T1}, h_{T2}, h_{T3}, and h_{T4} correspond to $|h_{T1}|^2 < |h_{T2}|^2 < |h_{T3}|^2 < |h_{T4}|^2$.

- ***Data Collection - Uplink (UL) Scenario***

The power domain multiplexing approach in uplink NOMA differs notably from downlink NOMA. In downlink NOMA, the base station (BS) employs superposition coding to achieve power domain multiplexing. In contrast, for uplink NOMA, users are only limited by their battery capacity, enabling both users to transmit at full strength. As a result, fluctuations in the users' channel gains lead to variations in the power domain observed by the BS receiver.

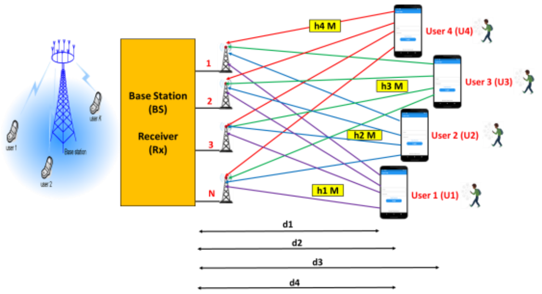

Figure 12: Wireless Network - 4 Users (64 × 64 MIMO-UL-NOMA) Power Domain

Assuming a 64x64 MIMO system and a bandwidth of 80 MHz in a wireless network, let x1, x2, x3 and x4 denote the messages that will be transmitted by four UL NOMA users - U1, U2, U3, and U4 - respectively, with both users' signals having the same strength. The various distances of the users from the base station (BS) are represented by d1 > d2 > d3 > d4, with d1 > d2 > d3 > d4 being the preferred order. Depending on the distance, U1 is the weak/far user from the BS, while U4 is the strong/near user. The selective Rayleigh fading coefficients are identified as hT1, hT2, hT3, and hT4 where |hT1|2 < |hT2|2 < |hT3|2 < |hT4|2, indicating the relationship between the coefficients and the users. The formulas used for the calculations are shown below along with their references from where these were taken or used:

Table 4: Design Formulas (UL)

S/No	Description	Formula	Reference
1	* Total Rayleigh fading channel (each user)	$h_{jT} = \sum_{j=1}^{N} h_{jT}$	[87]
2	* Signal Received at the Base Station	$y = \sqrt{P_{x1}}h_{1T} + \sqrt{P_{x2}}h_{2T} + \sqrt{P_{x3}}h_{3T} + \sqrt{P_{x4}}h_{4T} + w$	[88] [89] [90]
3	* Maximum rate User 4	$R_{U4} = \log_2\left(1 + \frac{P\lvert h_{4T}\rvert^2}{P\lvert h_{1T}\rvert^2 + P\lvert h_{2T}\rvert^2 + P\lvert h_{3T}\rvert^2 + \sigma^2}\right)$	[91] [92]
4	* Maximum rate User 3	$R_{U3} = \log_2\left(1 + \frac{P\lvert h_{3T}\rvert^2}{P\lvert h_{1T}\rvert^2 + P\lvert h_{2T}\rvert^2 + \sigma^2}\right)$	[91] [92]
5	* Maximum rate User 2	$R_{U2} = \log_2\left(1 + \frac{P\lvert h_{2T}\rvert^2}{P\lvert h_{1T}\rvert^2 + \sigma^2}\right)$	[91] [92]
6	* Maximum rate User 1	$R_{U1} = \log_2\left(1 + \frac{P\lvert h_{1T}\rvert^2}{\sigma^2}\right)$	[91] [92]
7	* Capacity U4 (specific target rate)	$C_4 = \sum_{i=1}^{N} \log_2\left(1 + \frac{P\lvert h_4\rvert}{P\lvert h_1\rvert + P\lvert h_2\rvert + P\lvert h_3\rvert + N_4}\right)$	[91] [92]
8	* Capacity U3 (specific target rate)	$C_3 = \sum_{i=1}^{N} \log_2\left(1 + \frac{P\lvert h_3\rvert}{P\lvert h_1\rvert + P\lvert h_2\rvert + N_3}\right)$	[91] [92]
9	* Capacity U2 (specific target rate)	$C_2 = \sum_{i=1}^{N} \log_2\left(1 + \frac{P\lvert h_2\rvert}{P\lvert h_1\rvert + N_2}\right)$	[91] [92]
10	* Capacity U1 (specific target rate)	$C_1 = \sum_{i=1}^{N} \log_2\left(1 + \frac{P\lvert h_1\rvert}{N_1}\right)$	[91] [92]
11	* Outage Probability Condition U1	$P_r\ (C_1(k)) < r_1) \Vert P_r\ (C_2(k) < r_2) \Vert P_r\ (C_3(k) \langle r_3 \Vert P_r\ (C_4(k) < r_4)) < r$	[91] [92]
12	* Outage Probability U1	$P_r(U1) = (\sum_{i=1}^{N} P_r(C_1(k)) < r_1) \Vert P_r(C_2(k) < r_2) \Vert P_r(C_3(k) \langle r_3 \Vert P_r(C_4(k) < r_4))/N$	[91] [92]
13	* Outage Probability Condition U2	$P_r\ (C_2(k) < r_2) \Vert P_r\ (C_3(k) \langle r_3 \Vert P_r\ (C_4(k) < r_4)) < r$	[91] [92]
14	* Outage Probability U2	$Pr(U2) = (\sum_{i=1}^{N} P_r\ (C_2(k) < r_2) \Vert P_r\ (C_3(k) \langle r_3 \Vert P_r\ (C_4(k) < r_4))/N$	[91] [92]
15	* Outage Probability Condition U3	$P_r\ (C_3(k) \langle r_3 \Vert P_r\ (C_4(k) < r_4)) < r$	[91] [92]
16	* Outage Probability U3	$Pr(U3) = (\sum_{i=1}^{N} P_r\ (C_3(k) \langle r_3 \Vert P_r\ (C_4(k) < r_4))/N$	[91] [92]
17	* Outage Probability Condition U3	$P_r\ (C_4(k) < r_4)) < r_4$	[91] [92]
18	* Outage Probability U3	$Pr(U4) = (\sum_{i=1}^{N} P_r\ (C_4(k) < r_4))/N$	[91] [92]

*Where;

j = 1, 2, 3, 4

N (No of Channels) = 64

y = Received Signal

w = Noise Power

R_{U4} = Maximum rate at which BS can decode the data of a nearby user (User 4)

R_{U3} = Maximum rate at which BS can decode the data of a nearby user (User 3)

R_{U2} = Maximum rate at which BS can decode the data of a nearby user (User 2)

R_{U1} = Maximum rate at which BS can decode the data of a nearby user (User 1)

OP = Outage Probability

r = User with different target rates (r_1 =1, r_2 =2, r_3 =3, r_4 =4)

C = Capacity of users with different target rates.

C_1 = Capacity of user 1 with specific target rate.

C_2 = Capacity of user 2 with specific target rate.

C_3 = Capacity of user 3 with specific target rate.

C_4 = Capacity of user 4 with specific target rate.

Pr = Outage Probability

N = Number of Transferred Samples

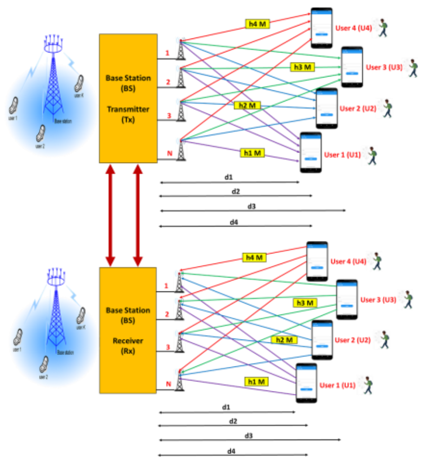

Figure 13: Wireless Network - 4 Users (64 × 64 MIMO-DL-UL-NOMA) Power Domain

Simulation Parameters

Using the MATLAB software program, the simulation parameters for the DL and UL NOMA power domains in 5G networks were incorporated, with and without MIMO. Tables 1 and 2 display the simulation parameters that were appropriately taken into account in the simulation model.

Table 5: Simulator Parameters for Downlink (DL) Scenario

S/No	Parameters	Values		
Downlink Scenario				
1	Number of Users		4	
2	Transmit Power		0 to 40 dBm	
3	Bandwidth	BW1		80 MHz
		BW2		200 MHz
4	Distances	User 1		900 m
		User 2		700 m
		User 3		400 m
		User 4		200 m
5	Power Coefficients	User 1		0.843
		User 2		0.219
		User 3		0.062
		User 4		0.022
6	Path Loss Exponent		4	
7	MIMO		64 X 64	
8	Modulation		QPSK	

Table 6: Simulator Parameters for Uplink (UL) Scenario

S/No	Parameters	Values		
Uplink Scenario				
1	Number of Users		4	
2	Transmit Power		-30 to 30 dBm	
3	Bandwidth	BW1		80 MHz
		BW2		200 MHz
4	Distances	User 1		900 m
		User 2		700 m
		User 3		400 m
		User 4		200 m
5	Path Loss Exponent		4	
6	MIMO		64 X 64	

The researcher employed MATLAB for the analysis in this study.

4. Results and Discussion

- *Downlink Results & Discussion*

According to the Downlink (DL) NOMA system results, adopting 64 X 64 MIMO came up with the following results:

- Enhanced Bit Error Rate (BER) Performance.
- Enhanced Spectral Efficiency (SE) performance.
- The near-far user problem solved,

- For varied power location coefficients, transmitted power, and distance parameters when compared without MIMO DL NOMA performance, the performance of all user's approaches that of the other users.

Performance of the DL NOMA Bit Error Rate (BER) versus transmitted power at 80 MHz BW is shown below in Figure 14.

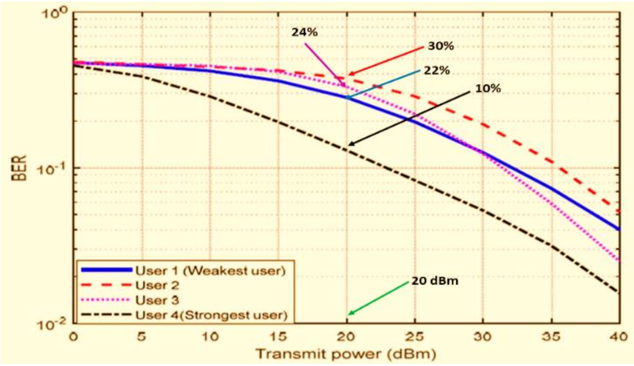

Figure 14: BER vs Transmitted Power (4 Users, Varied Distances & Power Coefficients) DL NOMA at 80 MHz Bandwidth

The results show that;

- As transmitted power rises, BER performance declines.
- As U4 is the closest, its BER performance is the best for all users.
- BER rates for U1, U2, U3, and U4 are determined to be 22%, 30%, 24%, and 10%, respectively, at a transmitter power of 20 dBm.
- BER performance declines as transmitted power increases.

Figure 15: Compares the DL NOMA BER performance against transmitted power at 200 MHz BW.

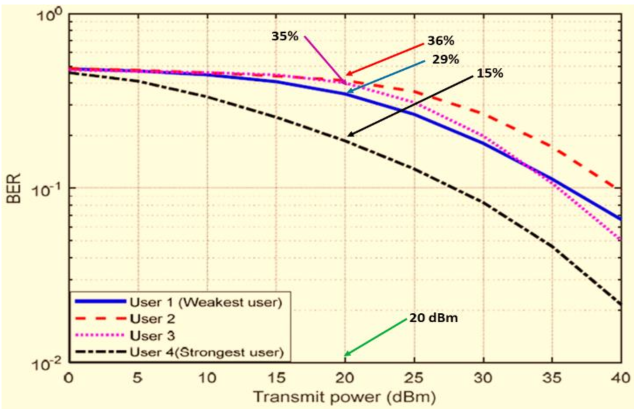

Figure 15: BER vs Transmitted Power (4 Users, Varied Distances & Power Coefficients) DL NOMA at 200 MHz Bandwidth

The results found that;

- U4 being the closest user, its BER performance is the best when compared to all other users.
- BER rates for U1, U2, U3, and U4 are determined to be 29%, 38%, 35%, and 15%, respectively, at a transmit power of 20 dBm.
- Best user U4 from the 64 x 64 MIMO DL NOMA improves BER performance from $10^{-1.48}$ to $10^{-4.93}$ at 200 MHz BW at a transmitter strength of 40 dBm and then from $10^{-1.68}$ to $10^{-5.1}$ at 80 MHz.
- In contrast, with a transmitter power of 40 dBm, the Spectrum Efficiency (SE) performance for the best user U4 is enhanced by 8 x $10^{-2.9}$ bps/Hz for 80 MHz BW and by $10^{-1.9}$ bps/Hz for 200 MHz BW.
- UL NOMA systems' results with 64 x 64 MIMO were improved the Outage probability (OP) for 80 MHz BW at Signal to Noise Ratio (SNR) of 1 dB was lowered by 14 x $10^{-2.9}$ and the average capacity rate performance increased by 11 bps/Hz.

Figure 16 below displays the DL NOMA BER performance as a function of transmitted power at 80 MHz BW and 64 x 64 MIMO. The BER rates for U1, U2, U3, and U4 are determined to be 18 x $10^{-3.8}$, 17 x $10^{-3.8}$, 7 x $10^{-3.8}$, and 4 x $10^{-3.9}$ at 20 dBm of transmitted power, respectively.

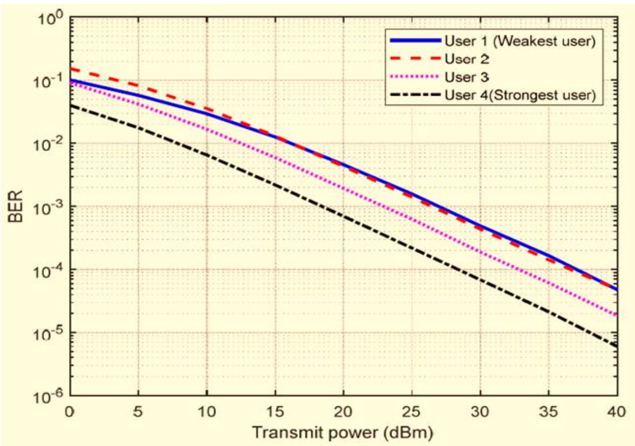

Figure 16: BER vs Transmitted Power (4 Users, Varied Distances & Power Coefficients) DL NOMA at 80 MHz Bandwidth with 64 x 64 for DL NOMA

A transmitted power of 20 dBm, the DL NOMA BER performance at 200 MHz BW and 64 x 64 MIMO is shown in Figure 17 below. The BER rates for U1, U2, U3, and U4 are determined to be 45 x $10^{-3.7}$, 42 x $10^{-3.8}$, 18 x 10-

$^{3.6}$, and 6 x $10^{-3.8}$,. The MIMO system improves BER efficiency.

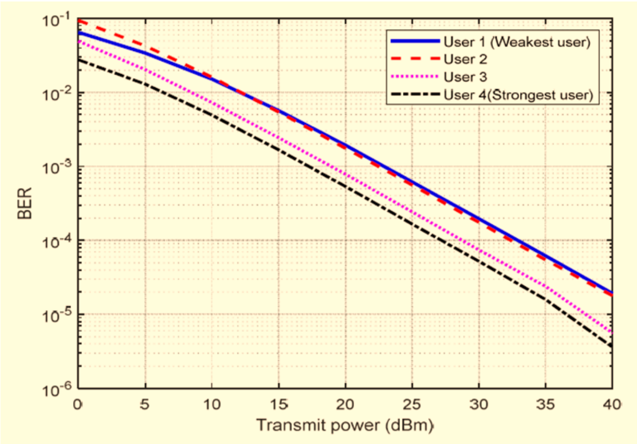

Figure 17: BER vs Transmitted Power (4 Users, Varied Distances & Power Coefficients) DL NOMA at 200 MHz Bandwidth with 64 x 64 for DL NOMA

Figure 18 plots the DL NOMA Spectral Efficiency (SE) performance against transmitted power at 80 MHz BW. The results reveal that SE performance improves with increasing transmitted power. The U4 BER performance is therefore the best for all users because it is closest one. Up until the transmitted power reaches 5 dBm, all users' SE performance is clearly distinct from one another.

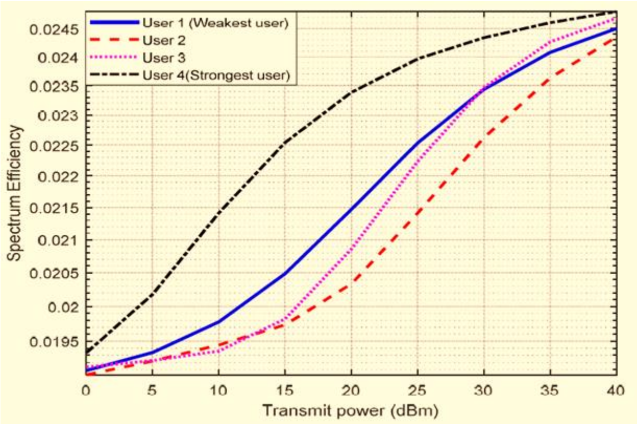

Figure 18: Spectral Efficiency (SE) vs Transmitted Power (4 Users, Varied Distances & Power Coefficients) at 80 MHz Bandwidth for DL NOMA

Figure 19 shows the relationship between DL NOMA SE performance and transmitted power at 200 MHz BW. The results show that SE performance improves as transmitted power increases. The finest is U4 SE performance considering that U4 is the closest user as compared to all other users. With an improvement rate of $10^{-2.2}$ in the BER, the results are better than those of the best U2 users.

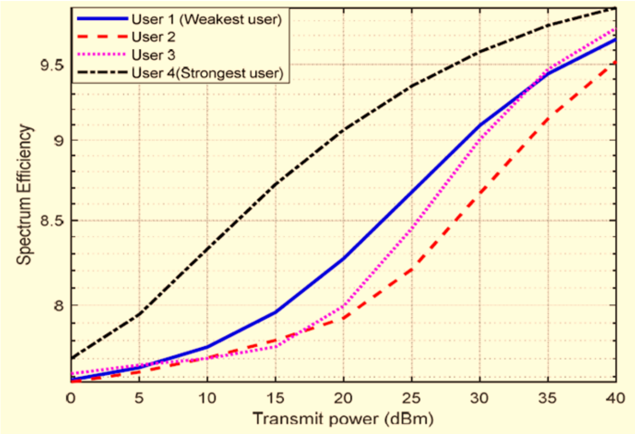

Figure 19: Spectral Efficiency (SE) vs Transmitted Power (4 Users, Varied Distances & Power Coefficients) at 200 MHz Bandwidth for DL NOMA

Figure 20 displays the DL NOMA SE's performance in terms of transmitted power at 80 MHz BW and 64 x 64 MIMO. The SE is fairly close for all users at 5 dBm of broadcast power.

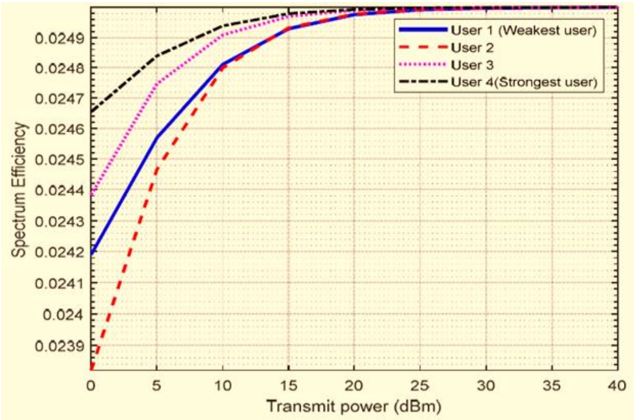

Figure 20: Spectral Efficiency (SE) vs Transmitted Power (4 Users, Varied Distances & Power Coefficients) with 64 x 64 MIMO and 80 MHz Bandwidth for DL NOMA

Figure 21 shows the performance of the DL NOMA SE vs transmission. power at 64 x 64 MIMO and 200 MHz BW. At 15 dBm of transmitter strength, the SE for all users is reasonably nearby. The SE performed is better; thanks to MIMO.

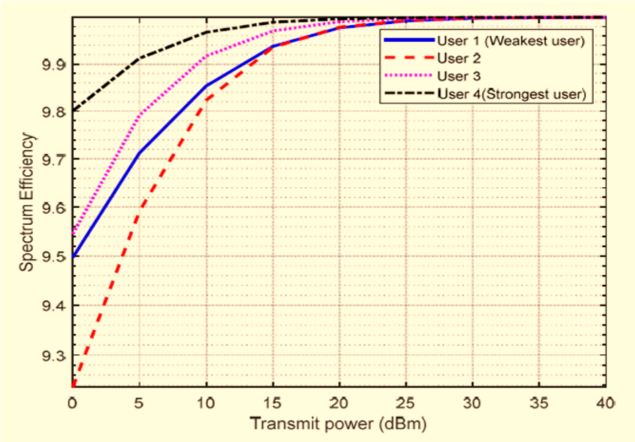

Figure 21: Spectral Efficiency (SE) vs Transmitted Power (4 Users, Varied Distances & Power Coefficients) with 64 x 64 MIMO and 200 MHz Bandwidth for DL NOMA

- ***Uplink Results & Discussion***

Figure 22 shows the UL NOMA average capacity rate vs. SNR at 80 MHz BW. Because U4 is the closest, the result demonstrates that the average capacity rate for U4 is best for all users. The average capacity rate for U1, U2, U3, and U4 is found to be 1.6873, 2.8718, 6.4960 and 12.7814 respectively.

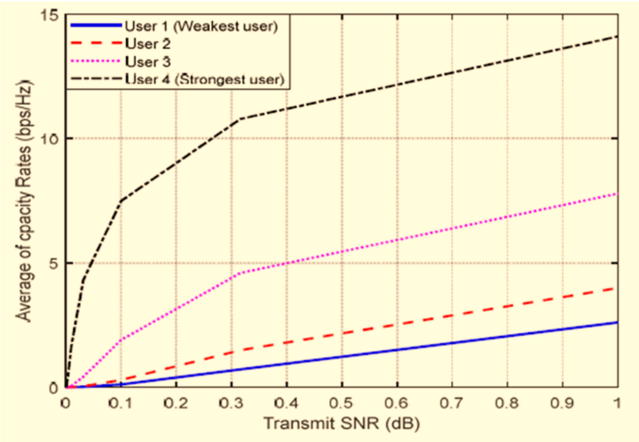

Figure 22: Average Capacity Rate vs SNR (4 Users, Varied Distances & Power Coefficients) and 80 MHz Bandwidth for UL NOMA

Figure 23 shows the UL average capacity rate at 200 MHz BW. Average capacity rates for U1, U2, U3, and U4 are found to be 2.5923, 3.89479, 7.7821, and 14.0972, respectively at SNR of 1 dB. The findings show that the average capacity rate performance increases along with an increase in SNR.

The performance of the capacity average rate was enhanced by 64 x 64 MIMO by 11 bps/Hz and decreased the OP by 11 x $10^{-2.9}$ for 200 MHz BW at 0.18 dB SNR for user U4, and reduced the OP by 14 x $10^{-2.8}$ for 80 MHz BW at SNR of 1 dB. In general, an increase in BW decreases OP and SE while increasing BER and the capacity average rate. MIMO greatly increases each user's throughput.

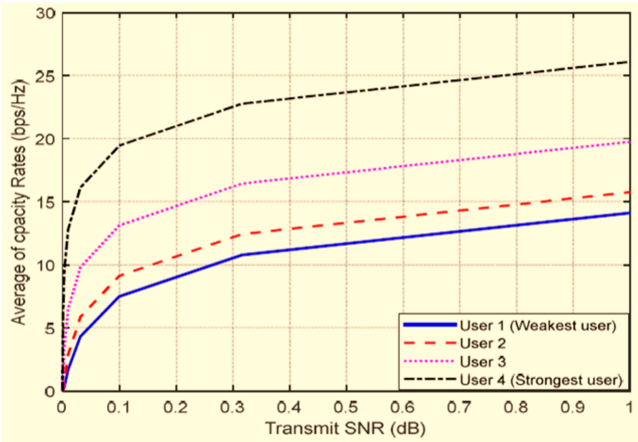

Figure 23: Average Capacity Rate vs SNR (4 Users, Varied Distances & Power Coefficients) and 200 MHz Bandwidth for UL NOMA

Figure 24 shows the average capacity rate performance for UL NOMA versus SNR at 80 MHz BW and 64 x 64 MIMO. The outcome for the four users were found to be four users is 12.8732, 14.3921, 18.4489, and 24.7714 respectively.

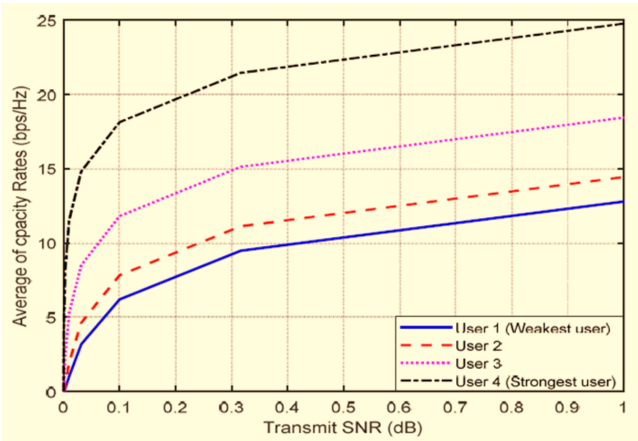

Figure 24: Average Capacity Rate vs SNR (4 Users, Varied Distances & Power Coefficients) with 64 x 64 MIMO and 80 MHz Bandwidth for UL NOMA

Figure 25 depicts average capacity rate performance in relation to SNR for 64 x 64 MIMO and 200 MHz BW UL NOMA. The findings indicate that when SNR rises, average capacity rate performance gets better. According to data gathered for four users at the SNR of 1 dB, the values were found to be 14.0921, 15.7563, 19.7586, and 26.1820 respectively. U4's average capacity rate performance is the best. Furthermore, BW and average capacity rate are positively correlated i.e. rising BW translating into rising average capacity rate. When system is improved utilizing MIMO technique, the average capacity rate rises sharply.

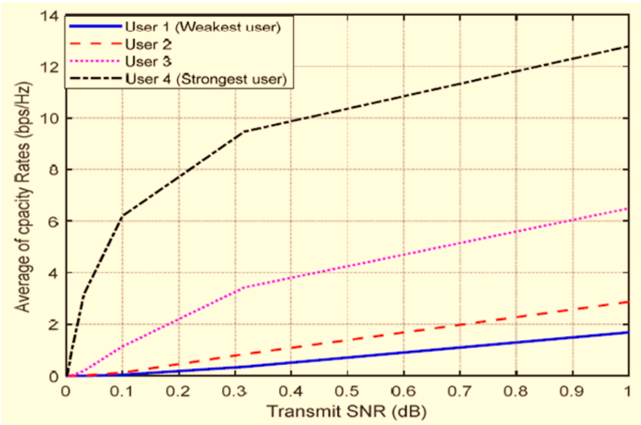

Figure 25: Average Capacity Rate vs SNR (4 Users, Varied Distances & Power Coefficients) with 64 x 64 MIMO and 200 MHz Bandwidth for UL NOMA

Figure 26 shows 80 MHz BW plot displaying the association between the UL NOMA of OP and SNR. The values for U1, U2, U3, and U4 are 98.8 x $10^{-1.9}$, 97.7 x $10^{-1.8}$, 43.3 x $10^{-1.9}$, and 14 x 10^{-3}, respectively, when SNR is 0.169 dB.

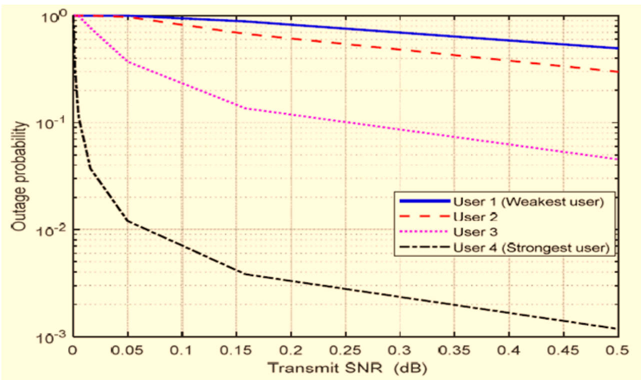

Figure 26: OP vs SNR (4 Users, Varied Distances & Power Coefficients) and 80 MHz Bandwidth for UL NOMA

The UL NOMA of OP versus the SNR is shown in Figure 4.14 at 200 MHz BW. The values for U1, U2, U3, and U4 are 0.9746, 0.9744, 0.2809, and 0.0173, respectively, at an SNR of 0.169 dB.

The results demonstrate that the OP performance degrades as the SNR increases. Results obtained are better than those of the top U2 users and have increase in average capacity rate.

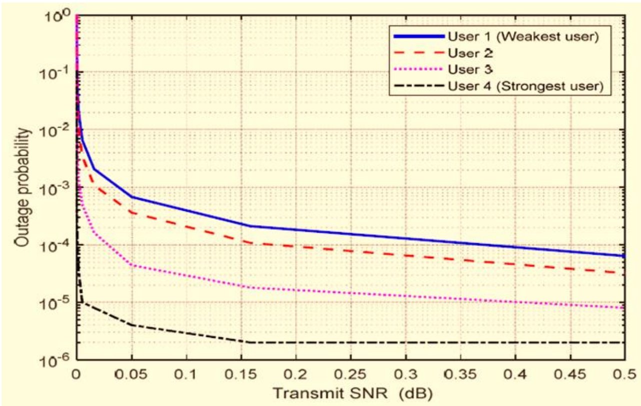

Figure 27: OP vs SNR (4 Users, Varied Distances & Power Coefficients) and 200 MHz Bandwidth for UL NOMA

The UL NOMA of OP vs. SNR is shown in Figure 28 at 80 MHz BW with 64 x 64 MIMO. The results for U1, U2, U3, and U4 are 0.0061, 0.0026, 0.0002, and 0.0001 at an SNR of 0.169 dB.

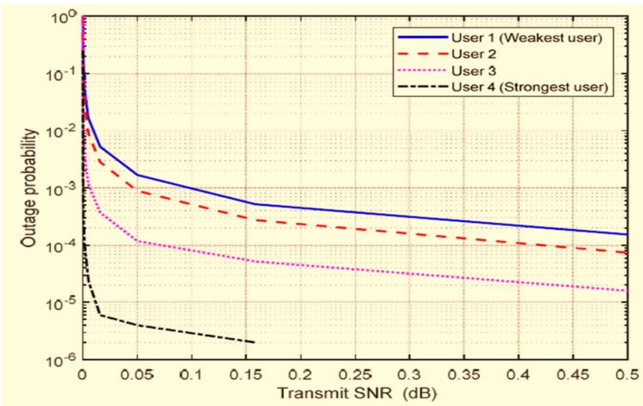

Figure 28: OP vs SNR (4 Users, Varied Distances & Power Coefficients) with 64 x 64 MIMO and 80 MHz Bandwidth for UL NOMA

The UL NOMA of OP vs. 64 x 64 MIMO at 200 MHz BW is shown in Figure 4.16. The values for U1, U2, U3, and U4 are 20 x $10^{-3.8}$, 10-3.9, $10^{-3.7}$, and $10^{-4.8}$ at an SNR of 0.169 dB. According to the results, the performance of the OP degrades as the SNR rises. A rise in BW causes a decrease in OP, and the two variables are inversely related. When the system is optimized using the MIMO approach, the OP drops significantly. The outcomes are better since there was an improvement rate of $10^{-1.8}$ in OP.

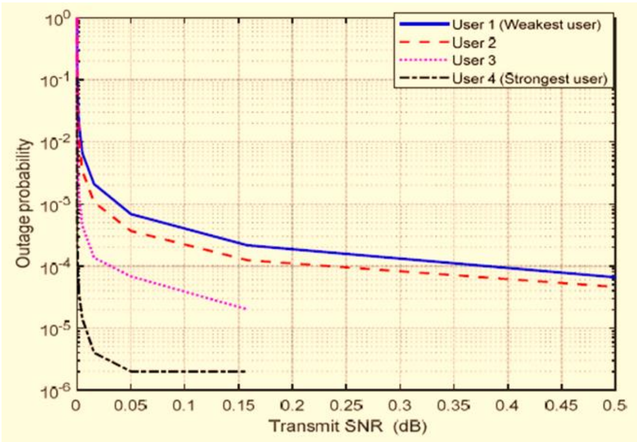

Figure 29: OPvs SNR (4 Users, Varied Distances & Power Coefficients) with 64 x 64 MIMO and 200 MHz for UL NOMA

5. Conclusions and Future Work

The study underscores the potential advantages of combining MIMO and NOMA technologies within B5G cellular systems, offering valuable insights into optimal configurations for improving performance across diverse parameters. Drawing conclusions from the investigation into the integration of multiple-input multiple-output (MIMO) and non-orthogonal multiple access (NOMA) technologies in B5G cellular systems, the findings are presented.

• Integrating MIMO and NOMA technologies offers a solution to various challenges encountered by B5G cellular systems, encompassing issues such as massive connectivity, low latency, and high dependability.

• The collaborative deployment of MIMO with NOMA leads to notable improvements in key parameters, including bit error rate (BER), spectrum efficiency (SE), average capacity rate, and outage probability (OP).

• The amalgamation of MIMO and NOMA effectively addresses the near-far user's predicament in downlink NOMA. This enhancement is manifested through improved BER and SE performance, aligning the performance of all users more closely.

• Implementation of 64 x 64 MIMO technology in downlink NOMA results in significant enhancements in BER for the best user. Simultaneously, in uplink NOMA, it improves average capacity rate performance and diminishes outage probability for the best user.

• An augmentation in bandwidth correlates with an increase in BER and average capacity rate, accompanied by a reduction in spectrum efficiency and outage probability.

The study exhibited the efficacy of Downlink (DL) and Uplink (UL) NOMA Power Domain (PD) in a 5G network, considering both scenarios with and without 64 x 64 MIMO technology. The following procedures were executed, accompanied by corresponding observations:

• Investigation and assessment of the Bit Error Rate (BER) and Spectral Efficiency (SE) performance of Downlink (DL) NOMA for varying distances and power location coefficients.

• Examination of the Average Capacity Rate and Outage Probability (OP) performance of Uplink (UL) NOMA under different conditions, including varied distances, Signal-to-Noise Ratio (SNR), and Bandwidth (BW).

• Results from the DL NOMA system indicated that the introduction of 64 x 64 Multiple-Input Multiple-Output (MIMO) technology not only enhanced BER and SE performance but also effectively addressed the near-far user's challenge, aligning the performance of each user closely with others.

• Comparative analysis between DL NOMA with and without MIMO revealed that, under factors such as different transmitted power, distance, and power location coefficients, the 64 x 64 MIMO DL NOMA, at 80 MHz BW and 200 MHz BW (with a transmitter power of 40 dBm), improved BER performance for the best user U4 from 10^-1.7 to 10^-5.2.

• In contrast, with a transmitter power of 40 dBm, the SE performance for the best user U4 witnessed an improvement of 0.8% bps/Hz for 80 MHz BW and 1.01% bps/Hz for 200 MHz BW. The results from UL NOMA systems, employing 64 x 64 MIMO, demonstrated notable enhancements.

• For the best user U4, the average capacity rate performance improved by 12 bps/Hz, the OP decreased by 0.0120 for 200 MHz BW at an SNR of 0.17 dB, and the OP decreased by 0.0150 for 80 MHz BW at an SNR of 1 dB.

• An increase in BW led to a reduction in SE and OP while increasing BER and average capacity rate.

• MIMO technology significantly improved the performance of each user.

Future Research

This study aims to contribute to the current literature by proposing an integrated network architecture that combines Multiple-Input Multiple-Output (MIMO) and Non-Orthogonal Multiple Access (NOMA) technologies. The goal is to tackle challenges such as massive connectivity, low latency, and high dependability while specifically addressing issues related to near/far users. It's crucial to highlight that this research does not explore the collaborative potential of MIMO cooperative NOMA and cognitive radio. Future research endeavors can investigate this unexplored area to unlock additional improvements in network performance.

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