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***Title: Performance Analysis of Beam Selection Techniques in Beamspace
MIMO-NOMA System***

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Performance Analysis of Beam Selection Techniques In Beamspace MIMO-NOMA System

Declaration

I hereby declare that the thesis entitled “***Performance Analysis of Beam Selection Techniques in Beamspace MIMO-NOMA System***” is my original work and has not been presented for a degree in any other university.

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Performance Analysis of Beam Selection Techniques In BeamSpace MIMO-NOMA System

Abstract

Massive Multiple Input Multiple Output (MIMO) technology, characterized by deploying numerous antennas at base stations, represents a breakthrough in wireless communication. It facilitates substantial enhancements in spectral efficiency and streamlines transmission processing. However, its notable drawback lies in its high power consumption. Consequently, BeamSpace MIMO has emerged as a pivotal technology in the realm of advanced 5G technology, offering a solution to address these challenges. In this thesis we study and analyze the beam selection algorithms in beamSpace MIMO systems. This thesis presents a performance analyze of beam selection techniques for beamSpace MIMO-NOMA systems. In the beamSpace MIMO-NOMA system, beam selection plays a critical role in enhancing the spectral efficiency and energy efficiency of the system. For this, first we analyze recent works on beam selection techniques, channel modeling, power allocation, clustering and precoding in massive MIMO systems.

In this thesis, is evaluate the performance of beam selections techniques for beamSpace MIMO-NOMA systems, including the maximal-magnitude (MM) beam selection technique, the maximum-SINR (MSINR) beam selection technique, and the minimum-capacity (MC) beamSpace MIMO-NOMA beam selection technique. Specifically, after UEs select a beam, we receive a new channel matrix the user selects the same beam is clustered in one group and served by a single beam by deploying NOMA scheme in each cluster. Finally, to maximize achievable sum-rate (ASR) optimization of power allocation of user in given cluster is solved and optimizing power allocation factors using power coefficient optimization approach is optimized the power coefficients for each user in the given cluster M by power allocation scheme. Computer simulations validate the numerical results; The MSINR improves the capacity of a system than MC and MM as number of users is increase, where the number of users is reached 50 users the spectral efficiency served user is 110, 85 and 75 respectively. Moreover, MSINR is enhance two methods as SNR and number of user increases. The simulation further confirms that MSINR has a higher energy efficiency than alternative approaches due to the selected beam's lower relative consumption of power. Finally, proposed MSINR beamSpace MIMO-NOMA schemes achieve higher spectrum efficiency (SE) and energy efficiency (EE) than the MC and MM beamSpace MIMO-NOMA schemes.

Key words: *BeamSpace MIMO, NOMA, Beam selection, Spectral efficiency, Energy Efficiency.*

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List of Abbreviations

ACO	Anti colony optimization
ADC	Analog to digital
ASR	Achievable sum rate
BS	Base Station
BS	Beam selection
CAP	Continuous aperture phased
CP	Circuit Power
CSI	Channel State Information
DL	Downlink
DLA	Discrete linear array
EE	Energy Efficiency
IA	Interference-aware
IU	Interference user
LTE	Long Term Evolution
LOS	light of sight
MC	Maximizing capacity
MM	Maximum magnitude
M-SINR	Maximizing signal-to-interference-noise-ratio
MIMO	Multiple Input Multiple Output
NLOS	Non light of sight
NUI	non-interferences user
OFDM	Orthogonal Frequency Division Multiplexing
PA	Power Allocation
PC	Power Consumption
PSN	Phase shifter network
RF	Radio Frequency
SDV	Singular decomposition value
SE	Spectral Efficiency
SISO	Single Input Single output
TAS	Transmission antenna selection
UE	User Equipment
ULA	Uniform linear array

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ZF Zero forcing

List of Symbols Notations

\mathbf{A}	Matrix
\mathbf{A}	Vector
A	Scalar
$A_{i,j}$	The element in the row i and the column j of \mathbf{A}
$\mathbf{A}(i, :)$ $i \in \mathcal{S}$	The sub-matrix of \mathbf{A} that consists of the i^{th} row of \mathbf{A} for all i
$\mathbf{A}(:, j)$ $j \in \mathcal{S}$	The sub-matrix of \mathbf{A} that consists of the j^{th} column of \mathbf{A} for all j
\mathbf{A}^H	Conjugate transpose of \mathbf{A}
\mathbf{A}^T	Transpose of \mathbf{A}
\mathbf{A}^{-1}	Inverse of \mathbf{A}
$\ \mathbf{A}\ _p$	Norm of \mathbf{A}
$\mathbf{A}(i, :)$ $i \in \Gamma$	The submatrix of \mathbf{A}
$\mathcal{CN}(\mathbf{m}, \mathbf{R})$	The complex Gaussian distribution with mean \mathbf{m} and covariance \mathbf{R}
$E\{\cdot\}$	Expectation
$\text{Log}_a(\cdot)$	Logarithm in base a
$\text{Max}\{\cdot\}$	Return the maximum element of its input
$\text{Min}\{\cdot\}$	Return the minimum element of its input
$ \mathcal{S} $	The number of elements in set
\mathbf{I}_N	The $N \times N$ identity matrix. $(i, j)^{th}$ element of \mathbf{H}
\emptyset	Empty set
"*"	Stands for conjugation. $\mathcal{A} \setminus \mathcal{B}$ denotes set difference

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Beamspace MIMO communication is an advantageous technology which is capable of meeting the needs of future mobile networks. On the other hand, the propagation characteristics and system requirements are the restrictive factors for utilization of mmWave communication. Hybrid and digital beamforming architectures can be evaluated as worthy candidates to utilize mmWave communication. In the hybrid architecture, selection of a few numbers of beams by exploiting the sparse structure of the beamspace channel provides high spectral efficiency with low complexity. In the realm of next-generation wireless networks, a multitude of emerging technologies have been developed to address the ever-growing demand for data traffic. Among these, mmWave communication has garnered significant attention in recent years due to its promising capabilities[1].

The mmWave spectrum, spanning from 30 GHz to 300 GHz, offers a vast amount of available bandwidth, leading to substantial improvements in data rates. Additionally, the small wavelength characteristic of mmWave allows for the integration of hundreds of antennas within a confined area. This feature is particularly advantageous in overcoming space limitations, especially when dealing with a massive number of antennas.

The emergence of mmWave communications operating within the 30-300 GHz range presents an opportunity to meet the escalating capacity demands of 5G networks. Beyond the significant increase in available bandwidth, the smaller wavelengths at mmWave frequencies enable the deployment of a greater number of antennas within the same physical space. This, in turn, facilitates the implementation of massive MIMO technology, which enhances both multiplexing and beamforming capabilities, thereby further improving network performance [1-5].

Indeed, studies have demonstrated that mmWave massive systems can achieve remarkable increases in system capacity. [1-2] However, the concept of beamspace MIMO has been

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introduced to significantly reduce the number of required RF (Radio Frequency) chains in such systems.

Beamspace MIMO, pioneered in earlier research, utilizes a lens antenna array to implement spatial discrete Fourier transformation, effectively transforming the traditional spatial channel into the beamspace channel. This transformation exploits the sparsity of the channel at mmWave frequencies. By selecting dominant beams based on the sparse beamspace channel, the number of necessary RF chains can be reduced.

Furthermore, the use of a lens antenna array enables the preservation of narrow beams even with a reduced number of RF chains. This reduction in the number of RF chains not only diminishes the power required per beam but also mitigates inter-beam interferences. Consequently, unlike traditional antenna selection techniques, beamspace MIMO with beam selection approaches optimal performance closely [3].

However, it's essential to acknowledge a fundamental limitation of beamspace MIMO, which has been explicitly or implicitly considered in all published papers on the subject. Each RF chain can only support one user at the same time-frequency resources. Therefore, the maximum number of users that can be supported cannot exceed the number of RF chains. This limitation arises from the requirement that the degree of freedom provided by the RF chains must be equal to or greater than the degree of freedom required by users to ensure the linear separation of signals for different users [1, 4].

The Beamspace MIMO-NOMA (Non-Orthogonal Multiple Access) system introduces a novel approach where the maximum number of users is no longer restricted by the number of RF chains. This system leverages NOMA to differentiate users in the power domain, highlighting the importance of users selecting their transmit powers judiciously. The main focus of the author lies in proposing a dynamic power allocation scheme aimed at maximizing the achievable sum rate. This is achieved through the resolution of a joint power optimization problem. The dynamic power allocation scheme aims to optimize the transmit powers of users, considering the unique characteristics of the Beamspace MIMO-NOMA system, to enhance the overall system performance and efficiency [1, 6].

The implementation of mmWave MIMO-NOMA systems presents several challenges, notably high-power consumption and hardware complexity. In practical scenarios, power consumption is a crucial consideration due to the utilization of high frequencies and a large number of

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antennas to compensate for high path loss. This can lead to excessive power consumption on hardware components. Additionally, the complexity of circuitry increases when a large number of antennas are employed. Therefore, an alternative approach to beamforming is essential to mitigate hardware complexity and power consumption.

In the context of the mmWave MIMO system discussed in this study, various beam selection methods have been proposed in the literature. These methods employ different selection criteria, such as MM, SINR, MC, interference-aware (IA) beam selection, iterative beam selection, and ant colony optimization (ACO)-based beam selection algorithms. However, these methods have not been thoroughly examined for integration with beam-space MIMO-NOMA communication systems.

Addressing these challenges requires innovative approaches to beamforming that effectively balance power consumption and hardware complexity while optimizing system performance. Integrating beam selection methods specifically tailored for beam-space MIMO-NOMA systems could potentially enhance the efficiency and effectiveness of mmWave communication systems [4], [7–10].

Massive antenna arrays understood that RF components may consume more than 70% of the energy by RF chains, including the power amplifier, and the power allocation for an ADC is able to improve the massive MIMO system and reduce channel estimation. In wireless cellular networks the performance transmission of the effect area is used to evaluate SE while power consumption is used to employ the BS for EE in a massive MIMO system. Having fewer UEs and antenna elements enables the BS to be able to enhance and optimize the EE trade-off when SE is low. When taking into account the fact that the transmit power is consumed power, the EE–SE trade-off for a MIMO Rayleigh fading channel exists precisely at a low SE [9, 10].

In this study, we aim to overcome the fundamental limit by proposing an analysis of beam selection performance to achieve a highly spectrum- and energy-efficient mmWave transmission scheme that integrates the innovative concept of NOMA with beam-space MIMO, termed beam-space MIMO-NOMA. NOMA is recognized as a promising candidate for 5G networks, offering improvements in spectrum efficiency and connectivity density. Unlike conventional orthogonal multiple access (OMA) schemes, which rely on time, frequency, or code domains, NOMA operates in the power domain.

By employing superposition coding at the transmitter and successive interference cancellation at the receiver, NOMA enables multiple users to be simultaneously supported using the same

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time-frequency-space resources. Additionally, the channel gain differences among users can be leveraged to achieve multiplexing gain through superposition coding. By integrating NOMA into beamspace MIMO, we anticipate potential performance gains.

Previous studies have primarily focused on the theoretical framework of beamspace MIMO-NOMA rather than its practical implementation. Our work extends this research by addressing key aspects of the system, including beam selection, digital precoding, and power allocation. By combining various algorithms and schemes, we can create different system structures. We evaluate the performance of these structures using spectral efficiency and energy efficiency as metrics.

The implementing of beamspace MIMO-NOMA poses challenges related to excessive power consumption and hardware complexity. In practical scenarios, power consumption is a critical concern due to the high frequency and extensive use of antennas required to mitigate path loss. Moreover, the complexity of circuitry increases with the use of a large number of antennas. Therefore, there is a pressing need for innovative beamforming methods to address these challenges and reduce hardware complexity and power consumption.

1.2 Statement of the Problems

The statement problem is about the challenges and difficulties in implementing a beamspace MIMO system, despite its potential advantages for satisfying capacity needs. Some of the issues include multiuser interference, user scheduling, channel modeling, complexity of system, precoding, multicellular operation, and deployment scenarios. These concerns are linked to certain massive MIMO system characteristics, namely a large number of antennas and RF chains at the base station, high complexity and power consumption, allocated bandwidth, and a large number of scheduled users.

To address these issues, beamspace MIMO can be used to reduce the number of RF chains, this can be limit the number of connected users, which can be addressed with NOMA techniques. Beside, inter-beam interference and imperfections in power allocation algorithms may reduce performance of a system. Previous approaches that allocated power based on fixed numbers of users and beams, this study considers a more flexible approach where the power allocation adapts to changes in the system configuration, which degrade system performance.

The research problem focuses on developing beam selection algorithms for beamspace MIMO-NOMA that reduce the number of RF chains without sacrificing performance, while improving spectral and energy efficiency in beamspace MIMO communication systems.

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Additionally, the thesis aims to evaluate the impact of beam selection techniques on the performance of beamSpace MIMO-NOMA scheme.

1.3 Objectives

1.3.1 General Objective

The main objective of this thesis is to analyze and optimize the performance of beam selection algorithms in beamSpace MIMO- NOMA scheme in communication system.

1.3.2 Specific Objectives

The specific objectives of this thesis is:

- ✓ To analyze the performance of beam selection techniques such as MM beam selection, MSNR beam selection, and MC beam selection in the beamSpace MIMO-NOMA system.
- ✓ To analyze the impact of different factors such as the number of beams, user, and signal-to-noise ratio on the performance of SE and EE.
- ✓ To enhance the system performance and achievable performance of beamSpace MIMO-NOMA system through power coefficient optimization.
- ✓ To proposed best beam selection technique for the beamSpace MIMO-NOMA system improving spectral efficiency and energy efficiency.

1.4. Significance of Study

Taking into account the reduction in power consumption achieved by connecting RF directly to the BS antenna, this approach offers several advantages:

- **Decreased Power Consumption:** Directly connecting RF to the BS antenna results in lower power consumption compared to conventional setups. This reduction in power consumption contributes to overall energy savings while promoting environmentally sustainable operations.
- **Increased Capacity:** By minimizing power consumption, more resources can be allocated to support additional users or enhance data transmission rates, leading to increased capacity within the system.
- **Reduced Hardware Complexity:** Simplifying the hardware setup by connecting RF directly to the BS antenna reduces system complexity. This

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simplification facilitates easier deployment, maintenance, and management of the system, ultimately lowering operational costs.

- **Enhanced Energy Efficiency:** As the system's capacity improves due to reduced power consumption, the energy efficiency of the BS antenna also improves. Energy efficiency and power consumption exhibit an inverse relationship, meaning that lower power consumption contributes to higher energy efficiency, thereby promoting more efficient use of resources.

In summary, connecting RF directly to the BS antenna results in lowered power consumption, increased capacity, reduced hardware complexity, and improved energy efficiency, making it a promising approach for optimizing the performance of wireless communication systems.

1.5. Motivation

The rapid development of the Mobile Internet and the Internet of Things is expected to meet tough needs for the 5th generation of wireless communication systems, which are pushed by estimates that mobile data traffic would expand 10-100 times between 2020 and 2030. mmWave communications, which operate between 30 and 300 GHz, offer a way to fulfill 5G's rapid capacity need. However, the technology of beam selection is the hot research area for 5G communication system. as a result motivated to study about beam selection algorithms. Furthermore, how to investigate with NOMA scheme which enhance capacity of a system.

The NOMA is used to suggest a beam selection algorithm's principle that chooses the same beam for every conflict user. It means that a single RF chain can provide service to a large number of people of users. As a result, the required number is reduced of radio frequency chains. Additionally, a NOMA power allocation methodology for conflict users, which aids in the successful implementation of SIC at the user level. Aside from SIC, using a NOMA power allocation technique improves system performance. The key challenge in beamspace MIMO-NOMA is to introduce further RF-chain reduction through designing more effective clustering approach without performance degradation.

1.6. Scope of the Study

To use a massive MIMO, the beam selection algorithms and NOMA scheme system approach has been studied. In a large MIMO system, analyzing transmission beam selection approaches and their effects on capacity and energy efficiency. Additionally, the performance of beam selections integrated with the NOMA system, as well as power allocation and interference reduction, will be studied. The proposed study's energy and spectrum efficiency at the

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downlink for a single cell will be the primary focus of this research. In this proposed study, the system will be examined utilizing a comprehensive approach that integrates a power allocation strategy, a beam selection algorithm, and the Non-Orthogonal Multiple Access principle. The objective is to enhance system performance while utilizing fewer RF chains compared to existing systems. By leveraging these techniques synergistically, the study aims to optimize resource utilization and improve the efficiency of wireless communication systems operating in mmWave frequencies. Finally, only Mat lab software is used to analyze the proposed system that will be built and modeled.

1.7 Contribution of Thesis

The main contribution of this thesis is analyzed and optimized performance of beam selection techniques in beamspace MIMO-NOMA. Proposed the best performed MSINR and MC beam selection based beamspace MIMO-NOMA approach. The author specifically examines at the optimization challenge of developing user clustering, beam selection, precoding design, and power allocation factor optimization in order to maximize the system's sum rate. We examined a given user by clustering solution for minimizing the total power consumption, we evaluate the sum rate performance of the proposed multi-beam beamspace MIMO-NOMA scheme, which denote the maximum number of beams connected to one RF chain. Several studies consequently choose MIMO-NOMA beams with a maximum magnitude based beamspace. The influence of other strategies, such as maximizing signal-to-interference-noise ratio and maximizing capacity beam selection, was not examined with beamspace MIMO-NOMA.

Additionally, we compared different beam selection algorithms with respect to SNR, user and complexity take as a metrics spectral efficiency and energy efficiency. Finally, we proposed a best beam selection algorithm which is MSINR Beamspace based MIMO NOMA followed by power allocation is better than others.

1.8 Limitation of the Study

The thesis focuses exclusively on downlink communication, emphasizing the utilization of power domain Non-Orthogonal Multiple Access. The investigation primarily involves theoretical analysis conducted through MATLAB simulations to evaluate performance metrics. The scope is limited to examining the effectiveness of power allocation strategies,

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beam selection algorithms, and NOMA principles in optimizing system performance within the specified parameters of downlink communication and power domain NOMA.

1.9 Structure of the Thesis

The thesis is structured into six chapters. The first chapter serves as an introduction, providing a general overview of NOMA, outlining the statement of the problem, stating the objectives of the thesis, and discussing the contributions and limitations of the research.

The subsequent chapters are organized as follows:

Chapter 2: Literature Review and Conceptual Framework This chapter delves into the literature review, discussing the fundamental concepts of Beamspace MIMO, highlighting the benefits and challenges associated with massive MIMO, introducing the basic concept of NOMA, and exploring beam selection and beamspace concepts. It provides a detailed explanation of downlink NOMA, including its technical working principles such as superposition coding, SIC, power domain in both uplink and downlink, and the advantages of NOMA compared to OMA.

Chapters 3 and 4: Analysis of Beam Selection Algorithms and System Model These chapters focus on the detailed analysis of various beam selection algorithms, including maximum magnitude, interference awareness, fully digital, and beamspace MIMO-NOMA-based algorithms. Additionally, the concept of beamforming, types of beamforming, system model, channel modeling, clustering, precoding, and power allocation are discussed in detail.

Chapter 5: presents the simulation results and discussions related to beam selection algorithms under different parameter settings.

Chapter 6: Conclusion and Suggestions for Future Work The final chapter provides conclusions drawn from the research findings and offers suggestions for future work in the field.

CHAPTER TWO

TECHNICAL BACK GROUND AND LITERATURE REVIEW

2.1 mmWave Communication

Cellular networks have traditionally operated within the congested sub-6 GHz microwave frequency bands. While these bands exhibit favorable propagation characteristics, their limited available bandwidth cannot adequately support the anticipated traffic demands of next-generation mobile services and applications. Consequently, there is a pressing need to explore higher frequency bands, which offer abundant bandwidth resources [1].

In this context, mmWave communication systems have garnered significant attention over the past few decades. Leveraging their vast available bandwidth, mmWave systems have demonstrated the capability to achieve gigabit-per-second data rates. However, the shorter wavelengths associated with mmWave frequencies pose challenges such as higher path loss, increased penetration loss, susceptibility to atmospheric absorption, and heightened attenuation, particularly in adverse weather conditions such as rain. Additionally, mmWave signals are prone to blockages by physical objects. In mmWave systems, addressing severe propagation losses and interference is crucial to achieve higher throughput and improved energy efficiency [1, 3 and 5].

On another hand the shorter wavelengths of mmWave frequencies allow for the integration of hundreds of antenna components within the same physical dimensions. This enables the deployment of highly steerable antennas, which effectively mitigate interference and minimize penetration loss caused by obstacles such as walls [6, 21, and 27].

In the context of mmWave communication frequency bands, the thesis reveals a burgeoning field with immense potential for revolutionizing wireless communication systems. mmWave frequencies, typically ranging from 30 GHz to 300 GHz, offer vast swaths of unused spectrum, enabling the transmission of large volumes of data at ultra-high speeds. Despite their promise, mmWave signals are susceptible to higher propagation losses and atmospheric absorption compared to traditional microwave frequencies. However, advancements in antenna technology, beamforming techniques, and signal processing algorithms have enabled the exploitation of mmWave frequencies for various applications, including 5G and beyond.

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In this thesis, the research is specifically focused on implementing and investigating beamforming and beam selection techniques within the mmWave frequency band. By leveraging the unique characteristics of mmWave signals and optimizing beamforming strategies, the aim is to enhance spectral efficiency, mitigate interference, and improve overall system performance in wireless communication networks. Through empirical analysis and simulation studies, this research contributes to advancing the understanding and utilization of mmWave communication frequency bands, paving the way for the development of more efficient and reliable wireless communication systems.

2.2 Massive MIMO

The demand for wireless communication throughput, reliability, and user density is continually growing. To address these increasing demands, wireless communication has evolved from Single-Input Single-Output (SISO) to massive MIMO systems. Traditional point-to-point communication systems, which utilize a single antenna at both the transmitter and receiver, have transitioned to modern communication systems employing a large number of antennas at both the base station and user terminal. This evolution allows for the simultaneous servicing of a large number of users [9].

The demand for wireless communication throughput, reliability, and user density continues to rise over time. To meet these increasing demands, wireless communication has evolved from SISO to massive MIMO systems. Traditional point-to-point communication systems, which utilized a single antenna at both the transmitter and receiver, have transitioned to more advanced systems that employ a large number of antennas at both the base station and user terminal to serve multiple users simultaneously [20].

MIMO technology became standardized and commercialized in 4G networks, laying the groundwork for further advancements in wireless communication. Massive MIMO has since emerged as a key feature of 5G communication, offering significant improvements in spectrum efficiency compared to traditional MIMO systems. By equipping base stations with a large number of antenna arrays, massive MIMO can provide uniformly good services to wireless user terminals, particularly in high-mobility environments [39].

The fundamental concept behind massive MIMO is to serve many user terminals simultaneously using a large number of antenna arrays at the base station. This approach improves spectrum efficiency by achieving large multiplexing gains. Additionally, the use of a large number of antennas enables the focusing of energy with extremely narrow beams on

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small regions where user terminals are located. This leads to a significant increase in energy efficiency [43].

In addition to these advantages, massive MIMO enhances communication reliability due to its excessive Degree of Freedom. This allows for more robust and reliable communication, even in challenging environments. Overall, massive MIMO represents a significant advancement in wireless communication technology, addressing the growing demands for throughput, reliability, and user density in modern networks. As massive MIMO is a promising technology with large gains in both spectral and energy efficiency, it is more likely operate at mmWave frequency bands where very large number of antenna arrays can be packed into small forms and has extremely wide bandwidth. Therefore, Massive MIMO technology at mmWave bands form an important part of current communication systems like 5G and beyond that are expected to support 1000 times faster data rates than the current standards [44].

The complexity of implementing massive MIMO systems with numerous antennas at both the base station and user terminals can pose challenges in terms of hardware, signal processing, and coordination. Additionally, the use of a large number of antennas and sophisticated signal processing algorithms can lead to high energy consumption, particularly problematic for battery-powered devices. Massive MIMO systems also require accurate channel state information at the transmitter for effective beamforming and interference management, incurring significant overhead for real-time channel estimation [44].

In multi-user scenarios, pilot contamination may occur when users share the same pilot sequences, leading to degraded system performance due to interference. Practical limitations in hardware cost, size, and complexity may further impede the implementation of massive MIMO, especially for mobile devices and small cells. While massive MIMO systems offer spatial multiplexing gain by serving multiple users simultaneously, this gain may diminish in scenarios with high user mobility or severe channel conditions, limiting overall capacity. Transmitting signals through numerous antennas may require non-linear power amplification techniques, introducing distortion and reducing system performance. Additionally, the substantial backhaul capacity required for data exchange between the base station and central processing unit presents challenges for network infrastructure and scalability.

2.3 Beamspace MIMO

Beamspace, a revolutionary concept in wireless communication, offers promising opportunities to enhance spectral efficiency and energy efficiency while reducing the number of required radio frequency chains. Traditional beamforming techniques have typically relied on processing signals in the spatial domain, requiring a dedicated RF chain for each beam. However, beamspace beamforming takes advantage of the sparsity of the channel's angular domain, allowing for a more efficient use of resources [2, 3, and 4].

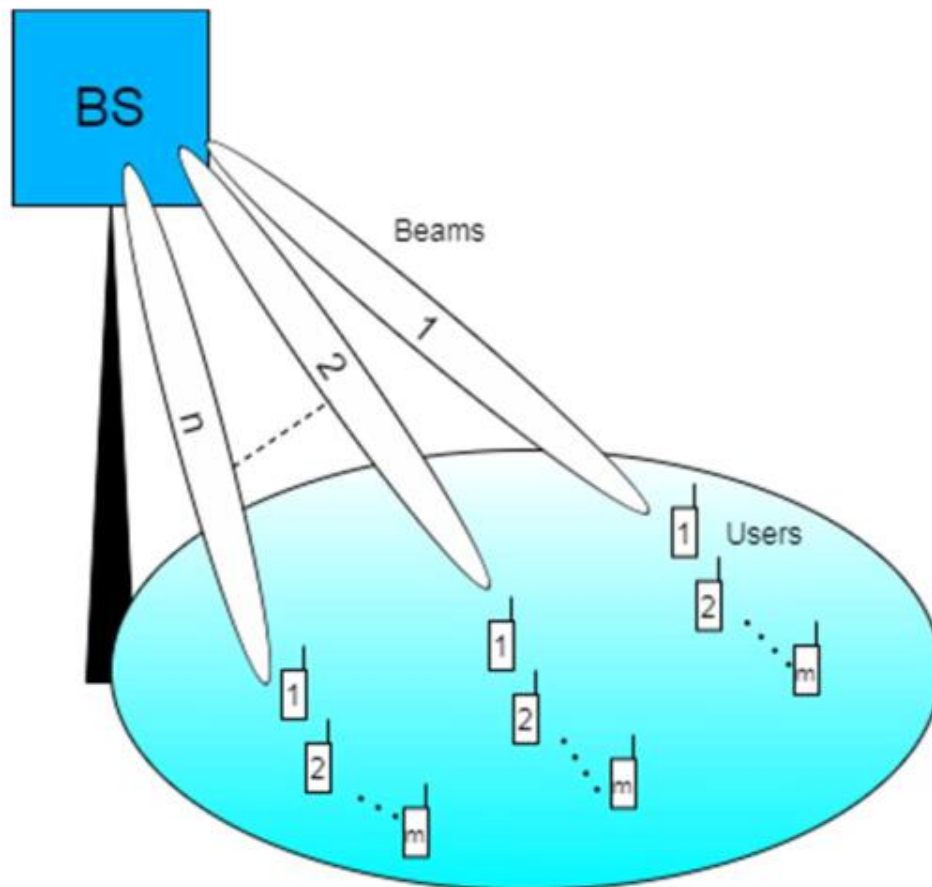


Figure 2.1 Beamspace MIMO mm wave channel model [12]

Beamspace beamforming leverages the spatial sparsity of the wireless channel by selecting a subset of dominant beams that capture the majority of the channel's energy as shown in the figure 2.1. By focusing processing resources on these dominant beams, beamspace beamforming significantly reduces the number of RF chains required, thereby reducing hardware complexity and power consumption [5].

One of the key benefits of beamspace beamforming is its ability to enhance spectral efficiency. By selecting a subset of dominant beams, beamspace beamforming concentrates transmit power and receiver sensitivity in the directions of the dominant beams, thereby

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maximizing signal-to-noise ratio and improving overall spectral efficiency. This concentrated transmission and reception enable simultaneous communication with multiple users using the same frequency resources, further enhancing spectral efficiency [6, 9].

Moreover, beamspace beamforming also improves energy efficiency by reducing the number of active RF chains. By focusing processing resources on a smaller subset of dominant beams, beamspace beamforming minimizes power consumption associated with RF chain activation, processing, and signal transmission. This reduction in power consumption not only improves energy efficiency but also extends the battery life of mobile devices, making beamspace beamforming particularly advantageous for wireless communication systems with stringent power constraints[1, 6, and 9].

Beamspace based beamforming is a transformative technology that offers significant advantages in terms of spectral efficiency and energy efficiency. By exploiting the spatial sparsity of the wireless channel, beamspace beamforming reduces the number of required RF chains while maximizing spectral efficiency and minimizing power consumption. This makes beamspace beamforming a promising solution for next-generation wireless communication systems aiming to meet the ever-increasing demands for higher data rates, improved reliability, and energy-efficient operation.

2.4 Beam selection

Beam selection refers to the process of choosing the optimal direction or set of directions for transmitting or receiving signals in a communication system equipped with directional antennas. This technique involves selecting specific beams or beamforming vectors to focus the transmission or reception of signals towards intended users or destinations, thereby maximizing signal strength, minimizing interference, and improving overall system performance. Beam selection plays a crucial role in various wireless communication technologies, such as massive MIMO, mmWave communication, and beamforming-based systems, where it helps enhance spectral efficiency, increase data rates, and improve energy efficiency [2, 3].

Wireless communication systems are constantly evolving to meet the growing demands for higher throughput, reliability, and user density. Beam selection techniques play a crucial role in optimizing the performance of these systems by selecting the most suitable directional beams for transmitting and receiving signals. In beamspace MIMO-NOMA systems, beam selection becomes even more critical due to the sparsity of the channel's angular domain and the need to serve multiple users simultaneously. Beam selection techniques are pivotal in

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optimizing the performance of wireless communication systems, particularly in the context of beamspace MIMO-NOMA systems. This paper explores various beam selection techniques, their implementation in beamspace MIMO-NOMA systems, and the advantages they offer in terms of spectral efficiency, interference mitigation, and energy efficiency [16,17, and 18].

2.4.1 Beam Selection Techniques

Beam selection techniques encompass various methods for selecting the optimal set of beams to maximize system performance. These techniques may include Maximum Magnitude Selection, Maximization of SINR Selection, Maximization of Capacity Selection, and Machine Learning-Based Beam Selection. Each technique has its advantages and is suited to different deployment scenarios and performance objective. Those beam selection techniques are explored in detail in next chapter.

2.4.2 Beam Selection in Beamspace MIMO-NOMA

In beamspace MIMO-NOMA systems, beam selection involves several key steps, including channel estimation, beamforming vector design, beam selection, and power allocation. The system selects the optimal set of beams based on criteria such as maximizing SINR, capacity, or energy efficiency while minimizing interference and power consumption. This ensures efficient and reliable communication with multiple users simultaneously [7, 9, 12, and 31].

2.4.3 Advantages of Beam Selection

Beam selection offers several advantages in beamspace MIMO-NOMA systems. Firstly, it maximizes spectral efficiency by concentrating signal power in the directions of intended users, leading to higher data rates and throughput. Secondly, beam selection helps mitigate interference by focusing transmission and reception in specific directions, thereby minimizing the impact of co-channel interference. Thirdly, it improves energy efficiency by optimizing the use of RF chains and focusing transmit power in specific directions, ultimately extending battery life. Lastly, beam selection techniques ensure user fairness by dynamically adjusting beamforming vectors and power allocation to accommodate varying channel conditions and user requirements, thus enhancing overall system performance and user experience [18].

2.5 Beamspace and Beam selection

Various studies have been conducted to reduce the hardware complexity and energy usage in an effort to solve this difficult problem. The antenna selection technique has been specifically thought of as a solution to this issue. However, there will be a clear performance loss. In a

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recent ground-breaking study, the idea of beamSpace MIMO was put further to significantly cut down on the number of RF chains needed in mmWave massive MIMO systems. BeamSpace MIMO can transform the traditional spatial channel to the beamSpace channel to capture the channel sparsity at mmWave frequencies by using the lens antenna array, which is involved in implementing spatial discrete Fourier transformation[2,4,6,9].

In beamSpace MIMO, dominant beams are selected based on the sparse beamSpace channel to reduce the number of required RF chains. Additionally, the use of a lens antenna array enables the preservation of narrow beams even with a reduced number of RF chains, leading to a significant reduction in the power required per beam and inter-beam interferences. Consequently, unlike antenna selection techniques, the performance of beamSpace MIMO with beam selection is close to optimal.

However, a fundamental limit of beamSpace MIMO, explicitly or implicitly considered in all published papers, is that each RF chain can only support one user at the same time-frequency resources. Therefore, the maximum number of users that can be supported cannot exceed the number of RF chains. This limitation arises from the requirement that the degree of freedom (DoF) provided by the RF chains must be larger than or equal to the DoF required by users. Otherwise, signals for different users cannot be separated by linear operation [17,18].

2.6. Non-Orthogonal Multiple Access

The technique of NOMA is widely recognized as a promising technology to enhance the capacity of future wireless communication systems. NOMA's fundamental concept involves supporting multiple users through transmitter power domain multiplexing and employing SIC at the receiver. This approach enables NOMA to achieve the downlink additive white Gaussian noise channel capacity region and significantly outperform conventional Orthogonal Multiple Access schemes.

Early research on NOMA primarily focused on scenarios where the transmitter comprises a single antenna. Subsequent studies delved into system-level assessments, considering functional aspects such as multiuser power allocation, overhead signaling, and propagation of SIC errors, and high mobility. Recent efforts have aimed to integrate MIMO technology into NOMA systems to achieve high performance, energy efficiency, and spectral efficiency [4],[21].

In the transmission process of NOMA, signals transmitted from the BS are superimposed for each user, with more power allocated to users located farther from the BS. Each user then

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decodes the signal containing information for all users, extracting their own intended signal first based on the received signal. NOMA employs power domain multiplexing, allocating different power levels to users within the same frequency spectrum instead of dividing the frequency spectrum like OFDMA [21]. The number of UEs selected to be assigned to the same time/frequency resources in NOMA can vary depending on the device configuration and system requirements. This flexibility enables NOMA systems to efficiently utilize the available resources and maximize the overall system capacity by serving multiple UEs simultaneously.

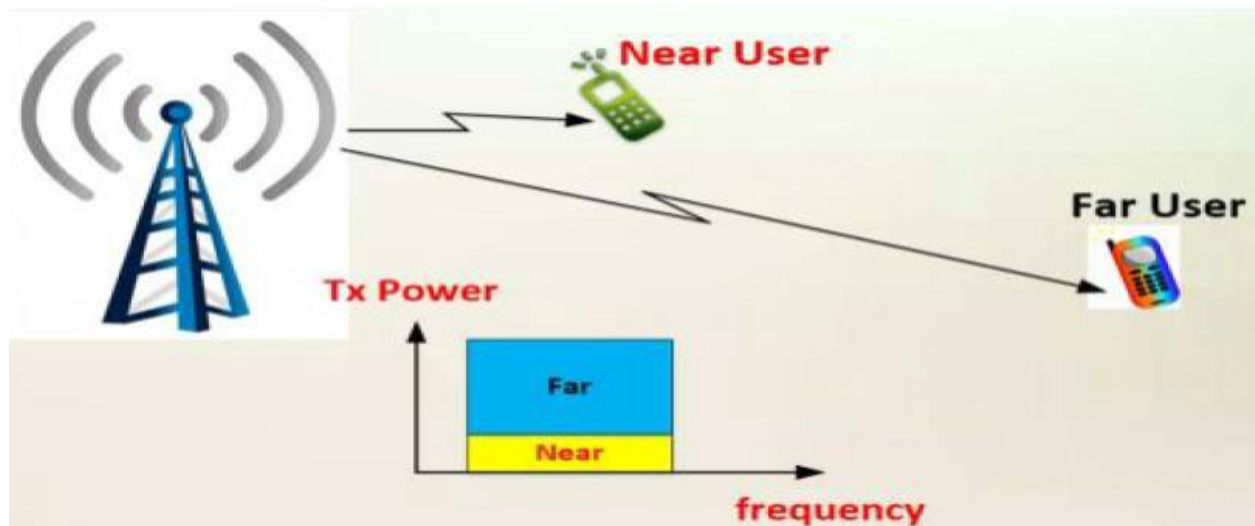


Figure 2. 1 Downlink MIMO NOMA systems [20].

The base station in a NOMA system selects two users for pairing based on their suitability for simultaneous transmission at the same time and frequency. This pairing typically involves a near-user with a strong channel gain and a far-user with a weak channel gain. During transmission, the base station splits the transmission power, allocating a higher share to the far-user and a lower share to the near-user.

Due to the power allocation scheme, the signal received by the far-user experiences minimal interference from the near-user signal. As a result, the far-user can decode its signal with relatively little additional interference. Conversely, the signal received by the near-user is significantly affected by interference from the far-user. In this scenario, the near-user first decodes the signal intended for the far-user and subtracts it from the composite NOMA signal. This process effectively cancels out the interference caused by the far-user's signal.

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However, it's important to note that the far-user is unable to cancel the interference caused by the near-user because its signal is too weak to be decoded. Therefore, the near-user can successfully decode its data from the cleaned signal after interference cancellation. This approach allows NOMA systems to efficiently serve multiple users with varying channel conditions, maximizing spectral efficiency and system capacity[8].

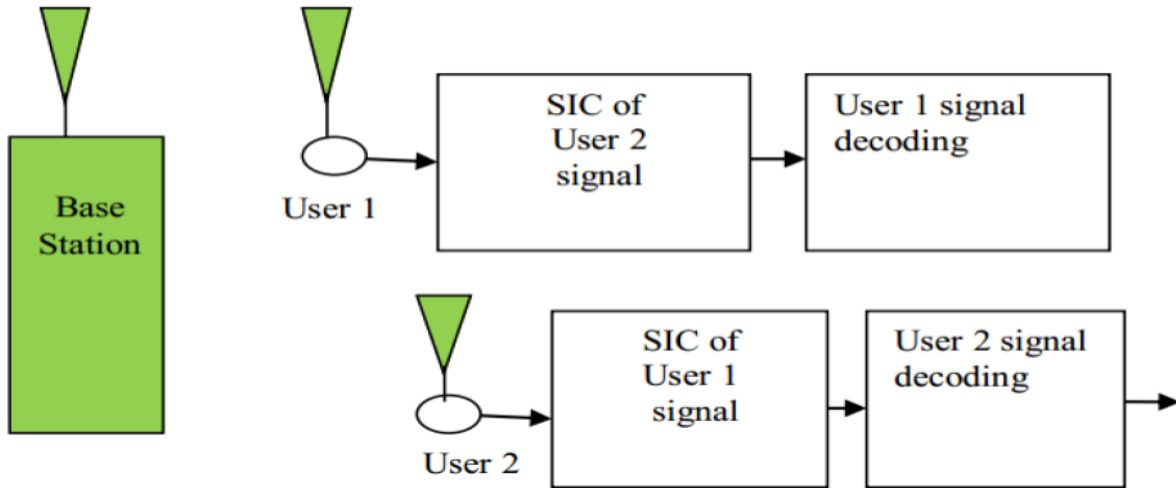


Figure 2. 2 Reception section of NOMA [17].

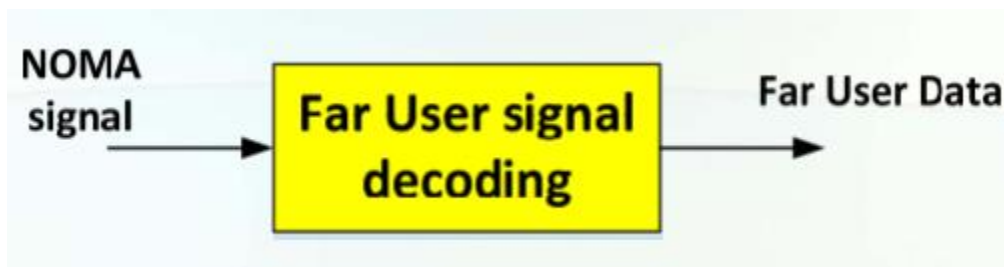


Figure 2. 3 Far user processing [22].

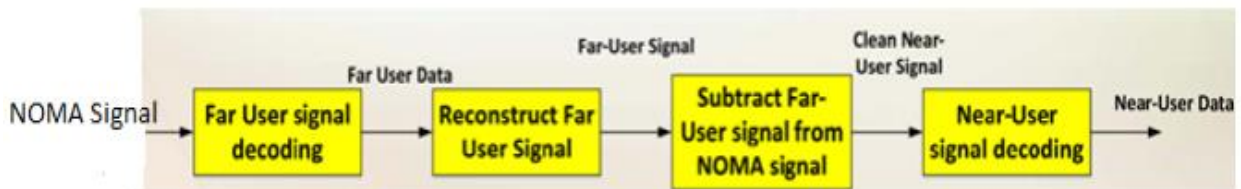


Figure 2. 4 Near user processing [22].

2.6.1 Downlink Power Domain NOMA

In a downlink Non-Orthogonal Multiple Access transmission scenario with a single antenna BS and N single antenna users with distinct channel gains, as depicted in Figure 2.7, the BS

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transmitter non-orthogonally transmits L different signals by superposing them over the same spectrum resources. All N User Equipment receivers receive their desired signals along with interferences caused by messages from other UEs.

To obtain the final desired signal, each SIC receiver first decodes the signal with the highest interference and then subtracts it from the superposed signal. Since each UE receives all signals, including desired and interfering signals, over the same channel, the superposition of different signals with different power levels is crucial for differentiation and subsequent SIC at each UE receiver[5,11,23, and 33].

In this NOMA setup, signals of NOMA users are superposed with a power level inversely proportional to their channel gains. Lower power is allocated for the user with higher channel gain, while higher power is allocated for the user with lower channel gain. Consequently, the user with the highest channel gain, despite receiving strong interferences due to relatively high powers allocated to messages of low channel gain users, can suppress all interfering signals. On the other hand, the user with the lowest channel gain, receiving low interferences due to relatively low powers allocated to messages of high channel gain users, cannot suppress any interferences [17].

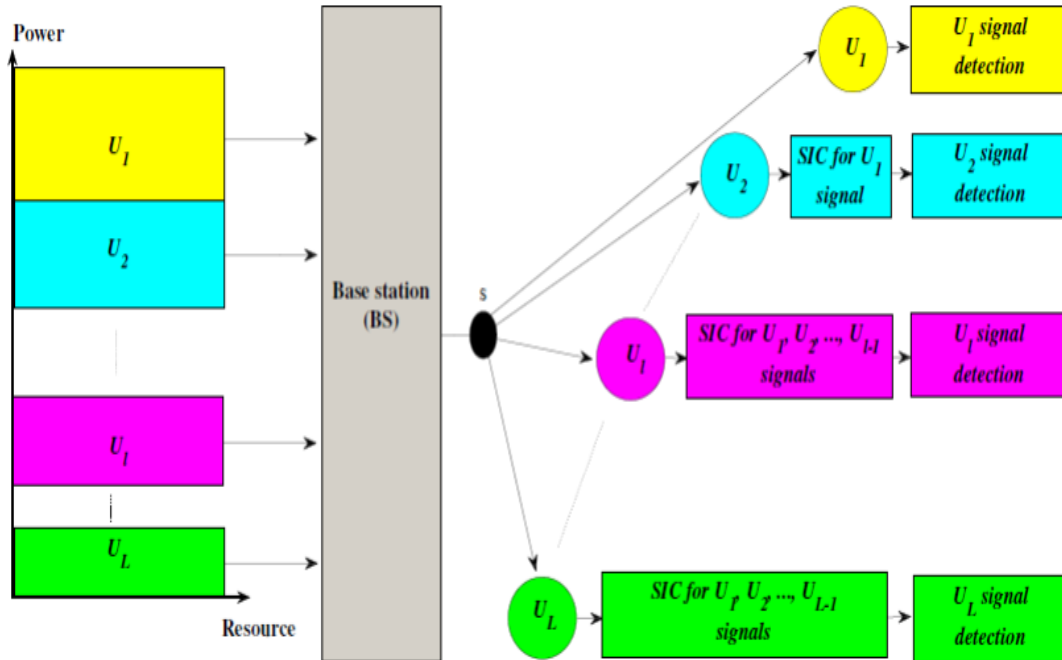


Figure 2. 6 Downlink NOMA network [25]

2.6.2 NOMA in Beamspace MIMO

MIMO combined with NOMA offers significant improvements in both energy efficiency and spectral efficiency while maintaining a simplified approach to linear signal processing. By

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utilizing techniques such as SIC for power domain NOMA and message passing algorithms for code domain NOMA, multi-user detection can be efficiently handled within the Baseband Unit (BBU) pool. Compared to traditional NOMA HetNets (Heterogeneous Networks), the structure of Remote Radio Heads (RRHs) in massive NOMA MIMO systems is significantly simplified. This simplification enables cost-effective deployment of RRHs over large-scale regions. Additionally, massive NOMA MIMO systems offer a large number of degrees of freedom, allowing for the suppression of intercellular interference through precoding of UE signals across various cells[36,39,41].

In the transmission process of NOMA, signals transmitted from the Base Station are superimposed for each user, with more power allocated to users located further away from the BS. Both users receive the same composite signal containing data for all users. Each user then decodes the strongest signal first and extracts its intended data from the received signal.

Overall, the integration of massive MIMO with NOMA offers enhanced EE and SE, simplified RRH structure, efficient multi-user detection, and suppression of intercellular interference, making it a promising technology for future wireless communication systems[24].

2.6.3 NOMA with Beam Selection

In order to enable the concurrent utilization of multiple antennas on the transmitter side, a corresponding number of parallel Radio Frequency chains at the front end are required. However, as the number of antennas increases, so does the complexity, power consumption, and cost of the device. To mitigate these challenges, an efficient beam selection technique opportunistically selects the best antenna from multiple antennas and utilizes a subset of transmission RF chains. This approach helps to reduce device complexity, power consumption, and cost without significant performance loss [9,26].

Research efforts should focus on developing a new Multiple Input Multiple Output-Non-Orthogonal Multiple Access scheme for downlink communications. In this scheme, a base station equipped with multiple antennas communicates with multiple users, each equipped with a single antenna. The objective of the scheme is to enhance the achievable rate by opportunistically allocating the targeted user rate based on channel conditions. This approach aims to improve the overall performance and efficiency of wireless communication systems, considering the dynamic nature of channel conditions and user requirement [25,43].

In the thesis, the basic concept of Power domain NOMA is explored as a means to enhance system capacity and reduce power consumption. This technique is leveraged for clustering

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users, effectively reducing interferences and optimizing resource allocation. By utilizing Power domain NOMA, the thesis aims to improve spectral efficiency and overall system performance in wireless communication networks.

2.7 Literature Review

Several interdisciplinary research studies and tests are executed through different numerical simulations and experimental methods around the world. Recently, as for beam selection algorithms and massive MIMO- NOMA, numerous researches have been investigated the effects on spectral and energy efficiency. Notably, in this discuss some of them in brief.

In [1], [27], the authors propose a novel spectrum and energy-efficient mmWave transmission scheme that integrates the concept of NOMA with beamspace MIMO, termed as beamspace MIMO-NOMA. By incorporating NOMA into beamspace MIMO systems, this approach allows for a larger number of supported users than the number of RF chains at the same time-frequency resources. The achievable sum rate of the proposed beamspace MIMO-NOMA in a typical mmWave channel model is analyzed, demonstrating significant performance gains compared to existing beamspace MIMO techniques.

In [18], [28], [29], a phase shifter network (PSN)-based precoding structure is proposed to address the challenge of supporting multiple users with a limited number of RF chains. The key idea is to utilize multiple phase shifters from each RF chain to select multiple beams, rather than just one, to capture most of the leaked power. Building on this structure, a rotation-based precoding algorithm is developed to maximize the SNR of each user by aligning the channel gains of the selected beams in the same direction. This approach aims to enhance the overall performance and efficiency of the mmWave communication system.

In [9], [30], A uniform beam selection algorithm is proposed by the authors. In particular, the users are first categorized into two sets based on the beamspace channel's sparsity. Next, using the cross-correlation of the beamspace channels, users pick the beams uniformly. Additionally, hybrid analog/digital architecture providing lower dimensional beamspace MIMO system is used. For the hybrid architecture, beam selection techniques exploiting the sparse nature of the mmWave channel become significant, they consider a downlink mmWave communication when the large number of antennas is utilized at the base station. For that system, we propose a beam selection and a correlation-based user selection algorithms to maximize the sum data rate.

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In [26], the authors consider asset assignment for a downlink, multi-User (MU) MIMO-NOMA framework that goes for growing the aggregate rate with interference alignment (IA) Technique. Utilizing SDV based IA; they proposed IA relied NOMA framework in which various clients are gathered together while the others are adjusted to the invalid space as obstruction. The focused on the gathering of clients utilize NOMA with a low multifaceted nature progressive power allotment conspires for aggregate rate augmentation. Also, an enhancement issue is defined to augment the total rate under the aggregate power and relative decency requirements. A low unpredictability imperfect answer for the two-client situation is gotten and after that reached out to the multi-client case by a various levelled matching plan. Another methodology is acquainted with assign the transmission intensity of every client utilizing an iterative sub gradient strategy.

In [31], the authors proposed a linear beam forming method in which all the get antennas mechanical assemblies can basically drop the Inter-cluster interference. Then again, the getting antennas in complete cluster are advanced toward the power space NOMA begins with SIC at the recipient closes. For inter-cluster and the intra-cluster control portion, they furnish dynamic power designation arrangements with a target to amplifying the general cell limit. A broad execution assessment is done for the suggested MIMO-NOMA framework and the output are separated and those for standard orthogonal multiple access (OMA) based MIMO structures and other existing MIMO-NOMA solutions.

In this [6], [18], [22], [31], [32], papers try to break this fundamental limit by proposing a spectrum and energy efficient mmWave transmission scheme that integrates the new concept of NOMA with beamSpace MIMO. Particularly, NOMA has also been considered as a promising candidate for 5G to improve spectrum efficiency and connectivity density

This study framework involves evaluating the performance of various beam selection algorithms, including MM, maximizing M-SINR, and MC beam selection algorithms. Although the performance and superiority of certain algorithms have been extensively tested, this study aims to investigate and analyze the performance of beam selection algorithms comprehensively. Furthermore, while there are several existing beam selection algorithms in the scenario, none of them have utilized the NOMA principle to select beams. Therefore, this study will explore the potential of integrating NOMA principles into beam selection algorithms to enhance their performance and efficiency.

In reference [6], the paper discusses and simulates the classification approach where the percentage of channel power captured by a subset of beams is fixed at $\eta = 95\%$. The study considers two scenarios: one where the maximum number of beams is fixed at 40 ($N = 40$),

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and another where it is fixed at the number of users K . However, fixed power allocation is limit to overall performance of system and not sufficient. To address this limitation, our study focuses on dynamic power allocation and optimization-based techniques. These approaches offer performance enhancements such as improved capacity, increased spectral efficiency, reduced interference, and enhanced user experience. By utilizing these techniques, we can achieve efficient resource utilization and adaptability, resulting in a more robust and efficient clustered communication system.

In contrast, in another paper [9], the author proposes a beam selection technique based solely on maximum magnitude. While this technique is straightforward, it does not consider other approaches like MSINR or MC techniques. In our study, we integrate beamspace MIMO-NOMA schemes and examine the performance of various beam selection techniques. By considering multiple factors and techniques, we aim to achieve better performance, as highlighted in the discussion of our simulation results. Based on the literature reviewed above, it is evident that conventional MIMO schemes only allow users within the same analog beam to be served as one NOMA group. However, in the context of massive MIMO, where the beam width is very narrow, conventional MIMO-NOMA schemes struggle to accommodate a larger number of users with a limited number of RF chains.

In the literature review, several gaps in the existing research are identified, including the persistence of a large number of radio frequencies, low spectral efficiency, energy inefficiency, imperfect power allocation methods, and the absence of power coefficient optimization. Additionally, fixed power allocation strategies have been commonly applied, lacking optimization for enhanced performance. To address these challenges, the thesis proposes a comprehensive solution framework. It introduces power coefficient optimization techniques to improve system efficiency and performance. Furthermore, the thesis explores the utilization of MSINR and MC algorithms alongside Beamspace MIMO-NOMA, departing from the traditional MM-based beam selection approach. By addressing these gaps and introducing best methodologies, the thesis aims to significantly advance the state-of-the-art in wireless communication systems.

CHAPTER THREE

BEAM SELECTION ALGORITHMS

This chapter introduces the concept of beamSpace MIMO-NOMA communication system within a downlink system. It explores the channel model, beamSpace representation of the system, beam selection algorithms, power allocation, and precoding techniques commonly used in lower frequencies, assessing their applicability to mmWave systems. Additionally, it discusses beam selection techniques found in the literature and presents a proposed algorithm tailored for the given system. Drawing from insights gathered through a review of related literature and a clear understanding of the problem statement, the methodology of this study is designed as follows.

3.1 System Model

This study focuses on a downlink communication system employing mmWave massive MIMO with a lens antenna array. The system comprises a BS equipped with N antenna elements and NRF radio frequency chains, serving K users, each with a single antenna.

At the BS, a DLA is utilized, which embodies the concept of beamSpace MIMO. The DLA can be modeled using a uniform linear array consisting of identical antenna elements, with N representing the number of antenna elements in the array. The spacing between each element is set to half the carrier wavelength, corresponding to a critically sampled ULA configuration. Additionally, a linear precoder is applied at the digital part of the BS, utilizing Number of RF chains.

In the single-beam beamSpace MIMO-NOMA communication system, following beam selection, only a limited number of beams are chosen to serve all users. Consequently, the received signal vector for all users can be represented as [1, 26].

$$\check{y} = \check{H}^H \check{P}_X + \check{w} \quad 3.1$$

In the equation (3.1) provided $\check{H} = [\check{h}_1, \dots, \check{h}_K] \in \mathbb{C}^{N \times K}$ where, \check{H} represents the channel matrix in the spatial domain, where and $\check{h}_k = [\check{h}_{1k}^*, \check{h}_{2k}^*, \dots, \check{h}_{Nk}^*]^H \in \mathbb{C}^{N \times 1}$ is the channel vector for the k^{th} user, containing the channel gain from the N elements of the uniform linear array (ULA). $\check{P} \in \mathbb{C}^{N \times K}$ is the precoding matrix, which mitigates multi-user interference for

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each user, and $\mathbf{x} \in \mathbb{C}^{K \times 1}$ is the transmitted symbol vector. The average power constraint at the antenna port is satisfied by $E \left[\|\check{\mathbf{P}}_{\mathbf{x}}\|^2 \right] \leq \rho$, where ρ the total is transmitted power. $\check{\mathbf{w}} \in \mathbb{C}^{K \times 1}$ Represents the additive white Gaussian noise (AWGN) vector, with $\check{\mathbf{w}} \sim \mathcal{CN}(0, \sigma^2 \mathbf{I}_K)$.

3.2 Channel Modeling

For simplicity, we consider the Saleh-Valenzuela (S-V) channel model [31] for mmWave communication, which is considered a time-invariant channel. The channel vector of the k^{th} user is denoted as:

$$\mathbf{h}_k = \alpha_{k,0} \mathbf{a}(\theta_{k,0}) + \sum_{l=1}^L \alpha_{k,l} \mathbf{a}(\theta_{k,l}), \quad 3.2$$

where $\alpha_{k,0}$ and $\mathbf{a}(\theta_{k,0})$ are the complex gain and the steering vector of the line-of-sight (LoS) component of the k -th user, $\alpha_{k,l}$ and $\mathbf{a}(\theta_{k,l})$ for $l = 1, 2, \dots, L$ denote the complex gain and the steering vector of the l -th non-line-of-sight (NLoS) component of the k -th user, L denotes the number of NLoS components. $\theta_{k,0}$ and $\theta_{k,l}$ for $l = 1, 2, \dots, L$ denote the corresponding spatial directions. Generally, the amplitudes $\{|\alpha_{k,l}|\}_{l=1}^{l=L}$ of NLoS components are 5 to 10 dB weaker than the amplitude $|\alpha_{k,0}|$ of LoS component [9].

The above steering vector can be expressed as a column vector where $\theta_{k,i}$ and $\beta_{k,i}$ represent the space angle and complex gain of the i -th propagation path for the k -th user, respectively. The first term in Eq. (1) represents the LoS component, while the second term represents NLoS components with N paths. The channel matrix of K users is denoted as \mathbf{H} . The $N \times 1$ steering vector $\mathbf{a}(\theta)$ is a discrete complex space sine curve, which is defined as:

$$\mathbf{a}(\theta) = \left[e^{-j2\pi\theta p} \right]_{p \in \mathcal{J}(N)} \quad 3.3$$

where $\theta = \frac{d}{\lambda} \sin(\phi)$ denotes the spatial direction distributed in a range $[-0.5, 0.5]$, ϕ represents the physical direction distributed in a range $[-\pi/2, \pi/2]$, $\mathcal{J}(N) = \{p - (N - 1)/2, p = 0, 1, \dots, N - 1\}$ is a symmetric set of indices centered around zero, d is the antenna spacing, λ is the wavelength of incident signal. In (4), we define $j = \sqrt{-1}$. In this paper, we consider a half wavelength antenna spacing, i.e., $d = \frac{\lambda}{2}$. According to [1 – 4], the lens antenna array functions as a unitary discrete Fourier transformation matrix \mathbf{U} of size $N \times N$. The transformation matrix \mathbf{U} contains the array steering vectors of N directions, which cover and equally divide the entire space as follows: where $\Gamma(N) = \{\ell - (N - 1)/2: \ell = 0, 1, \dots, N - 1\}$ is a symmetric set of indices centered around zero. The spatial direction is defined as $\theta = 0.5 \sin(\phi)$, which is related to the physical angle $\phi \in [-\pi/2, \pi/2]$.

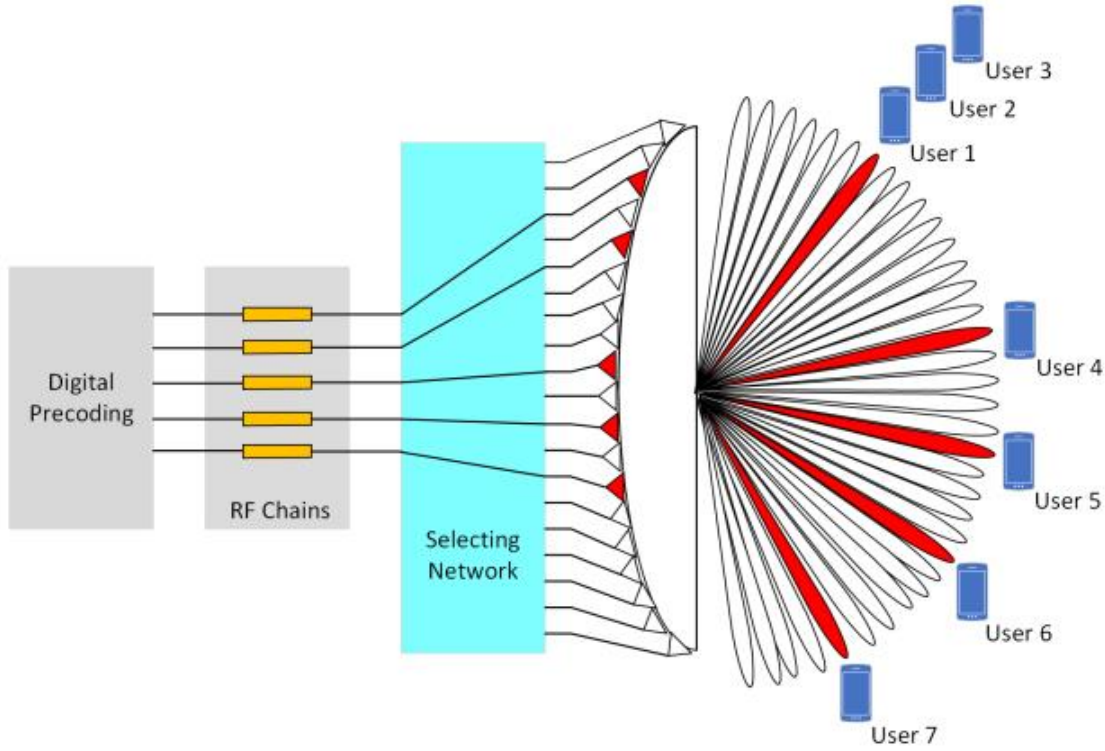


Figure 3. 1. System model of beamspace MIMO-NOMA [1]

3.3 Beamspace Representation

From the above equation 3.3, we can obtain the beamspace representation of the channel matrix by a unitary transformation. The unitary matrix used is given by:

$$U = \frac{1}{\sqrt{N}} [a(\bar{\theta}_1), a(\bar{\theta}_2), \dots, a(\bar{\theta}_N)] \quad 3.4$$

Where fixed intervals is $\Delta\bar{\theta}_0 = N1$. The columns of U represent steering vectors with N fixed space angles. Therefore, beamspace representation of S-V channel matrix is written as Where $\bar{\theta}_q = \frac{1}{N} \left(q - \frac{N+1}{2} \right)$ for $q = 1, 2, \dots, N$ denotes the pre-defined orthogonal spatial direction uniformly distributed in a range $[-0.5, 0.5]$. Then, the received signal vector $\tilde{\mathbf{Y}}$ in beamspace MIMO systems can be represented as

$$\tilde{\mathbf{y}} = \mathbf{H}^H \mathbf{U}^H \mathbf{W} \mathbf{P} \mathbf{x} + \mathbf{w} = \tilde{\mathbf{H}}^H \mathbf{W} \mathbf{P} \mathbf{x} + \mathbf{w} \quad 3.5$$

Where the beamspace channel matrix $\tilde{\mathbf{H}}$ is defined as

$$\tilde{\mathbf{H}} = \mathbf{U} \mathbf{H} = [\mathbf{U} \mathbf{h}_1, \mathbf{U} \mathbf{h}_2, \dots, \mathbf{U} \mathbf{h}_K] = [\tilde{\mathbf{h}}_1, \tilde{\mathbf{h}}_2, \dots, \tilde{\mathbf{h}}_K] \quad 3.6$$

where $\tilde{\mathbf{h}}_k = \mathbf{U} \mathbf{h}_k$ is the beamspace channel vector between the BS and the k th user, which is the Fourier transformation of the spatial channel vector \mathbf{h}_k in (3.2). As for the beamspace channel matrix $\tilde{\mathbf{H}}$ defined in (3.6), each row of $\tilde{\mathbf{H}}$ corresponds to one beam, and all N rows

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correspond to N beams with spatial directions $\bar{\theta}_1, \bar{\theta}_2, \dots, \bar{\theta}_N$, separately. In the context of mmWave communications, where the number of NLoS components L is significantly smaller than the number of beams N , the beamspace channel matrix $\tilde{\mathbf{H}}$ exhibits a sparse nature. Leveraging this sparse structure, it becomes possible to design dimension-reduced beamspace MIMO systems without sacrificing performance through beam selection. Specifically, based on the sparse beamspace channel matrix, a small number of beams can be selected to efficiently serve K users simultaneously, leading to a rewriting of the received signal vector as described in equation (5), [7, 8].

$$\tilde{\mathbf{y}} = \tilde{\mathbf{H}}_S^H \mathbf{W}_S \mathbf{P} \mathbf{x} + \mathbf{w} \quad 3.7$$

Where $\bar{\mathbf{H}}_r = \bar{\mathbf{H}}(i, :)_{i \in S}$ of size $|S| \times K$ is the dimension reduced beamspace channel matrix including selected beams, and S is the index set of selected beams. \mathbf{w}_r of size $|S| \times K$ is the dimension-reduced precoding matrix. Since the row dimension of \mathbf{w}_r is much smaller than N (the row dimension of the original precoding matrix), the number of required RF chains can be significantly reduced, and we have $N_{\text{RF}} = |S|$ [4].

In existing beamspace MIMO systems, each beam is typically limited to supporting only one user at most. Consequently, the maximum number of users that can be supported simultaneously at the same time-frequency resources is constrained by the number of available RF chains, namely $K \leq N_{\text{RF}}$. This limitation represents a fundamental constraint of beamspace MIMO systems, which has been acknowledged in various publications [3]. The rationale behind this constraint lies in the requirement that the DoF provided by the RF chains must be sufficient to accommodate the DoF required by the users for successful signal separation through linear operations. To overcome this inherent limitation, we propose a novel mmWave transmission scheme that integrates Non-Orthogonal Multiple Access (NOMA) with beamspace MIMO, as discussed in the subsequent subsections [4], [7], [33].

3.4 Beam Selection Algorithms

Beam selection leverages the sparse characteristics of the beamspace channel, enabling the creation of a low-complexity system. This approach reduces both hardware complexity and system dimensionality without significant performance degradation. By selecting the i^{th} row of the beamspace channel matrix, we construct the reduced-dimensional beamspace channel matrix $\hat{\mathbf{H}}_b$

$$\tilde{\mathbf{H}}_b = [\mathbf{H}_b(i, :)]_{i \in S} \quad 3.8$$

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Where, S is a set involving the indices of beams which are chosen to be transmitted. Therefore, Eq.3.9 with lower dimension is given as follows:

$$Y = \tilde{\mathbf{H}}_b^H \tilde{\mathbf{P}}_b \mathbf{x} + w \quad 3.9$$

Where, $\tilde{\mathbf{P}}_b \in \mathbb{C}^{\ell \times K}$ is the reduced dimensional precoder matrix which corresponds to $\tilde{\mathbf{H}}_b \in \mathbb{C}^{\ell \times K}$ and $\ell = |\mathcal{S}|$ where $\ell \leq K$. For the mmWave MIMO system discussed in this study, several beam selection methods are available in the literature and different selection criteria are handled such as magnitude maximization, signal to interference plus noise ratio maximization and capacity maximization. In addition, an interference aware beam selection, an iterative beam selection, an ant colony optimization (ACO) based beam selection and Greedy beam selection algorithms have been presented in the literature [7], [8], [26], [33]–[35].

3.4.1 Maximum Magnitude Beam Selection

The beam selection algorithm, known as the Maximum Magnitude beam selection, as described in [6], operates by selecting a beam or beams with the highest magnitude compared to other potential beams for a given user. To facilitate this process, channel or sparsity masks are defined for each user to identify the dominant beams.

$$\mathcal{M}_k = \left\{ m \in I(N_{\text{RF}}) : |h_{b,k}(m)|^2 \geq \gamma_k \max_m |h_{b,k}(m)|^2 \right\} \quad 3.10$$

Where, γ_k is the threshold taking a value between 0 and 1. Then, the mask for all the users can be denoted as:

$$\mathcal{M} = \bigcup_{k=1, \dots, K} \mathcal{M}_k \quad 3.11$$

The algorithm selects a total of ℓ beams, where $\ell = |\mathcal{M}|$, representing the number of beams to be chosen. It's important to note that the value of ℓ can vary depending on the specific channel conditions. If the mask is designed to select the d strongest beams for each user, it is referred to as a d -beam mask. The objective of the algorithm is to transmit the d strongest beams to ensure that each user receives maximum power. To achieve this, a threshold γ_k is individually determined for each of the K users.

This algorithm assumes that Non-Line-of-Sight components for all users have zero path gains, effectively assuming a strictly Line-of-Sight channel model. However, in practice, channel models with multipath components are more realistic, and the algorithm's performance in such environments should be thoroughly investigated. Additionally, the MM algorithm does not account for multi-user interference, which can significantly impact system performance [11].

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$$\tilde{\mathbf{H}} = [\mathbf{h}_{l,:}]_{l \in \mathcal{M}} \quad 3.12$$

The dimensions of the new channel matrix $\tilde{\mathbf{H}}$, denoted as $n_d \times K$ are determined by the number of dominant beams $n_d = |\mathcal{M}|$ identified in the sparsity mask. As shown in Eq. (3.12), the MM-S algorithm results in variable values of n_d depending on the specific channel realization. This variability arises from the user-wise selection performed by MM-S, which often results in multiple selections of the same beam for different users. Consequently, the number of required RF chains varies across different channel realizations and user configurations.

As a result, the direct application of MM-S in practical systems, where the number of RF chains is fixed, is not feasible [33]. When users are in close proximity, such as in mmWave propagation scenarios, their channels tend to exhibit high correlation. In such cases, the sparsity mask assigns the same dominant beam to users with similar channels. Research has shown, as presented in [8], that the likelihood of assigning the same dominant beam to multiple users is significantly high, particularly when a large number of antennas are deployed at the BS. Consequently, users experience significant multi-user interference. However, assigning the same beam to multiple users also leads to inefficient utilization of RF chains. The number of active RF chains in the system fluctuates based on the channel conditions, which is undesirable.

3.4.2 Maximization of SINR beam selection

The beam selection algorithm described in [40] is based on maximizing the Signal-to-Interference-plus-Noise Ratio (SINR). To derive the SINR, the precoder needs to be defined. Therefore, the received SINR for the k^{th} user can be analytically expressed as follows:

$$\text{SINR}_k(\rho) = \frac{\frac{\rho|\alpha|^2}{K} |\mathbf{h}_k^H \mathbf{f}_k|^2}{\frac{\rho|\alpha|^2}{K} \sum_{i \neq k} |\mathbf{h}_i^H \mathbf{f}_k|^2 + \sigma^2} \quad 3.13$$

where α is the scaling factor and σ^2 is the noise power. The ZF precoder eliminates the interference term in Eq. (3.13) which is stated by the summation and provides the received power as $\frac{\rho|\alpha|^2}{K}$. Thus, the SINR can be rewritten as:

$$\text{SINR}_K = \frac{\rho|\alpha|^2}{K\sigma^2} \quad 3.14$$

where the total transmit power is equally shared among the users. The objective of the algorithm is to deactivate a beam whose removal maximizes the SINR of the remaining

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system. Simplifying Eq. (3.13), we can focus on maximizing the SINR based solely on the parameter α , which is subject to the channel conditions:

$$\delta = \arg \max_j (\text{SINR}^{(j)}) = \arg \max_j (|\alpha^{(j)}|^2) \quad 3.15$$

where $\alpha^{(j)}$ corresponds to $H^{(j)}$ which is the remaining channel matrix after j th beam is disabled, and δ is the index of the disabled beam[36].

3.4.3 Maximization Capacity Beam selection

The maximization capacity-based beam selection scheme utilizes received beam power measurement to eliminate the need for capacity computation in scenarios where transmit and receive beams do not effectively communicate (i.e., measured beam power is below a threshold). By identifying these instances, the system reduces the computational load by focusing only on scenarios with potential for effective communication.

This approach involves optimizing MIMO capacity within a reduced space of possible transmit and receive beam-pairs across the antenna ports. The goal is to identify the best N sets of MIMO streams that maximize capacity while minimizing computational complexity. By prioritizing beam-pairs that offer promising communication potential, the method ensures efficient resource allocation without sacrificing performance. Additionally, this strategy ensures that computational complexity scales effectively with the number of antenna ports and the number of analogue beams per antenna port.

The complexity of the global optimum search stage is given by $N_s N_{RFxH} N_{RxH}$. The overall complexity of this scheme turns out to be $N_{RFxH} N_{RxH} (1 + N_s)$. As mentioned, to find best N beams using this method is difficult and needs considerable modification. The capacity maximizing streams of best- N beam pairs can be expressed as

$$\mathcal{C}_{\max, N} = \arg[\max_N \{(H_i)\}], i = 0, 1, \dots, (N_{RF}N)^{N_s} - 1 \quad 3.16$$

The search space over which capacity is maximized is $(N_{RF}N)^{N_s}$. The initial power computation-based reduction in the search space makes the capacity-based search space independent of N_{RFxH} and N_{RxH} thus reducing the complexity. Indeed, the power computation stage involves computation of the RSS over the $N_{RF}N_R N_{TxH} N_{RxH}$ beam pairs [36].

CHAPTER FOUR

PERFORMANCE OPTIMIZATION

In this chapter, we delve into the fundamental principles and methodologies underpinning these crucial concepts. Clustering facilitates the organization of users into coherent groups, enabling more efficient resource allocation and interference management. Precoding techniques, on the other hand, involve the manipulation of transmitted signals to exploit the spatial domain, maximizing signal quality at receivers. Meanwhile, power allocation power coefficient optimization methods aim to strike a balance between power consumption and system throughput, ensuring optimal utilization of available resources. Through a comprehensive examination of these interconnected concepts, we aim to provide insights into their synergistic roles and their significance in shaping the landscape of modern wireless communication systems.

4.1 User Clustering

In this section, we propose a clustering algorithm to minimize inter-cluster and inter-user interference and also propose a power allocation scheme that maximizes the sum capacity while guaranteeing the weak user's capacity. In this section, we present a clustering algorithm aimed at minimizing both inter-cluster and inter-user interference, coupled with a power allocation scheme tailored to maximize the sum capacity while ensuring the capacity of weaker users in NOMA-BF scenarios. The effectiveness of NOMA-BF heavily relies on the selection of users within each cluster, as it directly impacts the level of interference experienced by weaker users. To mitigate interference and optimize system performance, the clustering algorithm strategically selects two users from the total K users to form a cluster. The interference affecting weaker users in NOMA-BF is influenced by the specific users chosen within each cluster. Therefore, by carefully selecting the users for clustering, interference levels can be minimized [1, 9].

While an exhaustive search could theoretically maximize sum capacity by exploring all possible user combinations, it is impractical due to its high complexity. Instead, we propose a novel clustering algorithm designed to achieve interference reduction with manageable computational complexity. This algorithm considers two primary factors influencing interference: the correlation between channels and the disparity in channel gains among users within a cluster. First, if the channels of the strong and weak users in the n -th cluster, $\mathbf{h}_{n,1}$

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and $\mathbf{h}_{n,2}$, are highly correlated, $\mathbf{h}_{n,2}\mathbf{w}_m \approx 0$ for $m \neq n$ where \mathbf{w}_m is the BF vector of the m -th cluster ($1 \leq m \leq N$). This means that the higher the correlation between the two user channels,

In the multi-user scenario, clusters are formed by users served with the same beam. Despite containing only, a single user, each cluster experiences interference from other clusters. Hence, dedicated precoding vectors are required for each cluster to eliminate multi-user interference, Let $\mathcal{M} = \{1,2, \dots, M\}$, $\mathcal{K} = \{1,2, \dots, K\}$ are a set of clusters and users, respectively. Further, each cluster is having \mathcal{U}_m number of users, $m \in \mathcal{M}$, $0 < \mathcal{U}_m \leq k, k \in \mathcal{K}$. Each cluster contains exclusive users, $\mathcal{U}_i \cap \mathcal{U}_j = \emptyset, i \neq j, (i, j) \in \mathcal{M}$ | and $\sum_{m=1}^M \mathcal{U}_m = K$. After beam selection beamspace channel vector after beam selection for a user p in the cluster m can be expressed as, $\mathbf{h}_{m,p} \in \mathcal{C}^{M \times 1}$, $p = 1, \dots, \mathcal{U}_m$, and the corresponding precoding vector for the cluster m is \mathbf{w}_m . Therefore, the effective channel for a user p in the cluster m can be expressed as $|\mathbf{h}_{m,p}^H \mathbf{w}_m|$. Further, NOMA principle can be applied successfully, if the following condition is satisfied by the cluster m [26].

$$|\mathbf{h}_{m,1}^H \mathbf{w}_m|^2 \geq |\mathbf{h}_{m,2}^H \mathbf{w}_m|^2 \geq \dots \geq |\mathbf{h}_{m,\mathcal{U}_m}^H \mathbf{w}_m|^2 \quad 4.1$$

The condition for applying the NOMA principle to users in cluster m is justified. It's important to note that the precoding vectors \mathbf{w}_m , $m \in \mathcal{M}$, are designed to nullify inter-cluster interference. However, the precoding vector for cluster m may not nullify inter-cluster interference for each user within that cluster [18] Consequently, the precoding vector \mathbf{w}_m is engineered to nullify inter-cluster interference only for the strongest user because this user must decode its symbol using SIC [18]. This implies that the other users in cluster m , aside from the strongest user, will experience both inter-cluster interference and intra-cluster interference. Ultimately, the net interference received by user p in cluster m can be expressed as:

$$I_{m,p} = \underbrace{\sum_{i=1, i \neq m}^M \sum_{j=1}^{\mathcal{U}_i} P_{i,j} |\mathbf{h}_{m,p}^H \mathbf{w}_i|^2}_{\text{inter-cluster interference}} + \underbrace{\sum_{j=1}^{p-1} P_{m,j} |\mathbf{h}_{m,p}^H \mathbf{w}_m|^2}_{\text{intra-cluster interference}} \quad 4.2$$

Where $P_{i,j}$ is the power supplied to user j in the cluster i which is decided through a power allocation scheme to appropriately decode the desired symbol through SIC. The achievable performance for user p in the cluster m can be expressed as $R_{m,p} = \log_2 \left(\frac{P_{m,p} |\mathbf{h}_{m,p}^H \mathbf{w}_m|^2}{I_{m,p} + \sigma^2} \right)$,

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where σ^2 is the noise power and the achievable performance for users in the cluster m is given as $R_m = \sum_{p=1}^{U_m} R_{m,p}$ [5].

The net power supplied among K users is $\sum_{m=1}^M \sum_{p=1}^{U_m} P_{i,j} = \rho$. In our work, we are supplying equal power to all the non-conflict users, i.e., $\frac{\rho}{K}$. However, the conflict users may not be assigned the same power, but they must satisfy a condition $\sum_{p=1}^{U_m} p_{m,p} = U_m \frac{\rho}{K}$. It means the net power supplied for each cluster is equal to U_m (number of users in the cluster) times $\frac{\rho}{K}$. Thus, $P_{m,p}$ can be defined as $P_{m,p} = \alpha_{m,p} \frac{U_m \rho}{K}$, $p = \{1, \dots, U_m\}$ where $\sum_{p=1}^{U_m} \alpha_{m,p} \leq 1$, $\alpha_{m,p}, p \in \{1, \dots, U_m\}$ are the power coefficients of users in the cluster m . Therefore, the net interference received at user p in the cluster m can be redefined as

$$I_{m,p} = \underbrace{\sum_{i=1, i \neq m}^M \frac{U_i \rho}{K} |h_{m,p}^H w_i|^2}_{\text{inter-cluster interference}} + \underbrace{\sum_{j=1}^{p-1} \alpha_{m,j} \frac{U_m \rho}{K} |h_{m,p}^H w_m|^2}_{\text{intra-cluster interference}} \quad 4.3$$

The power coefficients can be determined using a NOMA power allocation scheme. Subsequently, the net achievable performance for K users is represented as $R_s = \sum_{m=1}^M R_m$. In the following section, we will detail a "beam selection algorithm and a NOMA power allocation scheme" for this purpose [9].

In each cluster, users utilize NOMA technology to share the same time-frequency resource. Different users are grouped together to form a cluster using various clustering methods. However, an exhaustive search for the optimal clustering configuration is impractical due to its high computational complexity. Therefore, we will introduce two sub-optimal clustering methods in the subsequent discussion. It's worth noting that we limit each cluster to contain no more than two users in this paper.

4.2 Precoding Matrix

As a straightforward and practical alternative, zero-forcing beamforming (ZFBF) has been employed to attain maximum capacity under perfect channel state information at the transmitter (CSIT) [6], [26], [37]. In ZFBF with N transmit antennas, the beamforming vector, W_n is formulated based on the user's channel, H_m , to satisfy the following condition:

$$\frac{H_m}{H_m} W_n = \begin{cases} 0 & \text{for } m \neq n \\ 1 & \text{for } m = n \end{cases} \quad 4.4$$

This indicates that there are no interference signals between the beams. Although a beam selection algorithm exhibits low complexity, it assigns the same beam to conflicting users. To address this, we leverage the NOMA principle for conflicting users. Algorithm 1 is utilized

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to assign beams to users, resulting in a beam channel matrix expressed as $\mathbf{H} = [\tilde{\mathbf{H}}]_{n \in \mathcal{B}}$, where $\mathbf{H} \in \mathbb{C}^{M \times K}$ represents the beamspace channel matrix post beam selection. Subsequently, we aim to derive a beamspace channel matrix containing only the channel vectors of the strongest users from each cluster, as discussed in the preceding subsection.

Thus, the beamspace channel matrix with the channel vectors of the strongest users can be represented as,

$\mathbf{H}_s = [\mathbf{h}_{1,1}, \mathbf{h}_{2,1}, \dots, \mathbf{h}_{M,1}] \in \mathbb{C}^{M \times M}$, $\mathbf{h}_{m,1} \in \mathbb{C}^{M \times 1}$, $m = \{1, \dots, M\}$. Further, we need to evaluate precoding vectors to nullify inter-cluster interference. We apply zero forcing scheme on \mathbf{H}_s and the precoding vectors for each cluster are obtained. Hence, precoding matrix is obtained

as, $\mathbf{W} = \frac{(\mathbf{H}_s^H)^{-1}}{\|(\mathbf{H}_s^H)^{-1}\|_F} \in \mathbb{C}^{M \times M}$, $\mathbf{W} = [\mathbf{w}_1, \mathbf{w}_2, \dots, \mathbf{w}_M]$, and $\mathbf{w}_m \in \mathbb{C}^{M \times 1}$, $m = \{1, \dots, M\}$.

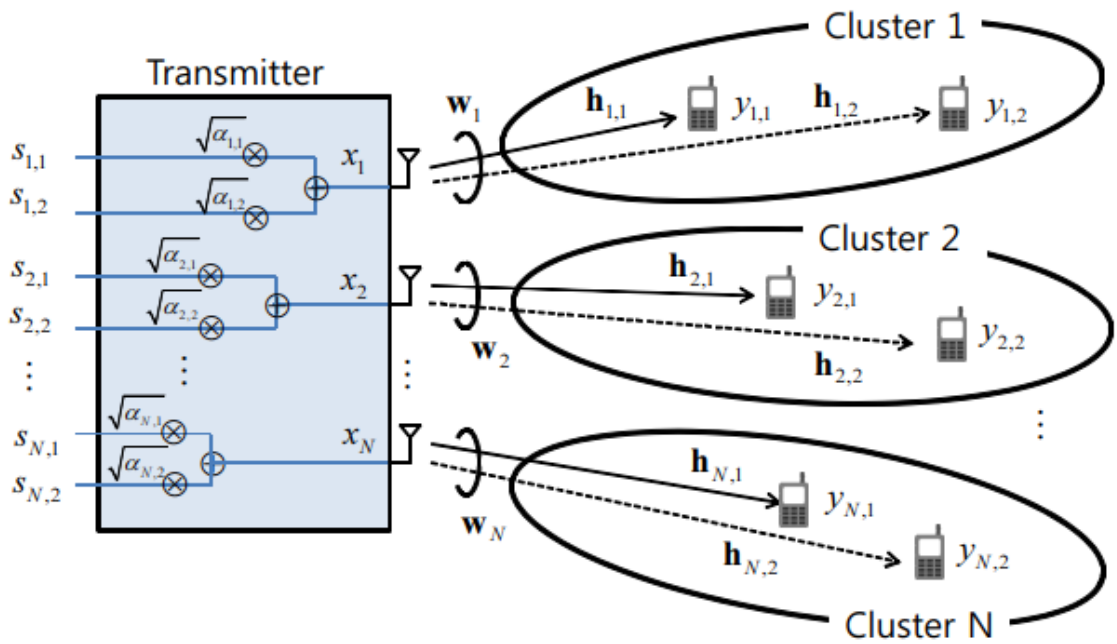


Figure 4. 1-NOMA-BF downlink system with N transmit antennas [14].

Where $1 \leq n, m \leq N$.

In conventional beamspace MIMO systems, where only one user can be accommodated in each beam (i.e., $K \leq N_{\text{RF}}$), the classical linear zero-forcing (ZF) precoding technique with low complexity can be applied to eliminate inter-beam interferences. This technique is easily implemented by computing the pseudo-inverse of the beamspace channel matrix for all users. However, in the proposed beamspace MIMO-NOMA system, the number of users exceeds the number of available beams, i.e., $K \geq N_{\text{RF}}$, implying that the pseudo-inverse of the

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beamSpace channel matrix with dimensions $N_{\text{RF}} \times K$ does not exist. Consequently, the conventional ZF precoding method cannot be directly employed [8], [33], [38].

4.3 Power Allocation and power coefficient based optimization

Beam selection algorithms has low complex, but may select same user to conflict user. We apply NOMA scheme for conflict users. We apply NOMA principle to conflict users. We use algorithm 1 to assign beam to a user and hence the beam channel matrix can be expressed as $\mathbf{H} = [\tilde{\mathbf{H}}]_{n \in \mathcal{B}}$ where $\mathbf{H} \in \mathbb{C}^{M \times K}$ is the beamSpace channel matrix after beam selection. Next, we need to obtain a beamSpace channel matrix having only the strongest users' channel vectors from each cluster as discussed in the previous sub-section. Then the beamSpace channel matrix with the strongest users' channel vectors can be expressed as,

$$\mathbf{H}_s = [\mathbf{h}_{1,1}, \mathbf{h}_{2,1}, \dots, \mathbf{h}_{M,1}] \in \mathbb{C}^{M \times M}, \mathbf{h}_{m,1} \in \mathbb{C}^{M \times 1}, m = \{1, \dots, M\} \quad 4.5$$

Further, we need to evaluate precoding vectors to nullify inter-cluster interference. It is necessary to guarantee user fairness and decode symbols received corresponding to each user by applying SIC. We allocate power in the cluster m to maximize the minimum achievable rate (the max-min fairness) among the \mathcal{U}_m number of users. Thus, power allocation optimization in the cluster m defined as,

$$\begin{aligned} & \max_{\alpha_{m,1}, \dots, \alpha_{m, \mathcal{U}_m}} \min_p \{R_{m,p}\} & 4.6 \\ & \text{C1: subject to } \sum_{p=1}^{\mathcal{U}_m} \alpha_{m,p} \leq 1 \\ & \text{C2: } \alpha_{m,p} \geq 0, p = \{1, \dots, \mathcal{U}_m\} \end{aligned}$$

Where $\alpha_{m,p}, p = \{1, \dots, \mathcal{U}_m\}$ the power coefficient in Constraint is C1 satisfies the power constraint for the cluster M Constraint C2 ensures some amount of power to each user present in the cluster M .

It is difficult to solve this optimization problem (4.6). So, we introduce a new variable to simplify the problem as suggested in [39]. Say \mathcal{R} is a minimum achievable rate among the \mathcal{U}_m number of users then optimization problem in (4.7) can be redefined as,

$$\begin{aligned} & \max_{\alpha_{m,1}, \dots, \alpha_{m, \mathcal{U}_m}, \mathcal{R}} \mathcal{R} \\ & \text{C1: subject to } \sum_{p=1}^{\mathcal{U}_m} \alpha_{m,p} \leq 1 \\ & \text{C2: } R_{m,p} \geq \mathcal{R}, p = \{1, \dots, \mathcal{U}_m\} \\ & \text{C3: } \alpha_{m,p} \geq 0, p = \{1, \dots, \mathcal{U}_m\} \end{aligned} \quad 4.7$$

Where constraint C2, $R_{m,p} \geq \mathcal{R}, p = \{1, \dots, \mathcal{U}_m\}$, is a sufficient and necessary conditions for ensuring the minimum where constraint C2, $R_{m,p} \geq \mathcal{R}, p = \{1, \dots, \mathcal{U}_m\}$, is a sufficient and

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necessary conditions for ensuring the minimum achievable rate by each user. Further, the achievable rate by each user. Further, the achievable rate of each user should not be lower than \mathcal{R} and there must be at least one user, whose achievable rate $R_{m,p}$ is equal to \mathcal{R} . Yet, we can always maximize \mathcal{R} to minimize the gap between $R_{m,p}$ and \mathcal{R} . Due to the non-linearity of the equations, $R_{m,p} \geq \mathcal{R}, p = \{1, \dots, \mathcal{U}_m\}$, this optimization problem is still difficult to solve. However, we can find the solution, if we satisfy all the above constraints.

In the next step, we find the power coefficients which satisfy the constraints, $C3: \alpha_{m,p} \geq 0$, and $C2: R_{m,p} \geq \mathcal{R}, p = \{1, \dots, \mathcal{U}_m\}$, over variable $\alpha_{m,p}, p = \{1, \dots, \mathcal{U}_m\}$. Thus, the optimization variables $\alpha_{m,p}, p = \{1, \dots, \mathcal{U}_m\}$ are obtained as

$$\begin{aligned} \alpha_{m,1} &= \eta \left(\frac{K\sigma^2}{\mathcal{U}_m \rho |h_{m,1}^H w_m|^2} \right), \\ \alpha_{m,2} &= \eta \left(\alpha_{m,1} + \frac{\sum_{i=1, i \neq m}^M \frac{\mathcal{U}_i \rho}{K} |h_{m,2}^H w_i|^2 + \sigma^2}{\frac{\mathcal{U}_m \rho}{K} |h_{m,2}^H w_m|^2} \right), \\ &\vdots \\ \alpha_{m,\mathcal{U}_m} &= \eta \left(\sum_{p=1}^{\mathcal{U}_m-1} \alpha_{m,p} + \frac{\sum_{i=1, i \neq m}^M \frac{\mathcal{U}_i \rho}{K} |h_{m,\mathcal{U}_m}^H w_i|^2 + \sigma^2}{\frac{\mathcal{U}_m \rho}{K} |h_{m,\mathcal{U}_m}^H w_m|^2} \right) \end{aligned} \tag{4.8}$$

Where, $\eta = 2^{\mathcal{R}} - 1$, and $\alpha_{m,p}, p = \{1, \dots, \mathcal{U}_m\}$. The set of equations (4.8) are obtained by constraint C3. Further, the above optimization problem can be re-defined as

$$\begin{aligned} &\max_{\eta} \{\eta\} \\ C1: &\text{subject to } \sum_{p=1}^{\mathcal{U}_m} \alpha_{m,p} \leq 1 \end{aligned} \tag{4.9}$$

using a set of equations given by (4.7) and we can write

$$\sum_{p=1}^{\mathcal{U}_m} \alpha_{m,p} = (1 + \eta) \sum_{p=1}^{\mathcal{U}_m-1} \alpha_{m,p} + \eta \left(\frac{\sum_{i=1, i \neq m}^M \frac{\mathcal{U}_i \rho}{K} |h_{m,\mathcal{U}_m}^H w_i|^2 + \sigma^2}{\frac{\mathcal{U}_m \rho}{K} |h_{m,\mathcal{U}_m}^H w_m|^2} \right) \tag{4.10}$$

Further, substituting the value of $\alpha_{m,\mathcal{U}_m-1}$ in (4.11) we obtain,

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$$\sum_{p=1}^{u_m} \alpha_{m,p} = (1 + \eta) \sum_{p=1}^{u_m-2} \alpha_{m,p} + (1 + \eta)\alpha_{m,u_m-1} + \eta \left(\frac{\sum_{i=1, i \neq m}^M \frac{u_i \rho}{K} |h_{m,u_m}^H w_i|^2 + \sigma^2}{\frac{u_m \rho}{K} |h_{m,u_m}^H w_m|^2} \right) \quad 4.11$$

$$\begin{aligned} \sum_{p=1}^{u_m} \alpha_{m,p} &= (1 + \eta)\eta \sum_{p=1}^{u_m-2} \alpha_{m,p} + (1 + \eta)\eta \left(\frac{\sum_{i=1, i \neq m}^M \frac{u_i \rho}{K} |h_{m,u_m-1}^H w_i|^2 + \sigma^2}{\frac{(u_m - 1)\rho}{K} |h_{m,u_m-1}^H w_m|^2} \right) \\ &+ \eta \left(\frac{\sum_{i=1, i \neq m}^M \frac{u_i \rho}{K} |h_{m,u_m}^H w_i|^2 + \sigma^2}{\frac{u_m \rho}{K} |h_{m,u_m}^H w_m|^2} \right) \end{aligned} \quad 4.12$$

One can repeat this step for all the values of $\alpha_{m,p}, p = u_m - 1, u_m - 2, \dots, 1$ and obtain

$$\sum_{p=1}^{u_m} \alpha_{m,p} = \sum_{p=1}^{u_m} (1 + \eta)^{u_m-p} \eta \left(\frac{\sum_{i=1, i \neq m}^M \frac{u_i \rho}{K} |h_{m,p}^H w_i|^2 + \sigma^2}{\frac{u_m \rho}{K} |h_{m,p}^H w_m|^2} \right) \quad 4.13$$

Now the optimization problem in (4.8) can be written as

$$\begin{aligned} &\max_{\eta} \{\eta\} \\ \text{C1: subject to } &\sum_{p=1}^{u_m} (1 + \eta)^{u_m-p} \eta \times \left(\frac{\sum_{i=1, i \neq m}^M \frac{u_i \rho}{K} |h_{m,p}^H w_i|^2 + \sigma^2}{\frac{u_m \rho}{K} |h_{m,p}^H w_m|^2} \right) \leq 1 \end{aligned} \quad 4.14$$

Now we need to solve optimization problem (4.14) to obtain the closed-form expression of $\alpha_{m,p}, p = \{1, \dots, u_m\}$ and thus, the expression of $\alpha_{m,p}, p = \{1, \dots, u_m\}$ can be obtained by atough to directly find the solution. However, the optimization problem (4.14) is having only a single optimization variable i.e., η . Therefore, we can find the value of η in the range of $[0, \tau]$ using the bisection method, where τ is the upper bound. The value of $\eta = 2^R - 1, \eta$ represents the minimum SINR among the u_m number of users in the cluster m [6],[26].

Algorithm - Power allocation Algorithm for cluster M

- 1: Input: precoding vector: w_m , channel vector: $m = \{1, \dots, M\}, h_{m,p}, p = \{1, \dots, u_m\}$
- 2: Evaluate upper bound: $\tau = \log_2 \left(\frac{\rho u_m}{K} |h_{m,1}^H w_m|^2 / \sigma^2 \right)$
- 3: Define the maximum and minimum value of η : $\eta_{min} = 0, \eta_{max} = \tau$
- 4: Evaluate: $\eta = \frac{\eta_{min} + \eta_{max}}{2}$
- 5: The search accuracy: δ
- 6: while $\eta_{max} - \eta_{min} < \delta$ do
- 7: if $f(\eta) < 1$ then
- 8: Set as a minimum vale of η : $\eta_{min} = \eta$

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- 9 : else
- 10: Set as a maximum value of η : $\eta_{max} = \eta$
- 11: end if
- 12: end while
- 13: Obtain the value of η
- 14: Evaluate power coefficients: $\alpha_{m,p}, p = \{1, \dots, U_m\}$

To determine τ , we allocate all power, i.e., i.e., $\sum_{p=1}^{U_m} p_{m,p} = U_m \frac{\rho}{K}$, to the user with the best channel condition, i.e., user 1 in cluster m. This ensures that user 1 achieves the highest Signal-to-Interference-plus-Noise Ratio (SINR), resulting in the highest data rate for the strongest user in cluster m, given by $\tau = \log_2 \left(\frac{\rho U_m}{K} |\mathbf{h}_{m,1}^H \mathbf{w}_m|^2 / \sigma^2 \right)$. In Algorithm 1, τ serves as the upper bound to determine the value of η . Therefore, we adjust η iteratively to obtain a feasible solution. If the minimum value of the constraint in the optimization problem (4.14) is greater than 1, we decrease the value of η to find a feasible solution, and vice versa. The stopping criterion for the bisection search is to meet a predetermined accuracy requirement for η . Thus, we derive power coefficients for each user in cluster m using the proposed NOMA power allocation scheme [1], [9].

CHAPTER FIVE

RESULT AND DSICUSSION

In this chapter, we evaluate the performance of beam selection algorithms by analyzing the simulation results of the proposed system and comparing them with related work in the literature, aiming to fulfill the research objective. The simulations are conducted under the following assumptions. Users are uniformly distributed within a circular cell with a radius of 200 meters centered on the BS. An exclusion zone is considered to ensure that forward and reverse link transmissions occur in the far field of the transmitting antennas and are properly received at the receivers.

The simulation results presented in this chapter are obtained using the same values for the system parameters: N (number of transmit beams) = 256, number of users $K = 32$, transmit power $\rho = 32$ mW (15 dBm), and SNR = 0-20 dB, with each user having a single receive antenna. The spatial channel between the access point and user $k, k \in \{1, \dots, K\}$, is considered to be having one LoS components with path gain $\beta_k^{(0)} \sim_{CN} (0, 1)$ and two NLoS components with path gain $\beta_k^{(\ell)} \sim_{CN} (0, 1)$ and $\ell = 1, 2$. The path gains $\beta_k^{(\ell)}, \ell = 0, 1, 2$ are considered to be uncorrelated to each other. The spatial frequencies, $\vartheta_k^{(\ell)}$ of user k , are uniformly distributed in the interval $U \in [-0.5, 0.5]$.

5.1 Simulation Parameter Setup

Table 5. 1. Simulation input parameter

List	Input parameter	Value
1	Number of antenna Beam (N)	32-256, Accordingly variable
2	Number of user (K)	32
3	SNR	0-20 dB
4	Power of single RF chain	250 mW
5	Transmitted power of the system (ρ)	32 mW
6	Number of paths	3
7	Signal Wave length (λ)	1m
8	Distance between antenna (D)	$\lambda/2$
9	LOS considered path gain in one cell	1
10	NLOS considered path gain in one cell	2
11	Iteration	100

In this thesis, the performance of various methods was evaluated based on Spectrum Efficiency and Energy Efficiency. The proposed Maximum SINR based beam selection algorithm is compared with existing methods, including Maximum Magnitude Selection, Maximization of SINR Selection, and Maximization of Capacity Selection, in a beamspace MIMO-NOMA scheme. A fully digital MIMO system is used as a reference. MM-S selects beams based on the largest magnitude elements, while MSINR and MC Maximization of capacity algorithms explore all possible combinations of beams to maximize SINR or capacity, respectively. The evaluation considers both the strongest user-based equivalent channel and the SVD-based equivalent channel. A power allocation algorithm is proposed to mitigate interferences. Specifically, ZF precoding is applied in both fully digital MIMO and beamspace MIMO scenarios.

In the subsequent subsections, the performance of the proposed beamspace MIMO-NOMA scheme is analyzed in terms of spectrum efficiency and energy efficiency, providing insights into its effectiveness compared to existing methods.

5.2 Spectral Efficiency

As shown above figure 5.1 spectral efficiency against SNR of four beam selection algorithm's where number of user $K=32$. From the result observe and suggest MSINR beamspace MIMO-

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NOMA followed by power allocation-based beam selection scheme can achieve higher spectral efficiency than maximum magnitude as well as MC beam-space MIMO-NOMA beam selection. As there is no beam selection in full digital MIMO and number of RF equal to number of user RF chain are employed to connect all user. It is logically that can achieve the best spectral efficiency as illustrated figure in 5.1. However, Figure 5.4 demonstrates that fully digital MIMO exhibits the lowest energy efficiency.

Figure 5.2 shows a spectrum efficiency against number of users comparison, with SNR set to 10dB. The simulation findings show that when the number of users K increase greater, the performance difference between the MM beam-space MIMO-NOMA and the proposed beam-space MIMO-NOMA increase. This is because the more user there are, the more probable it is that the same beam will be chosen for each of them. as a result conventional beam-space MIMO will suffer a noticeable performance reduction, whereas suggest MSINR beam-space MIMO-NOMA based beam selection will continue to function well performed than others.

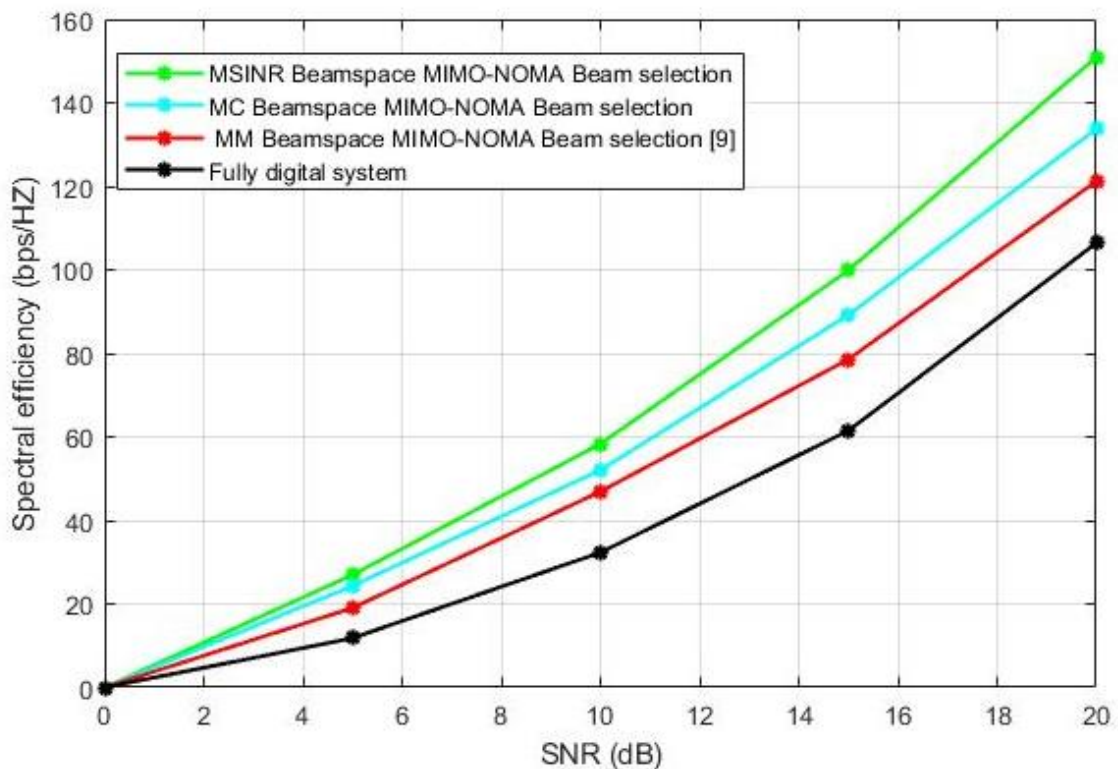


Figure 5.1 Spectral Efficiency Against SNR

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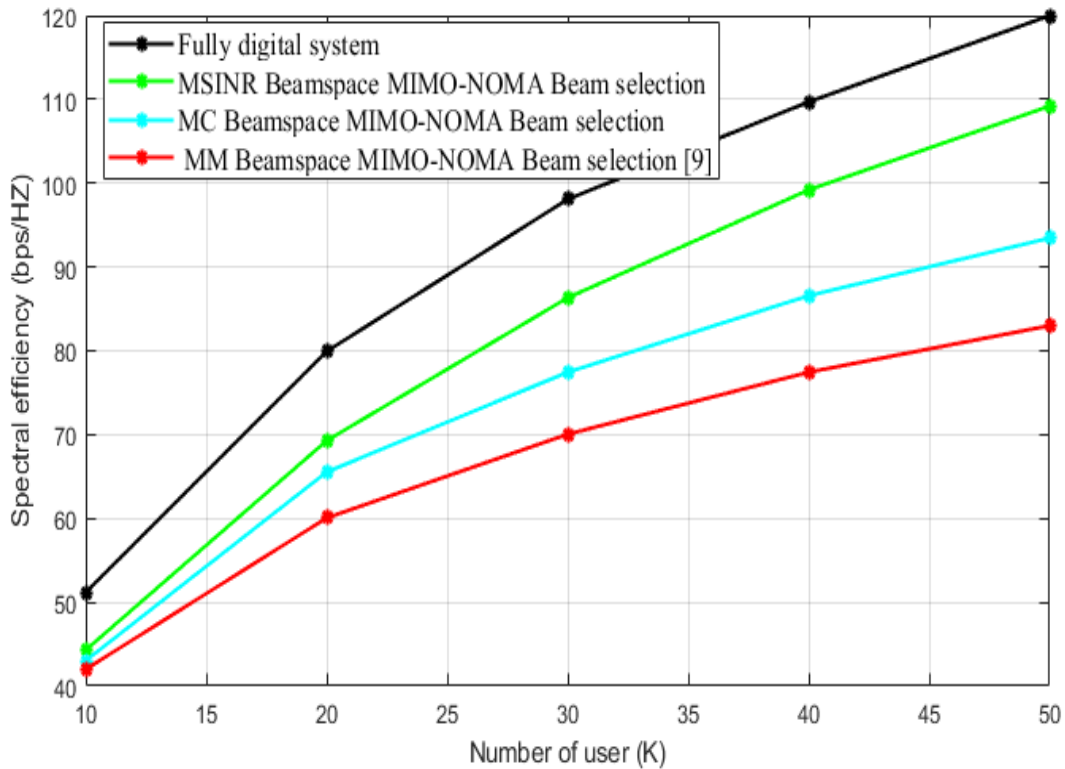


Figure 5.2 Spectral Efficiency against User K where, SNR=10

Figure 5.2 illustrates the achievable sum-rate of the proposed beam selection algorithm combined with NOMA principles and a power allocation scheme. The performance of this proposed method is compared with the MM beam selection approach, which selects beams based on large magnitude elements, and the MC beam selection method.

The results clearly demonstrate that the MSINR beam selection algorithm, coupled with the power allocation scheme, outperforms the other beam selection algorithms. Additionally, the sum-rate achieved by employing full-dimensional ZF precoding, where all N beams are active, is depicted as an upper bound on achievable performance.

Notably, when the number of beams is determined based on the upper bound approach using η , the capacities obtained by both algorithms closely approach the optimal performances. Specifically, the MSINR algorithm achieves performance very close to the full-system with minimal degradation.

5.3 Energy Efficiency

The energy efficiency is simulated against SNR in figure 5.3, with K=32 user. The proposed MSINR beamspace MIMO-NOMA based beam selection is found to be more energy efficient

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than the other their techniques. In Comparison to existing MM beamspace MIMO-NOMA, which serve many users in each beam other than techniques. Furthermore, the proposed MSINR beamspace MIMO-MOMA method has a substantially higher energy efficiency than the completely MM and MC beamspace MIMO-NOMA scheme, in which the number of RF chains is equal to the number of BS antennas, resulting in very high energy consumption, for example, 300 mW per RF chain. In the proposed MSINR beamspace MIMO-MOMA approach, however, the number of RF chains is substantially fewer than the number of antennas. As a result, RF chain energy consumption can be significantly lowered when compared to a completely full digital MIMO scheme.

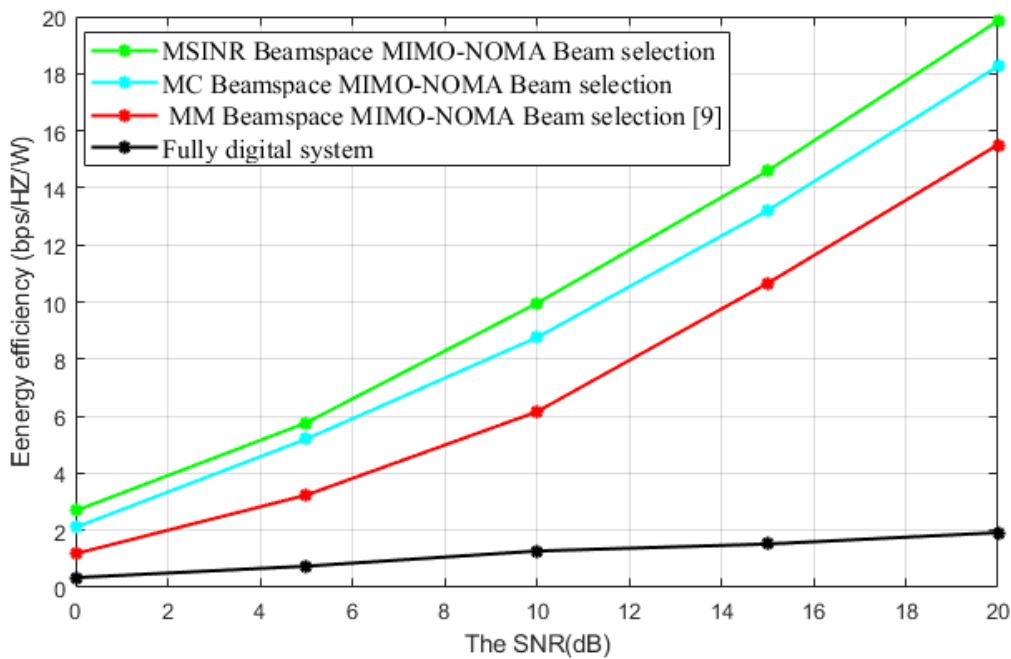


Figure 5.3 Energy Efficiency against SNR

Figure 5.4 shows the performance comparison in terms of energy efficiency vs the number of users, with SNR set to 10dB. Even if the number of users is very huge, the suggested beamspace MIMO-MOMA strategy has a higher energy efficiency than the other three schemes (e.g., 50 users are simultaneously served). Energy efficiency of a wireless system is commonly defined as the ratio of the achievable sum rate to the associated energy consumption of the system. This is expressed mathematically as below [9].

In downlink massive MIMO systems, the total power consumption consists of the sum of radiated power and circuit power consumption. Therefore, the energy efficiency can be expressed as the ratio of the total amount of data that can be reliably transmitted per unit of time to the total amount of consumed power.

$$\rho_{tot} = P_{tx} + P_{CP} \tag{5.1}$$

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Where P_{tx} the power is consumed by the power amplifier and P_{CP} represents the circuit power consumption of the system. Depend on this we can write the power consumption equation as follows. The energy efficiency ε is defined as the ratio between the achievable sum rate R_{sum} and the total power consumption [15], i.e.

$$\varepsilon = \frac{R_{sum}}{\rho + N_{RF}P_{RF} + N_{RF}P_{SW} + P_{BB}} \text{ (bps/Hz/W)} \quad 5.2$$

Where ρ the maximum is transmitted power, P_{RF} is the power consumed by each RF chain, P_{SW} is the power consumption of switch, and P_{BB} is the baseband power consumption. Particularly, we adopt the typical values $P_{RF} = 300$ mW, $P_{SW} = 5$ mW, and $P_{BB} = 200$ mW [4]. It is evident from Figures 5.3 and 5.4 that the proposed "MSINR beam selection algorithm accompanied by NOMA principle followed with a power allocation scheme" achieves significantly higher energy efficiency compared to other existing beam selection algorithms. Notably, the full-dimensional ZF approach exhibits high power consumption as it activates all N beams.

The relevance of interference among users, which is optimized by MSINR, becomes more pronounced as the scenario becomes more populated. As observed when applying the algorithms with a high value of η , the Maximization of Capacity (MC) technique starts outperforming MM-based beam selections after the number of user's increases to approximately $K \approx 50$. This trend is attributed to the high spectral efficiency achieved by the MC technique. It is noteworthy how the values of power efficiency obtained by the MM-S criterion rapidly decrease with the number of users in the scenario. This decrease is due to the lower capacities obtained with such an approach as the effects of scattering and multipath increase.

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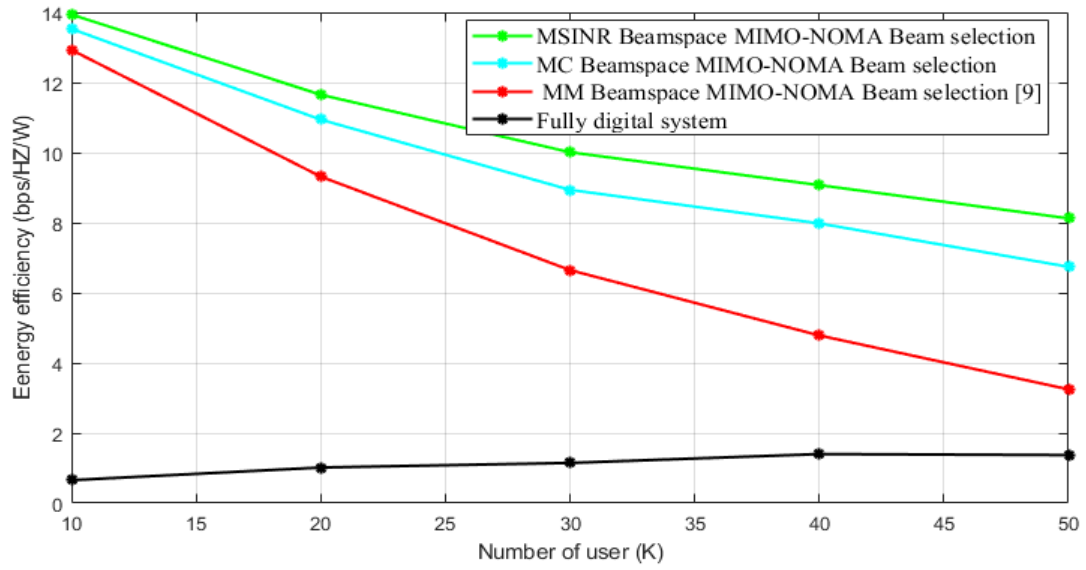


Figure 5. 4. Energy efficiency against the number of users K, where SNR = 10 dB

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusion

To enhance user performance in terms of spectral and energy efficiencies, beamSpace MIMONOMA beam selection techniques has been introduced. This thesis considered single cell downlink communication system. Parts of beam space MIMO-NOMA system were elaborated, which consist of beam selection, clustering, power allocation and precoding. In addition, the beam selection techniques for beamSpace MIMO-NOMA communication system schemes such as MM beamSpace MIMO-NOMA based beam selection beamSpace MIMO-NOMA based beam selection and MSINR beamSpace MIMO-NOMA based beam selections were compared and the performance of a techniques with respect to SE and EE were evaluated. On the basis of those analysis the researcher forwarded the following conclusions:

- Several studies choose MM techniques for beamSpace MIMO-NOMA schemes while, it is straightforward. This study, however, considers MSINR and MC beam selection analysis and mathematical models, which are more advanced techniques by EE and SE than MM beamSpace MIMO-NOMA.
- This MSINR MIMO-NOMA new transmission scheme is designed in order to achieve a better trade-off between spectrum efficiency and energy efficiency. Particularly, user clustering, beam selection, precoding design and power allocation, factors are carefully designed. Specifically, a user select same beam is user clustered in one group served by NOMA. The concept of NOMA is adopted inside each cluster. Then designed based on the principle of a ZF by selecting users with the strongest equivalent channel gain in each beam in order to restrain the inter-beam interferences. Furthermore, to suppress both inter-beam and intra-beam interferences, the joint optimization of power allocation is proposed to maximize the ASR, and optimization algorithm is developed.
- The simulation results confirm the superiority of the proposed beam selection technique over MC and MM methods, as it exhibits better performance in terms of both power consumption and the ability to serve more users. This observation aligns

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with the theoretical analysis, further validating the effectiveness of the beam selection approach.

- As a conclusion and as simulation results shown that the proposed MSINR beamspace MIMO-NOMA systems can be approached to the spectral performance of the enabled fully digital-based scheme and maintained relatively better spectral performance compared to MC-Beamspace MIMO-NOMA proposed in and “MM-Beamspace MIMO-NOMA [9]” schemes with very low power consumption. This result demonstrated the effectiveness of the proposed system.

6.2 Recommendation and future work

The Beamspace MIMO based beam selection schemes studied in this thesis are focused on a single-cell wireless network. However, future works could extend these schemes to systems with more than two cells, thereby enhancing spectrum utilization efficiency. Additionally, it is recommended that future research endeavors incorporate the evaluation of energy efficiency in the uplink system.

- **Both uplink and downlink beamspace MIMO-NOMA Systems:** Investigate energy-efficient designs and strategies for both uplink and downlink beamspace MIMO-NOMA systems. Develop techniques to optimize power allocation, transmit beamforming, and resource utilization to minimize power consumption and promote green communications.
- **The study of multi-cell optimization of beamspace MIMO-NOMA system:** this thesis focused on downlink and single cell communication system, while future work may consider multi-cell environment as another interesting area to be investigated. Moreover, considering multi-antenna users can also take as a future research interest.
- **Integrating Artificial Intelligence into Beamspace MIMO Systems:** One promising avenue for future research is the exploration of Machine Learning-Based Beam Selection in massive MIMO systems. Machine learning algorithms have demonstrated remarkable capabilities in various domains, and their application to intelligent beam selection and optimization holds significant potential for enhancing the performance of massive MIMO systems. By leveraging machine learning techniques, such as neural networks, reinforcement learning, and deep learning, researchers can develop intelligent algorithms that adaptively select and optimize beam configurations based on dynamic network conditions and user requirements.

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