Performance Evaluation of Beamspace(BS) Multiple Input Multiple Output(MIMO) NOMA System to Enhance Spectral Efficiency of 5G Wireless Networks

Yidnekachew Solomon Haile

A Thesis Submitted to

The Department of Computer Science and Engineering

School of Electrical Engineering and Computing

Presented in Partial Fulfillment of the Requirement for the Degree of

Master's in Computer Science and Engineering (Network)

Office of Graduate Studies

Adama Science and Technology University

June, 2023

Adama, Ethiopia

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APPROVAL PAGE FOR M.Sc THESIS

We, the advisors of the thesis entitled ”Performance Evaluation of Beamspace (BS) Multiple Input Multiple Output(MIMO) NOMA System to Enhance Spectral Efficiency of 5G Wireless Networks” and developed by Yidnekachew Solomon Haile, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

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Major Advisor Signature Date

We, the undersigned, members of the Board of Examiners of the thesis by Yidnekachew Solomon Haile have read and evaluated the thesis entitled ”Performance Evaluation of Beamspace(BS) Multiple Input Multiple Output(MIMO) NOMA System to Enhance Spectral Efficiency of 5G Wireless Networks” and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of **Master’s in Computer Science and Engineering (Network)**.

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Chairperson Signature Date

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External Examiner Signature Date

Finally, approval and acceptance of the thesis is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

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Department Head Signature Date

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School Dean Signature Date

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Office of Post graduate studies, Dean Signature Date

DECLARATION

I hereby declare that this Master Thesis entitled ”Performance Evaluation of Beamspace(BS) Multiple Input Multiple Output(MIMO) NOMA System to Enhance Spectral Efficiency of 5G Wireless Networks” is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

________________________________ _____________ _____________

Name of student Signature Date

RECOMMENDATION OF ADVISORS

We, the advisors of this thesis, hereby certify that we have read the revised version of the thesis entitled "Performance Evaluation of Beamspace(BS) Multiple Input Multiple Output(MIMO) NOMA System to Enhance Spectral Efficiency of 5G Wireless Networks" prepared under my/our guidance by **Yidnekachew Solomon Haile** submitted in partial fulfillment of the requirements for the degree of **Master's in Computer Science and Engineering (Network)** .

Therefore, we recommend the submission of revised version of the thesis to the department following the applicable procedures.

________________________________	_____________	_____________
Major Advisor	Signature	Date

ACKNOWLEDGEMENT

I also would like to give my sincere gratitude to my advisor , Dr. Ketema Adere [PhD], for his patient guidance, useful advice and encouragement during my study. I have been tremendously lucky to be advised by him, because of his caring about my research progress, useful conversations, enthusiastic support, unyielding belief and his timely and comprehensive respond to my correspondence and questions. Accomplishing my research in time would be have been substantially more challenging without his support and understanding. I also very much appreciate that he gave me the opportunity to decide upon the subject matter of the research for this thesis on my own.

Also, I value and most grateful for the support I have received from all my family members. Their inspiration and love have motivated me greatly in the pursuit of successful research outcomes, who have provided unending inspiration during the years of this study.

Finally, I'd want to express my gratitude to my colleagues, friends, and and all of those I have had the pleasure to work with, for they have given me continuous encouragement towards completing this thesis.

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List of Acronyms

1G:	First generation
2G:	Second generation
3G:	Third generation
3GPP:	Third Generation Partnership Project
4G:	Fourth generation
5G:	Fifth generation
BS:	Beamspace
CDMA:	Code Division Multiple Access
D2D:	Device-to-Device
EE:	Energy Efficiency
IMT:	International Mobile Telecommunications
IoT:	Internet-of-Things
LTE:	Long Term Evolution
M2M:	Machine-to-Machine
MIMO:	Multiple-Input Multiple-Output
MISO:	Multiple-Input Single-Output
mm-Wave :	Millimeter Wave
MUSA:	Multi-User Shared Access
NOMA:	Non-Orthogonal Multiple Access
OFDM:	Orthogonal Frequency Division Multiple
OFDMA:	Orthogonal Frequency Division Multiple Access
OMA:	Orthogonal Multiple Access
QoS:	Quality of Service RB- resource block
SE:	Spectral Efficiency
SNR:	Signal-to-Noise Ratio
SVD:	Singular Value Decomposition
TDMA:	Time Division Multiple Access
UHD:	Ultra-High Definition
ZF:	Zero Forcing

ABSTRACT

Future requirements for wireless and cellular communication in the present and the following ten years call for the support of a wide range of services, including system average throughput, the explosion of mobile traffic, live HD streaming, improved location-based services (LBS), M2M communication, cloud computing, etc. These provide numerous difficulties in terms of spectrum efficiency, data flow, capacity, and coverage. As a result, there will be a significant amount of traffic demand in the down-link direction, and future generations of wireless networks are expected to ensure excellent quality of service (QoS) and offer ubiquitous services for multiple users. The millimeter wave (mmWave) communications introduced to achieve the rapidly growing network capacity requirements for next-generation wireless systems. In millimeter-wave (mmWave) large MIMO systems, the recently developed beamspace multiple input multiple output (BS-MIMO) idea can greatly reduce the number of radio-frequency (RF) chains necessary without obviously compromising performance. However, The main limitation of existing BS MIMO is that the number of supported users cannot be more than the number of RF chains using the same time-frequency resources. In this thesis, we provide a novel, spectrum-efficient mmWave transmission method that combines BS-MIMO and the idea of non-orthogonal multiple access (NOMA) in order to overcome this basic restriction. By employing NOMA, BS-MIMO systems may accommodate more users than the number of RF chains using the same time-frequency resources. An obvious performance boost over the existing BS-MIMO is shown when the suggested BS-MIMO NOMA is compared to its potential achievable sum rate in a typical mmWave channel model. Following that, a precoding strategy based on the zero-forcing (ZF) concept is created to minimize inter-beam interferences in the BS-MIMO-NOMA system. Finally, an iterative optimization algorithm with low complexity is developed to realize the dynamic power allocation.The simulation's results show that compared to the already in use BS-MIMO OMA, the proposed BS-MIMO-NOMA may achieve a higher spectrum efficiency.

Key Words: – BS-MIMO NOMA, 5G, mm-Wave Multiple Users, NOMA.

CHAPTER ONE
INTRODUCTION

1.1 Introduction

The most dynamic and quickly developing technological field in the communication industry is wireless communication technology. Wireless communication is a method of transmitting data from one area to another without the use of physical connections like wires, cables, or other means. In a communication system, information is typically sent across a short distance from a transmitter to a receiver. Both wired and wireless communication systems are possible, as well as communication medium can be guided and unguided. Technology of the fifth generation (5G) will offer fast and secure connectivity. With 5G technology, data speeds over 4G networks are expected to grow 100-fold. The current 4G LTE networks are outperformed by the wireless networks of the fifth generation. It was built especially to satisfy the needs of modern technological advancements, which include a considerable growth in data, practically universal connectivity, and increased interest in the Internet of Things. Later generations will use 5G Technology as a fully autonomous entity after initially coexisting with the current 4G Technology, Figure 1.1 (Rao & Prasad, 2018).

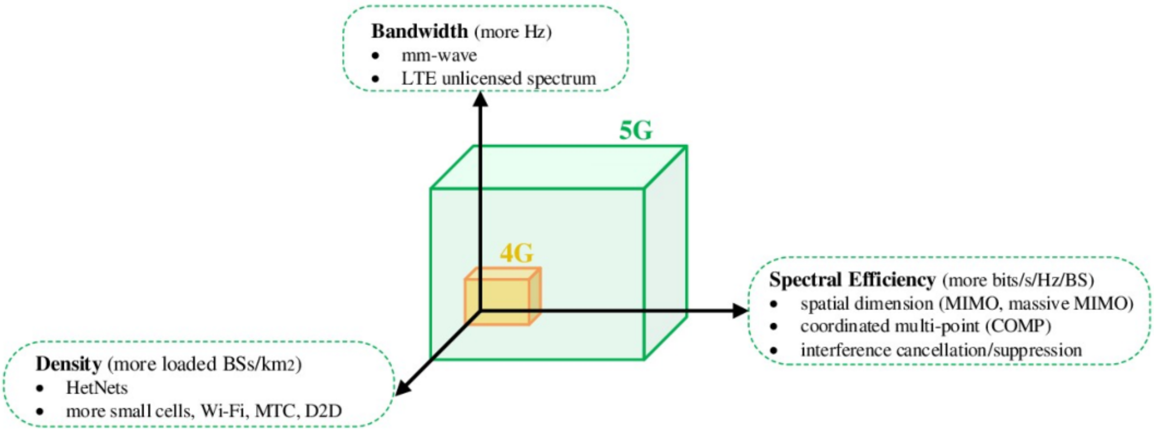


Figure 1.1: Key drivers for Wireless evolution

The technology of the fifth generation goes beyond mobile internet to an immense Internet of Things (IOT). The main distinction between 5G and 4G technology is that the latter is 100 times less agile. Less power is consumed and there is a 1 millisecond latency on the 5G network. Simply put, the massive IOT objects are revolutionized by 5G technology, which goes beyond mobile phones. Technology in 5G are: New radio frequencies, Frequency range 1 (< 6 GHz), Frequency range 2 (> 24 GHz), FR2 coverage, Massive MIMO, Edge computing, Small cell, Beamforming, Wifi-cellular convergence, NOMA (non-orthogonal multiple access), SDN/NFV and Channel coding.

An upcoming radio access technology called NOMA is intended to help 5G networks reach high data rates and capacities. Researchers are interested in finding alternatives to the current OMA due to the users' constant need for capacity. Under unfavorable channel conditions, the OMA technique's bandwidth resource allocation delivered a low spectral efficiency. In contrast, the NOMA method often allots bandwidth to users independent of the state of the channel. This is a substantial increase in spectral efficiency over OMA. High capacity and improved spectral efficiency are also possible with NOMA.

1.2 Research Motivation

Current wireless communication technologies are insufficient to meet the requirements of future wireless networks. Ericsson predicts that by 2027, the average monthly smartphone data consumption will be 41GB, driven by data-hungry applications and the exchange of massive amounts of data between wireless connected machines (Ericsson, 2020). 5G, in conjunction with other technologies like cloud computing, the internet of things, artificial intelligence, and machine learning, will open up new innovation opportunities in various market segments. To handle this tremendous growth in data traffic, future wireless networks must have 1,000 times more capacity than the present generation, and new technologies such as massive MIMO, mm-Wave communications, D2D communications, and NOMA have been proposed (Jijo et al., 2021). Thus, the development of new cutting-edge wireless network technologies is essential to meeting the high demands of the future.

1.3 Problem Statement

Spectrum scarcity is one of the most pressing issues facing wireless communication networks due to the exponential growth of multimedia applications. Future wireless networks pose a number of new challenges, such as the rapid increase in connected devices with diverse service requirements, the diversity of applications, the volume of traffic demands, and the consistent quality of user experience everywhere and anytime. As the number of devices connected to wireless networks grows, spectrum resources will become increasingly scarce, which will be critical. The fundamental restriction on existing systems is that the total number of supported users cannot exceed the total number of RF chains operating at the same time-frequency resources. This is due to the limitations of orthogonal resource allocation and the number of simultaneously transmitting users. To address these challenges, it is necessary to develop advanced technologies that can support a large number of user connections and efficiently utilize the available spectrum.

1.4 Research Questions

- What is the analysis of BS-MIMO NOMA to achieve better spectral efficiency than other scheme?
- What is the performance of mm-Wave transmission scheme that integrates Beamspace(BS)-MIMO with non-orthogonal multiple access (NOMA)?
- What is the comparison between spectral efficiency performance of proposed BS-MIMO NOMA and BS-MIMO OMA?

1.5 General and Specific Objectives

1.5.1 General Objective

The general objective of this thesis is to evaluate the performance of BS-MIMO NOMA system to enhance spectral efficiency of 5G wireless networks.

1.5.2 Specific Objective

The specific objectives of this study are as follows:

1 To analyze BS-MIMO NOMA outperform other previously used technique in terms of Energy Efficiency and Spectral Efficiency.

2 To evaluate the performance of the proposed BS-MIMO NOMA in mm-Wave communications.

3 To comparing the performance of the proposed method with the existing approach.

1.6 Significance of Study

The simplicity and compatibility of these methods enable integration into various existing and future wireless communication systems. The key contributions of the proposed technique are:

- Efficient utilization of a single transmitter to transmit multi-user signals on the same time/frequency resource. This is in comparison to spatial multiplexing schemes where each stream requires separate RF chains.
- Interference elimination by multi-user signal superposition. The users see the received signal as a single composite signal without interference from other users' signals. Consequently, increased capacity without significant loss in error performance is achieved.
- Improved signal reliability from spatial diversity without incurring the substantial increase in both complexity and overheads.
- Significant reduction in the cost of Radio Frequency (RF) chains associated with transmit antennas, while still achieving spatial multiplexing and diversity gains.
- Reduction in signaling overheads, maximize system capacity without employing channel preceding.

1.7 Thesis Contribution

The significant contributions in this thesis include:

- In order to reduce inter-beam interferences in the proposed BS-MIMO NOMA system, the equivalent channel vector for each beam is computed in order to implement precoding based on the zero-forcing principle (ZF).
- Iterative optimization algorithm with low complexity is used to realize the dynamic power allocation.

1.8 Thesis Outline

The thesis consists of five chapters.

- Chapter 1 discussions focus on the thesis's objectives, problem statement, and research introduction. Research questions are presented.
- Chapter 2 explains the ongoing research in the topic of NOMA-MIMO and its many current implementations. Offers insights into the fundamental ideas involved in the study as well as the circumstances and problems with the multiple access approach now in use.

- Chapter 3 research method for the research is discussed. explains the system model used to support the thesis and how different strategies were employed for the system. On the basis of current implementation, fundamental expressions are developed, and any necessary alterations are made in accordance with our thesis requirements. and gives the insight into the evaluation of the parameters and the analytical results are presented in a detailed manner.

- Chapter 4 the numerical and simulation results are used to evaluate and discuss the system's performance for various parameters. Here, the majority of the research questions are discussed.

- Chapter 5 provides major outcomes based on results and draws a conclusion for the full investigation. Future research is also discussed in order to create new advancements to the study, and it is assumed that the reader is fully aware of the research.

CHAPTER TWO
LITERATURE REVIEW

2.1 Background of the Study

Mobile internet services have become an essential part of modern life, with the majority of human activities relying on them (Navarro-Ortiz, Romero-Diaz, & Sendra, 2020). These activities include socializing, business-related activities, video streaming, and other services essential to daily living. The rapid emergence of new technologies, such as Machine-to-Machine (M2M) systems, ultra high definition (UHD) 4K videos, real-time interactive services, and cloud computing, has transformed the way we use mobile devices. This shift has significant implications for the design and development of mobile devices, as well as the infrastructure required to support them. Therefore, understanding the impact of these changes on mobile communication networks is critical to ensure their continued evolution to meet the needs of modern society.

To meet these demands, a number of requirements need to be satisfied.

- First, the number of users that can be accommodated within a cell needs to be significantly increased without necessarily increasing the number of Base Stations.
- Secondly, future generation data and multimedia traffic require a high data rate in order of hundreds of Mb/s for high mobility users and up to Gb/s for low mobility or fixed users with the end-to-end lateness not exceeding 5 ms.
- Thirdly, the expected increase in data traffic should not have a significant cost on battery life.
- Finally, the cost of delivering high quality services and high data rate should be kept affordable.

Therefore, fulfilling these requirements requires maximizing bandwidth efficiency, exploiting all available degrees of freedom (time, frequency, power and space), minimizing power consumption and utilization of fading and interference which would lead to improved performance and capacity (Larsson, Edfors, Tufvesson, & Marzetta, 2014).

Wireless communication is rapidly expanding due to the continuous improvement of living conditions, and it is expected that people will be surrounded by smart items in smart homes, streets, offices, and cities, leading to the creation of a smart world (Navarro-Ortiz et al., 2020). The development of the smart world will result in a significant increase in the number of active connections, data traffic demand, and supported service variety, necessitating a sizable exchange of information between users and base stations. As a result, future generations of mobile networks are required to ensure high quality of service (QoS) and provide ubiquitous services for numerous users, given the huge traffic demand in the down-link direction (Chettri & Bera, 2019).

However, current wireless communication technologies struggle to address these issues due to the limited radio resources represented by the wireless spectrum and transmission power, with orthogonal multiple access (OMA) serving as the backbone air interface. This restricts them by the number of concurrent users transmitting and the orthogonal resource allocation. To satisfy these challenges, advanced technologies such as massive multiple input multiple output (MIMO), millimeter wave (mm-Wave) communications, device-to-device (D2D) communications, and Non-orthogonal multiple access (NOMA) must be designed and developed to enable dense user connections and make effective use of the available spectrum (Navarro-Ortiz et al., 2020). These technologies fulfill the high demands of data rates and massive connection, leading to the continued evolution of wireless communication technology to meet the needs of modern society.

2.2 Wireless Communication Technology

Wireless communication technology has revolutionized the way we communicate, with services accessible almost everywhere on Earth through cellular wide area networks, local area networks, and satellite services (Björnson, Hoydis, & Sanguinetti, 2017). This wireless connectivity has become as essential as electricity and has spurred new applications and services such as streaming media and machine-to-machine communications. Looking into the future, new innovative wireless services will emerge that cannot be predicted today. The amount of wireless voice and data communications has grown at an exponential pace for many decades, with a 32% annual growth rate, known as Cooper's law. The Ericsson Mobility Report predicts an even faster compound annual growth rate of 42% in mobile data traffic from 2016 to 2022 (Björnson et al., 2017). Therefore, understanding the evolution of wireless communication technology is crucial to meeting the needs of modern society.

2.3 Wireless Networks Evolution

Cellular wireless networks have advanced significantly since the release of the first 1G system in 1981, with a new mobile generation emerging every 10 years (Attaran & Attaran, 2020). The development of 4 or 5 technological generations, including 1G, 2G, 3G, and 4G networking technologies, has revolutionized society. 1G enabled mass-market mobile telephony, 2G brought global interoperability and reliable mobile telephony with SMS text messaging, 3G provided high-speed data transfer capability for downloading information from the Internet, and 4G significantly improved data capability and speed, making online platforms and high-speed mobile internet services available to the masses. 5G technology will be the most powerful cellular wireless network, with extraordinary data capabilities, unrestricted call volumes, and infinite data broadcast, ushering in a new era of wireless communication. The evolution of cellular wireless networks discussed in figure 2.1 and table 2.1.

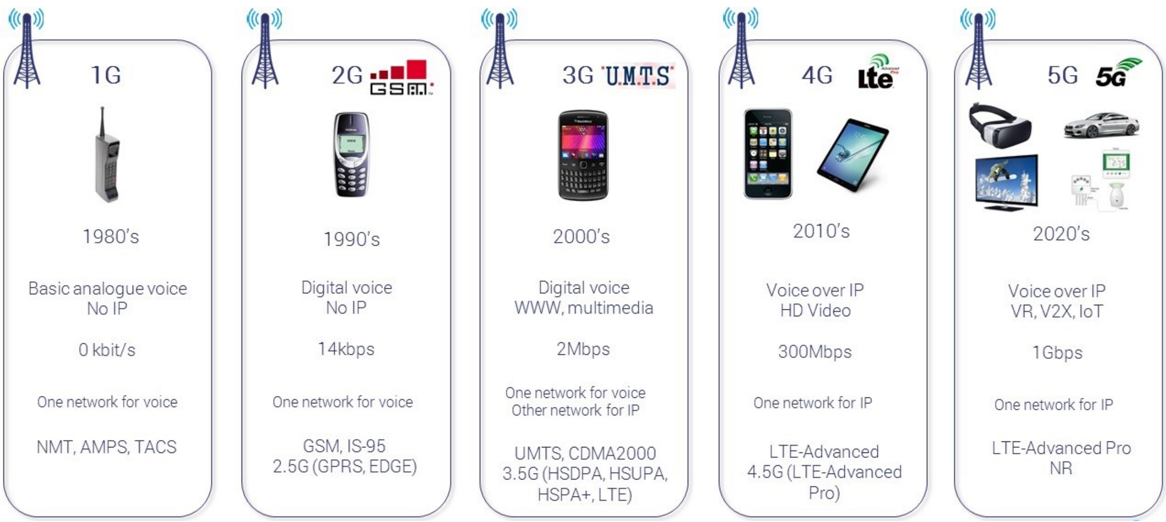


Figure 2.1: Wireless technology evolution

Multiple access techniques, such as FDMA, TDMA, and CDMA, have been used in the history of telecommunications, with most of them based on one of these methods. Hybrid approaches and modifications also exist, such as hybrid TDMA and FDMA systems, and OFDM. However, the introduction of a new air interface technique has led to significant breakthroughs in communications, as demonstrated by the revolution brought about by the GSM and its TDMA air interface technology. Currently, SC-FDMA and OFDMA are becoming the most reliable and best access techniques in use today. The evolution of multiple access techniques discussed in table 2.1.

Table 2.1: Evolution of Cellular Network: From 1G to 5G

	1G	2G	3G	4G	5G
Period	1980 - 1990	1990 - 2000	2000 - 2010	2010 - 2020	2020 - 2030
Frequency	Analog signal (30 KHz)	1.8GHz (digital)	1.6 - 2.0 GHz	2 - 8 GHz	3 - 300 GHz
Data rate	2kbps	64kbps	144kbps - 2Mbps	100Mbps – 1Gbps	1Gbps ¡
Modulation Technique		GMSK	QPSK, 16QAM	QPSK, 16 QAM and 64 QAM	256 QAM
Multiplexing	FDMA	TDMA	W-CDMA	OFDMA and MIMO	OFDM, NOMA, FBMC and Massive MIMO
Standards		GSM, EDGE, GPRS	UMTS, CDMA2000, HSPDA,EVDO	LTE advanced,IEEE 802.16 (WiMAX)	CDMA,BDMA
Switching		circuit/packet	Packet	all packet	all packet
Technology	Analog cellular	Digital cellular (GSM)	CDMA, UMTS, EDGE, WCDMA, Bluetooth	802.16e WiMax, LTE, 3GPP,MIMO, OFDM, 802.20	
Features	Voice only	Data connectivity,Voice Streaming with mobile web browsing support.	Universal access to different mobile devices made possible along with Multimedia streaming services.	High Definition streaming supported. Portability increased further.	Dynamic Information access, Wearable devices with AI Capabilities

2.4 Key Capabilities of 5G

The following should be enabled by 5G (Chin, Fan, & Haines, 2014):

I User experienced data-rate: 0.1-1Gbps.

II Connection density: 1 $million\ connections/Km^2$.

III End-to-end latency: milli-second level.

IV Traffic volume density: 10 $Gbps/Km^2$.

V Mobility: higher than 500 Km per hour.

VI Peak data-rate: tens of Gbps.

The three most important of these criteria are user perceived data rate, connection density, and end-to-end latency. Meanwhile,The deployment and operation of networks must be done much more efficiently with 5G. Compared with 4G, 5G should have 3 to 5 times' improvement on spectrum efficiency and more than 100 times' improvement on energy and cost efficiency.

2.5 Candidate Technologies and Spectrum

There are several developing technologies that have been suggested by numerous organizations and businesses to fulfill the aforementioned 5G requirements, include: (Chin et al., 2014):

i Novel multiple access, such as Nonorthogonal multiple access (NOMA), SCMA (Sparse Code Multiple Access), MUSA (Multiuser Shared Access), PDMA (Pattern Division Multiple Access), and RSMA (Resource Spread Multiple Access) (this kind of technologies can increase the spectrum efficiency, user experienced data rate, system capacity, and connection density).

ii New waveforms, like filtered-OFDM, UFMC (Universal Filtered Multicarrier), window-OFDM, and so forth, to maximize the spectrum utilization.

iii Massive MIMO technologies to increase the spectrum efficiency, user experienced data rate, and system capacity.

iv New channel coding such as polar code and LDPC(Low Density Parity Check Code), to increase the spectrum efficiency.

v Software defined air interface and end-to-end network slicing to increase the system flexibility to support all kinds of services and to enhance the overall network cost efficiency.

Three options exist to meet the growing spectrum needs of 5G services. The most urgent issue is to identify new spectrum for IMT, both below and above 6 GHz. The primary spectrum bands for IMT are those below 6 GHz, with C band expected to play a significant role in the near future. Refarming spectrum utilized by old systems is the second. The third is to encourage the use of new technologies that will allow radio services to share spectrum.

2.6 Diving into 5G spectrum

5G spectrum bands with various capacities are available. (Jiang & Liu, 2017)::

- Low-band 5G spectrum is made up of a combination of previously underutilized bands and re-farmed spectrum from the first two mobile generations. This type of spectrum is suitable for building out a foundation for 5G coverage.

- Mid-band spectrum spans the 1-6GHz channels and includes both newly licensed spectrum for mobile services and the 3G/4G bands that are currently in use. Wider bands are used to boost capacity, and new radio technology offer more 5G coverage and capacity per band.

- High-band spectrum is brand-new for 5G and permits the introduction of high-performance services in designated zones. Although this spectrum band's 5G coverage is smaller than that of low- and mid-band spectrum, it covers wider areas than Wi-Fi hotspots.

Low- and mid-band services may be provided by already-built macro towers, and inside areas can be served by outdoor radios. In order to cover outdoor spaces for high-band service delivery, radios on towers and small cell poles are used, whilst for inside coverage, indoor small cell solutions are used. All three bands will smoothly get 5G services as they become more widely accessible over time.

2.7 Multiple Access Techniques

Numerous access is the provision of communication services between multiple transmitters and receivers simultaneously over a single channel in a wireless communication system employing channelization techniques based on time, frequency, or code. One of the fundamental features of wireless cellular networks is multiple access (MA). In general, there are three types of MA techniques:

- Orthogonal and

- Non-orthogonal approaches.

Orthogonal approaches include Time-Division Multiple Access (TDMA), Frequency-Division Multiple Access (FDMA), and orthogonal-Frequency-Division Multiple Access(OFDMA) to ensure that signals from many users are orthogonal to one another and have zero cross correlation (Vaezi et al., 2019).

Non-orthogonal methods, such as random waveform code-division multiple access (CDMA), trellis-coded multiple access (TCMA), and interleave-division multiple access(IDMA), provide non-zero cross correlation among the signals from various users. (Vaezi et al., 2019).

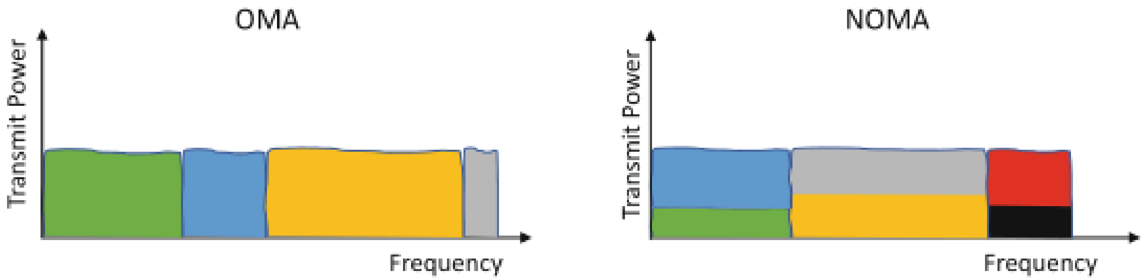


Figure 2.2: OMA and NOMA power and spectral allocations

2.7.1 Orthogonal Multiple Access(OMA)

The Orthogonal Multiple Access (OMA) approach splits the system's available resources (such as electricity or bandwidth) evenly before allocating them to the users via the channels. In this scheme, using different basis functions, the receiver separates un-wanted signals to obtain the desired signal(S. R. Islam, Avazov, Dobre, & Kwak, 2016). The channel can be divided using a variety of techniques, including frequency division, time division, and coding division. Performance of different division technique are different and will depend on the traffic characteristics of the system.

OMA has a number of appealing advantages, such as the use of higher order modulation methods to boost single user rate, the assignment of orthogonal signal sub-spaces to various users to prevent intra-cell interference, and its insensitivity to the near-far effect. In packet domain services, the OMA can achieve high system throughput with a straightforward receiver architecture. The spectral power efficiency, vulnerability to cross-cell interference, and frame synchronization necessary to preserve orthogonality are all weaknesses of OMA. In every wireless network, whether old and new, OMA is used. Orthogonal Frequency-Division Multiple Access (OFDMA), Code-Division Multiple Access (CDMA), and Time-Division Multiple Access (TDMA) are all utilized in 2G, 3G, and 4G, respectively. (Cai, Qin, Cui, Li, & McCann, 2017).

Table 2.2: Multiple access in different generations of cellular networks(Vaezi et al., 2019).

Cellular generation	MA technique	Duplex method	Physical resources	Notable examples
1G	FDMA	FDD	Frequency	AMPS, NMT
2G	TDMA	TDMA	Time slots	GSM, IS-54
3G	CDMA	FDD/TDD	Time slots/PN Codes	WCDMA
4G	OFDMA	FDD/TDD	Time/Frequency	LTE, LTE-A
5G	OFDMA	FDD/TDD	Time/Frequency	5G-NR

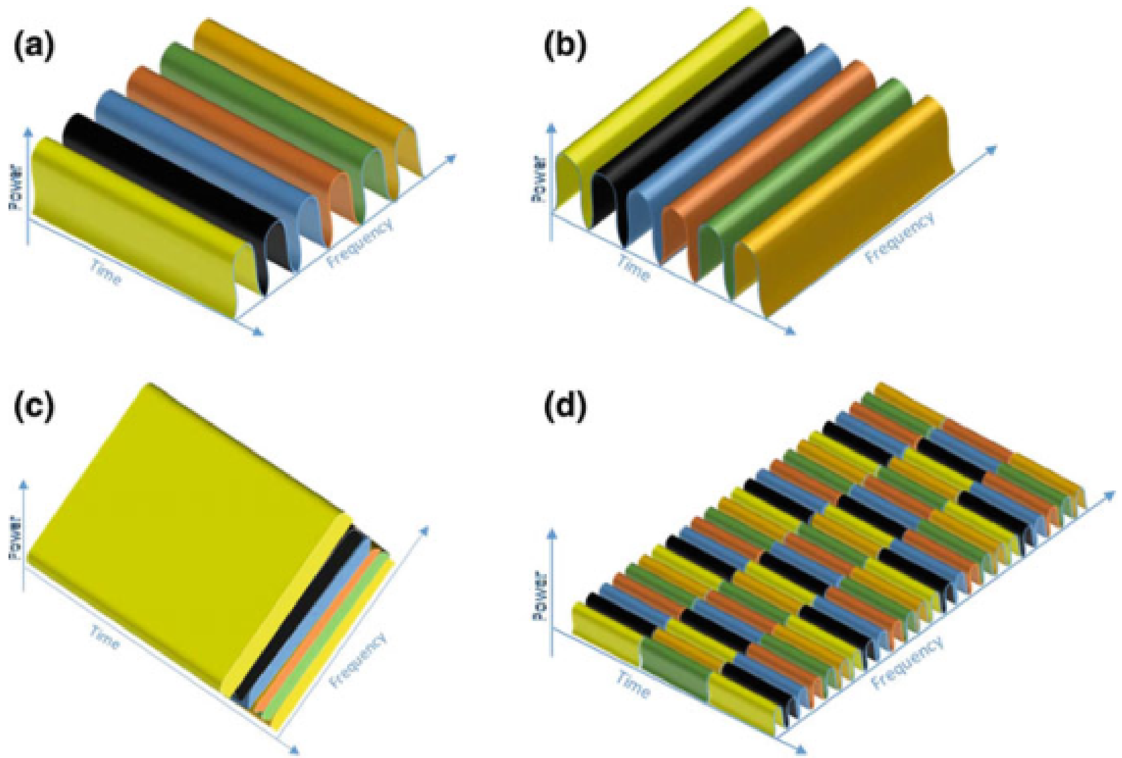


Figure 2.3: Overview of various multiple access techniques: a FDMA, b TDMA, c CDMA, d OFDMA-4G

2.7.1.1 Frequency-Division Multiple Access (FDMA)

The most traditional MAC method used in mobile communications systems is Frequency-Division Multiple Access (FDMA). In order to serve M concurrent users, the available system bandwidth W is divided into M equal narrow band frequency channels, with each user receiving an exclusive channel. In order to reduce inter-channel interference brought on by power amplifiers running close to saturation's non-linear effects, which widen the signal's bandwidth and produce inter-modulation frequencies, there must be a frequency gap between the user channels.(Miao, Zander, Sung, & Slimane, 2016).

2.7.1.2 Time-Division Multiple Access (TDMA)

The widely utilized multiple access technique of Time-Division Multiple Access (TDMA) has been implemented in several wired and wireless digital transmission systems. For shared medium networks, it is a channel access technique (CAM). By splitting up the signals into distinct time slots, several users can share the same frequency channel. Time periods for data transmission and reception are frequently repeated, and these time slots are used to allocate users. Since there is a guard period between each user's data bursts to prevent overlapping, the transmission is not continuous. The hand-off is made easier since it can be done during idle time and it also results in minimal battery usage because the user's transmitter may be switched off when not in use. Due to the various time delays, it is necessary to synchronize the time slots in order to ensure orthogonality. This is done by utilizing a reference station from which all other stations get information on the position and timing of the burst(Icev, 2011).

2.7.1.3 Code-Division Multiple Access (CDMA)

With its flexibility in increasing user capacity at the price of a marginal error performance, Code-Division Multiple Access (CDMA), one of the most cutting-edge approaches to satisfy the enormous demand for wireless communication, may accomplish high capacity data traffic. However, there is a limit to how many users multiple access mechanisms like TDMA and FDMA can support (Rappaport & Annamalai, 2002). It is a multiplexing technique that allows users to access a channel concurrently and asynchronously by modulating and dispersing their data-bearing signals using previously allocated signature sequences.
The system can support more users since this method employs longer spreading codes than DS-CDMA. Since all user signals from other cells might be regarded as noise, CDMA technology is mostly employed in military applications. Third-generation mobile radio systems and GPS products both use it(Hara & Prasad, 1997).
The system can support more users since this method, in contrast to DS-CDMA, employs longer spreading codes. Due to the ability to consider all user signals from other cells as

noise, CDMA technology is mostly employed in military applications. Devices like third-generation mobile radio systems and GPS gadgets utilize it.

The primary drawback of CDMA is the ineffective use of capacity brought on by bandwidth increase. Additionally, the number of sequences restricts the total number of users on a particular channel with a same bit rate.

2.7.1.4 Orthogonal Frequency-Division Multiple Access (OFDMA)

Widely used in the wireless broadband network, orthogonal Frequency-Division Multiple Access (OFDMA) is a multi-user communication technique that is based on orthogonal frequency division multiplexing (OFDM). It can overcome the limitations of signaling transmission and increase the rate of transmission (Hussain, Hussain, Khokhar, & Iqbal, 2007). It divides the channel frequency into many parallel streams and modulates each stream into a single carrier or sub-carrier, enabling us to divide the whole bandwidth into non-overlapping channels and simultaneously broadcast data to numerous users.

These sub-carriers preserve the smallest possible frequency separation with the time-domain waveform in order to preserve orthogonality. Nevertheless, there is frequency overlap in the signal spectra of the many sub-carriers (Hussain et al., 2007). Thus, the bandwidth that is available is appropriately utilized. The OFDM transmitter can modify its signaling technique to fit the channel if it has access to the channel information.

The Inverse Fast Fourier Transform (IFFT), which enables a greater number of sub-carriers with little complexity, can be used to implement OFDM. The OFDM system can distribute more power to users with lower signal to noise ratio (SNR) and less power to users with higher SNR thanks to sub-channelization (Ahmadi, 2019).

2.7.2 Non-Orthogonal Multiple Access(NOMA)

A promising multiple access method for the 5G network is non-orthogonal multiple access. Numerous important difficulties are addressed, including fast data rates, minimal latency, and widespread connection. Multiple users may be accommodated concurrently with superposition coding at the transmitter, and by using successive interference cancellation (SIC) at the receiver, the close user decodes and subtracts the distant user signal, high spectral efficiency can be reached. The faint signal from the nearby user may be decoded by the remote user without any interference (Ding, Yang, Fan, & Poor, 2014).

The use of orthogonal resource allocation among users in an orthogonal multiple access

(OMA) system, such as TDMA and FDMA, prevents intra-cell (inter-user) interference. Thus, the amount of accessible orthogonal resources determines the maximum number of users that may be handled. Intra-cell interference in the distribution of user resources is permitted and used by non-orthogonal multiple access (NOMA). This interference is reduced by using interference cancellation techniques like multi-user detection (MUD) or success interference cancellation (SIC). In Release 16, the 3GPP is taking into account the NOMA method. It is possible to implement it in the power domain, the code domain, or other domains.

- ***Power domain NOMA:*** exploits the channel strength differences between users and is the optimal capacity-achieving multiple access technique in a single-cell network. The spectrum and power allocation for power domain NOMA is graphically compared with that of OMA in figure 2.2. In NOMA-based systems, two users can share the same spectral band, with a varying amount of power allotted to each user.

- ***Code domain NOMA schemes:*** often make use of multi-user detection techniques that are simple. Examples of code domain NOMA include sparse code multiple access (SCMA), interleave division multiple access (IDMA), and low-density spreading (LDS)-CDMA.

When employing NOMA, some potential advantages include (Shin et al., 2017).

- Massive connectivity: The quantity of orthogonal resources limits OMA, but not NOMA. NOMA theoretically supports an infinite number of users.

- Lower latency: While NOMA can allow flexible scheduling and grant-free transmission, OMA waits for available resource blocks to transmit, which is done by waiting for an access grant.

- Improved spectral efficiency (bps/Hz): A limited amount of bandwidth can be used by an OMA user while the entire bandwidth can be used by every NOMA user. When compared to OMA, correctly grouped users might have higher data rates.

2.8 Non-orthogonal Multiple Access (NOMA) Viewpoints

As the two main technologies SC and SIC continue to mature both in theoretical and practical aspects, NOMA is able to be applied in the next generation networks without considering the implementation issues. By invoking SC technique, the base station transmits the combination of superposition coded signals of all users' messages. Without loss of generality, the channel gains of users are with respect to a particular ordering (e.g., increasing order or decreasing order). In the traditional OMA schemes, one of the popular power allocation policy is water filling policy. However, in NOMA, users with poor channel conditions are supposed to allocate more power. By doing so, it can ensure that the users with poor channel condition can decode the message of themselves by treating other users' messages as noise. For those users which are in good channel conditions, SIC technologies can be applied to enable subtract the interference from other users with poorer channel conditions.

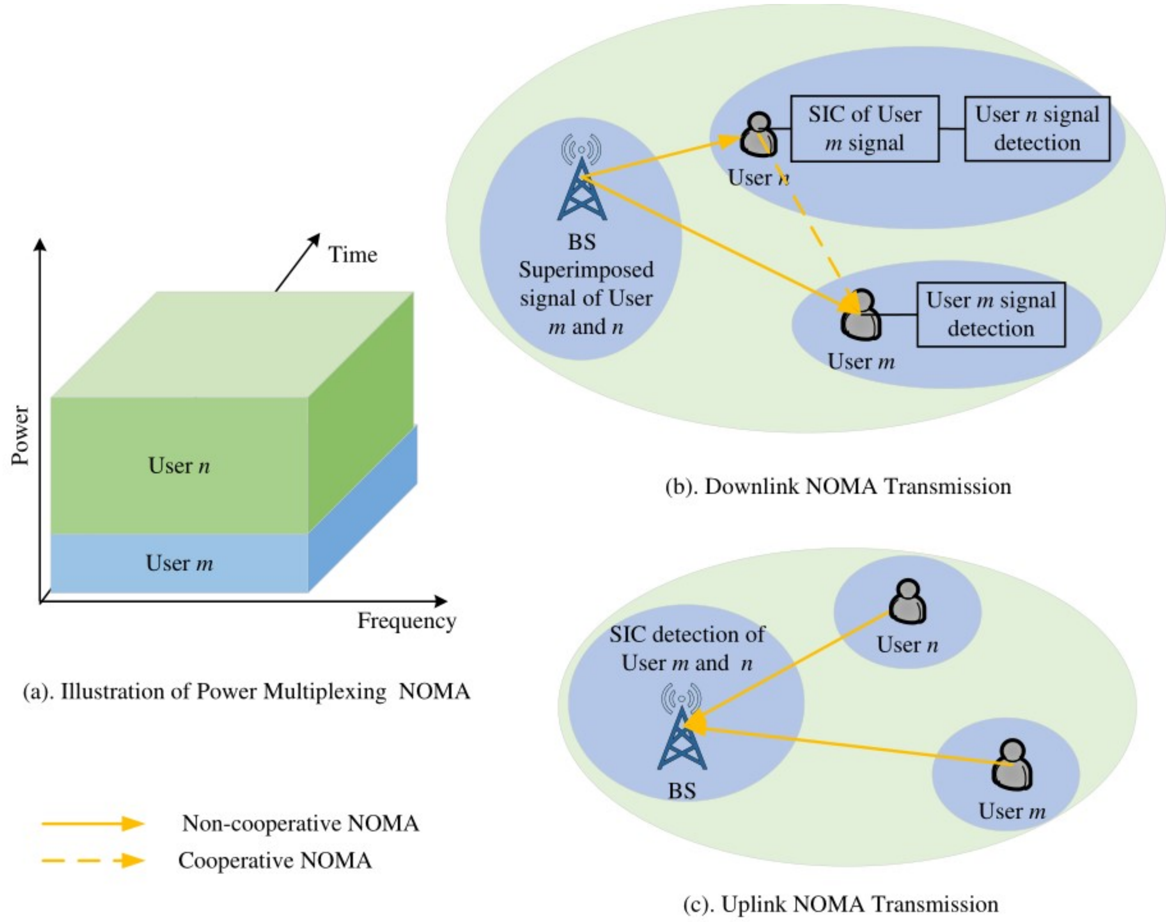


Figure 2.4: Illustration of NOMA transmission.

In the following, we present and discuss different viewpoints used to define non- orthogonality in NOMA (Vaezi et al., 2019) (Saito et al., 2013).

2.8.1 What Drives NOMA?

High throughput, low latency, and massive connection must be supported by the next generation of wireless networks.

Power domain NOMA multiplexes users by taking use of their different channel gains. In this thesis, we discuss NOMA in the power domain, a method that can enhance wireless communication by virtue of the following advantages (Vaezi et al., 2019) (S. Islam, Zeng, & Dobre, 2017):

- ***Massive Connectivity:*** There seems to be a general understanding that NOMA is necessary for widespread connection. This is due to the fact that all OMA approaches have a built-in restriction on the number of people they can service (e.g. the number of codes in CDMA and the number of resource blocks in OFDMA). NOMA, on the other hand, potentially has the ability to serve an arbitrary number of users, even inside a single resource block, by superimposing all users' signals. NOMA can therefore be adapted to Internet of Things (IoT) applications where a large number of devices intermittently broadcast a limited number of packets.

- ***Low Latency:*** The latency requirements for 5G applications might vary greatly and in some situations be quite strict. For improved mobile broadband (eMBB) and ultra-reliable and low-latency communications (URLLC), for instance, the ITU stipulates user plan latency requirements of 4 ms and 1 ms, respectively.

- ***High Spectral Efficiency:*** The downlink peak spectral efficiency should be 30 bits/s/Hz in accordance with ITU specifications for IMT-2020. In comparison to OMA, NOMA delivers a greater user-fairness and a higher spectral efficiency. In a single-cell network, NOMA is the theoretically best method of exploiting the spectrum for both uplink and downlink communications, as will be illustrated in. Every NOMA user may take advantage of the whole bandwidth, but OMA users are restricted to a smaller amount of the spectrum that is inversely proportionate to the number of users, which explains how such higher performance is possible.

NOMA may also be integrated with additional upcoming technologies to further increase spectral efficiency and provide greater throughput, such as massive MIMO and millimeter wave (mm-Wave) technologies.

2.9 Millimeter Wave (mm-Waves)

The radio frequency spectrum known as millimeter waves, or extremely high frequency (EHF), is well suited for 5G networks. With millimeter wave technology, transmission is possible at frequencies between 30 GHz and 300 GHz, which is higher than the frequencies utilized by mobile devices earlier, which were below 5 GHz. These frequencies are known as millimeter waves because their wavelengths range from 1 mm to 10 mm, as opposed to the radio waves now utilized by cellphones, which have wavelengths that are typically several dozen centimeters (Al-Falahy & Alani, 2019).

To achieve the necessary coverage when using mm-Wave for 5G mobile communications, a huge number of base stations are needed. A millimeter wave capacity is one of the features that is most likely to be implemented into the 5G technologies being developed for 5G cellular telecommunications networks. The spectrum below 4 GHz is thin, hence frequencies up to 60 GHz are being studied.

2.9.1 Benefits of Millimeter Wave Technology

Today, microwave technology is being employed in a wide range of applications. The microwave frequency bands may therefore be completely used in the future. Millimeter wave can therefore be employed as a solution.

Furthermore, using millimeter waves have following advantages (Rappaport et al., 2017):

- Its wider bandwidth can provide a better transmission rate, spread spectrum functionality, and interference immunity.
- Extremely high frequencies allow multiple short-distance usages at the same frequency without interfering each other.
- It needs a beam with a narrower width. A higher frequency results in a narrower beam when using an antenna of the same size.
- Hardware size is decreased. The smaller the size of the antenna that may be employed, the higher the frequency.

Multiple access is a serious issue that might make mm-Wave communications in cellular systems ineffective. One of the biggest obstacles to mm-Wave communications is the capacity to support numerous users. Due to the high power consumption and high hardware cost, the number of radio-frequency (RF) chains, which is substantially lower than the number of antennas, is frequently limited in the mm-Wave band.

In this case, the number of RF links is equal to the number of consumers that one RB can supply. Due to this limitation, it is critical that NOMA be integrated into mm-Wave communications (mm-Wave-NOMA) in order to get around it and dramatically increase the number of users. Additionally, the users' channels are closely connected due to mm-Wave's tightly directed feature, which is ideal for the use of NOMA. By utilizing these unique advantages, the integration of mm-Wave communications with NOMA can provide immense potentials to allow the ultra-high bandwidth and extensive connectivity in B5G and 6G.

2.10 MIMO wireless communication

The core of a reputable communications system and the fundamental to any commercially successful network are speed and efficiency in today's fast-paced environment. MIMO (multiple-input, multiple-output) communication technology is a development in wireless communication that has increased scalability and enabled the provision of lower latency services to a higher number of customers, as shown in figure 2.5.

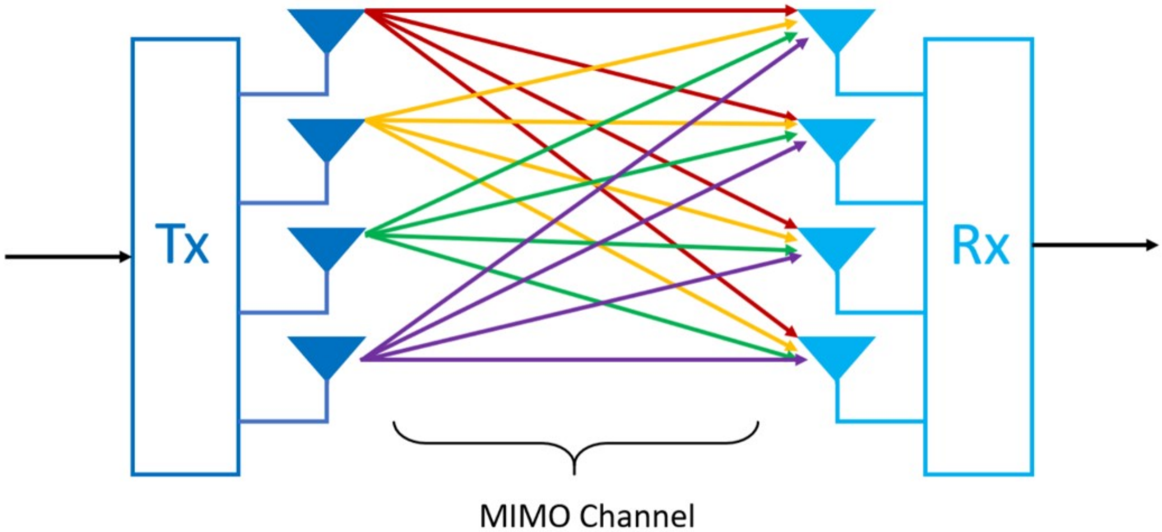


Figure 2.5: MIMO technology (Jon Mundy, 2019)

MIMO, a cutting-edge technology at the time, made use of several antennas at the transmitting and receiving ends to improve the speed of data transmission. However, antenna arrays using MIMO techniques are utilised for simultaneously transmitting and receiving several data streams over the same radio channel, which is facilitated by multipath propagation, with the inclusion of multiplexing techniques like OFDM.

MIMO technology constitutes a breakthrough in wireless communication system design. The technology offers a number of benefits that help meet the challenges posed by both the impairments in the wireless channel as well as resource constraints. In addition to the time and frequency dimensions that are exploited in conventional single-antenna (single-input single-output) wireless systems, the leverages of MIMO are realized by exploiting the spatial dimension (provided by the multiple antennas at the transmitter and the receiver) (Agiwal, Roy, & Saxena, 2016).

2.11 The Importance of Spectral Efficiency

The quantity of data that can be transmitted over a particular bandwidth is referred to as spectral efficiency. It may be used to assess how effectively two various systems utilise the same frequency. This is significant given that spectrum is frequently restrictive; there is only a finite amount of frequency available for transmission. Using the spectrum in a way that optimizes the capacity or throughput available can thus result in increased throughput. The unit of measurement for spectral efficiency is bits per second per hertz (bps/Hz).

This is why spectral efficiency is a crucial criterion for assessing the performance of wireless radios. The throughput, speeds, and overall subscriber experience can all be affected by duplicate transmissions or slower data rates. Retransmissions, which can result in unacceptably long delays and jitter in the applications, are particularly dangerous for online gaming and video conferencing.

The spectral efficiency of various solutions may differ due to interference, which is another consideration. Retransmission of the same data is necessary because interference muddles transmissions. Multiple transmissions of the same data may be necessary to efficiently transmit it due to the level of interference already present. As a result, as more time passes while sending fewer bits of information, a link's overall capacity decreases.

2.12 Related work

In (Al-Abbasi & Khamis, 2021), This paper investigated how to increase the spectral efficiency (SE) of non-orthogonal multiple access (NOMA) by optimizing the power allotted to each NOMA user in accordance with their channel conditions. To maximize the effectiveness of the NOMA system, an optimization problem for SE maximization is proposed. Three power assignment techniques are given to address the posed problem. The first one is a constant weight based water-filling strategy. Second, two power assignment (PA) schemes—one based on high weight and the other on low weight—are suggested. The high weight based PA technique, in particular, relies on a weighting factor that employs the user index inside the decoding order to fractionate and assign each user a significant amount of the total transmission power available.

In (Arora & Singh, n.d.), the context of next-generation communication systems, non-orthogonal

multiple access (NOMA) has been gaining impressive support. In comparison to its numerous orthogonal systems, this specific scheme's main benefits are fast data speeds, greater spectrum, and energy efficiency. The rapid expansion of the Internet of Things and the need for greater data rates, improved spectral efficiency, and higher energy efficiency in the next fifth generation (5G) wireless networks (IoT). In this study, we adopted a power domain-based non-orthogonal multiple access (NOMA) scheme and compared it to an orthogonal Frequency-Division Multiple Access (OFDMA) method that is presently in use. In comparison to the present approach, the simulation results demonstrate that the suggested NOMA scheme produces a significantly greater data rate with higher spectral and energy efficiency.
In (Wang, Tang, Qi, Cui, & Zheng, 2020) The 5G technologies known as heterogeneous networks (HetNet) and non-orthogonal multiple access (NOMA) have been viewed as the most promising. For HetNet to attain improved spectral efficiency, NOMA technology integration is a trend that cannot be avoided. As a result, we create an innovative network scenario that takes use of sectorization. By sectorizing a two-tier NOMA heterogeneous network with an uplink, we seek to maximize the energy efficiency of all tiny cells in this article. To begin with, we employ the Karush-Kuhn-Tucker (KKT) optimum conditions and the Lagrange dual technique to achieve the closed-form power allocation solution. The greedy technique is the foundation of a low-complexity subchannel allocation algorithm that is also suggested. Our suggested strategy is superior than other current schemes, according to simulation data, and obtains a large increase in energy efficiency.
In (Yapıcı, Güvenç, & Dai, 2020), this study, we provide a novel non-orthogonal multiple access (NOMA) architecture that takes use of the directional propagation properties of mmWave communications to increase spectrum efficiency through non-orthogonal signaling. Then, the UE pairs for NOMA transmission are created using both the one-bit angle feedback and the conventional one-bit distance feedback method. Therefore, the suggested method is known as two-bit NOMA. For situations when two-bit NOMA is ineffective due to the lack of a UE pair, we also suggest an unique hybrid technique known as combined NOMA. The numerical outcomes demonstrate that the suggested approach beats one-bit NOMA schemes with either angle- or distance-only feedback and has an outage sum-rate performance that is very near to that for the ideal full-resolution feedback.
Related Researches gap analysis:

Table 2.3: Related Research

Articles	Contribution and Research Direction	Gap
(Pal & Sarawadekar, 2019)	BS-MIMO-NOMA proposed for mmWave communication in perfect CSI Integrating power domain NOMA with BS-MIMO, spectral and energy efficiency.	Dynamic power allocation isn't applied to solve joint power optimization problem
(Liu, Li, Cheng, Zhang, & Gao, 2019)	Beamspace MIMO-NOMA Systems precoding matrix through zero-forcing (ZF) beamforming method. Formulate the energy efficiency (EE) maximization optimization problem as a fractional programming.	spectral efficiency was not evaluated
(Liaqat, Noordin, Abdul Latef, & Dimyati, 2020)	Power domain-NOMA (PD-NOMA) Increase the performance of spectral utilization in downlink networks	Dynamic power allocation scheme were not designed
(Al-Abbasi & Khamis, 2021)	Iterative power assignment, Two power assignment schemes are proposed. Spectral efficiency (SE) enhancement of NOMA system	mmWave beamspace MIMO scheme were not designed,
(Mengistu & Mihrete, 2022)	BS-NOMA) with estimating BS channel Pilot-based channel estimation technique with a compressive sensing (CS) tool used Evaluation of spectral and energy efficiency	Iterative optimization algorithm not considered

CHAPTER THREE
MATERIALS AND METHODS

3.1 Introduction

This chapter describes the Materials and Methods that is pursued in this study, which was designed with the aim to provide answers to the research objective given in chapter 1. The methodology starts by looking at tools available to do this thesis. MATLAB software was chosen for the simulation. After that, we study performance evaluation and resource allocation designs for non-orthogonal multiple access (NOMA) in wireless communication systems. In contrast to conventional orthogonal multiple access (OMA) schemes, NOMA allows multiple users to share the same degree of freedom via superposition coding and the successive interference cancellation (SIC) decoding. Inspired by the solid foundations from the information theory perspective, NOMA has rekindled the interests of researchers as a benefit of the recent advancement in signal processing and silicon technologies. This thesis attempts to address these problems by providing a unified performance analysis and a systematic resource allocation design for NOMA in wireless mmWave communication systems. Mainly, to break the existing limit of the existing BS-MIMO OMA, the BS-MIMO NOMA is proposed. BS-MIMO, in which a user can use each beam simultaneously on frequency resources. The number of users is larger than the number of RF chains in the proposed BS-MIMO NOMA. The use of NOMA enhances the ability of the BS MIMO in massive merger. All users' power allocation is optimized by increasing the achievable rate and a functional optimization algorithm has been developed to suppress interference. A simulation program's framework was created to imitate a typical wireless environment. Experiments were then set up in order to assess the performance of methods under assumed channel conditions.

In this thesis,We take into account a single-cell downlink mm-Wave communication system in which the base station(BS) is outfitted with N antennas and NRF RF chains and simultaneously supports K single-antenna users. The system model of existing BS-MIMO will be introduced at first in this section, and then the proposed BS-MIMO NOMA scheme will be presented in detail.

3.2 Materials

In this thesis, a MATLAB/R2021b MEX file package software is used for the simulation. The MATLAB version of the packages necessary for the simulation.

3.3 Research Method

In this thesis, we propose a spectrum-efficient mm-Wave transmission technique called BS-MIMO NOMA, which combines the newly developed idea of non-orthogonal multiple access (NOMA) with MIMO. To increase spectrum efficiency and connection density, NOMA in particular has been viewed as a possible choice for 5G. Contrary to orthogonal multiple access (OMA) methods, which rely on the time, frequency, and code domains or on combinations of these, NOMA can be implemented in a brand-new domain called the power domain. Multiple users can be supported concurrently at the same time, frequency, and space resources by performing super-position coding at the transmitter and successive interference cancellation (SIC) at the receiver. The super-position coding process can also translate the channel gain difference between users into multiplexing gain. Power allocation is optimized by increasing the achievable rate and a functional optimization algorithm has been developed to suppress interference. There may be a performance increase by including NOMA into BS MIMO.

3.4 System Design

Involve the following:

- Analyzing the mathematical model for the mm-Wave MIMO-OMA.
- Analyzing the mathematical model for mm-Wave transmission scheme that integrates the new concept of non orthogonal multiple access (NOMA) with BS MIMO.
- Performing successive interference cancellation (SIC) at the receiver and super-position coding at the transmitter. At the same time, frequency, and space resources, multiple users may be accommodated at once. The channel gain disparity between users can be converted into multiplexing gain via superposition coding.
- Evaluating the performance of the suggested strategy to improve the spectral efficiency of the 5G wireless network.
- Compare the proposed method to the previous method.

3.5 Simulation parameters

Table 3.1: Simulation parameters

Simulation parameters		
Parameter	Description	Value
N	Number of beams (Transmit Antennas)	256
K	Number of users	32, 64, 128
L	Number of paths per user	3
lamada	Wavelength	1
P	Total transmitted power	32
I_{max}	Iteration times of power allocation	30
SNR_dB	SNR	$10dB$
N_iter	Iteration	100
P	Total transmitted power	32

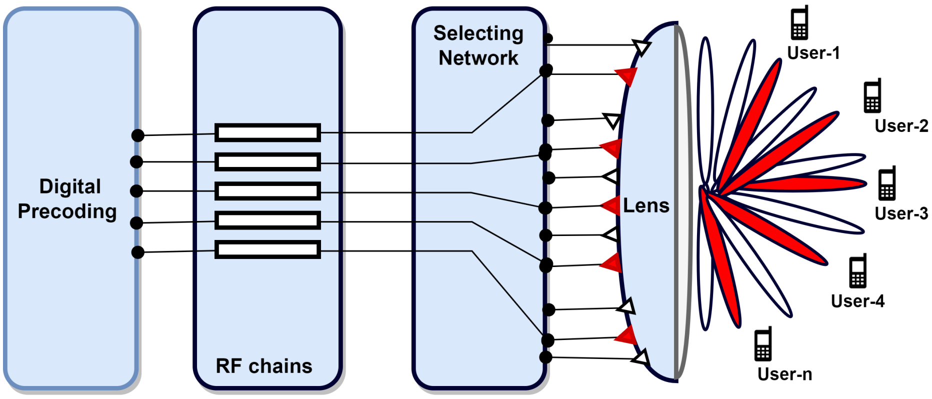
Notation:

We use upper-case and lower-case boldface letters to denote matrices and vectors, respectively.

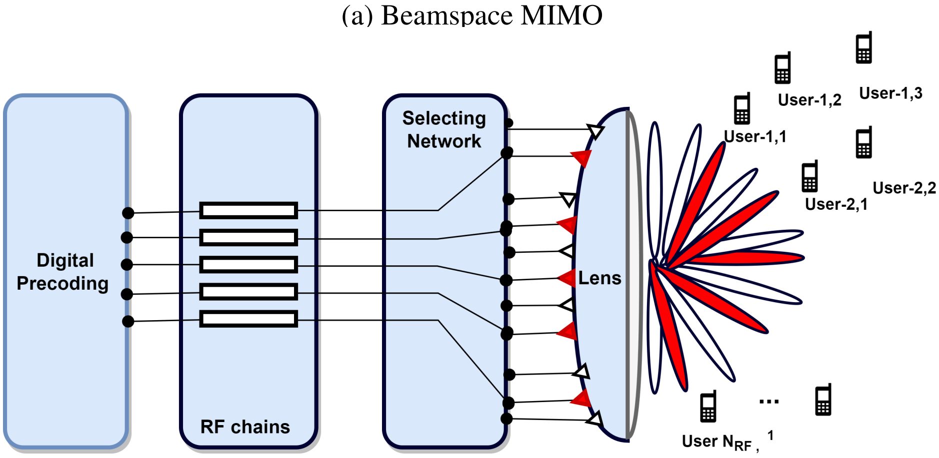
$(.)^T$, $(.)^H$, $(.)^{-1}$, $(.)^{\dagger}$, $tr(.)$, and $\| . \|_p$ denote the transpose, conjugate transpose, matrix inversion, Moore-Penrose matrix inversion, the trace of the matrix, and l_p norm operation, respectively.

$diag\{p\}$ denotes the diagonal matrix whose diagonal elements consist of the elements in the vector. $p.E\{.\}$ denotes the expectation. $|\Gamma|$ denotes the number of elements in set $\Gamma.A(i,:)_{i\varepsilon\Gamma}$ denotes the sub-matrix of A that consists of the i_{th} row of A for all $i\varepsilon\Gamma$. We use the notation $\mathscr{C}\mathscr{N}(m,R)$ to denote the complex Gaussian distribution with mean m and covariance R. Finally, I_N is the $N \times N$ identity matrix.

3.6 System Model



(a) Beamspace MIMO



(b) Beamspace MIMO-NOMA

Figure 3.1: System Model of MIMO Architecture

3.7 Beamspace(BS) MIMO-OMA

Based on system model, we can easily obtain mathematical model for massive MIMO systems.In traditional MIMO systems, the received signal vector $y = [y_1, y_2, , y_k]^T$ can be expressed as:

$$y = H^H W P_s + v \tag{3.1}$$

where $s = [s_1, s_2, , s_k]^T$ is the $K \times 1$ transmitted signal vector for all K users with normalized power $E(ss^H) = I_k$, $P = diag(p)$ includes the transmitted power for all K users where $p = [\sqrt{P_1}, \sqrt{P_2}, , \sqrt{P_k}]$ satisfied $\sum_{k=1}^{k} P_K \leq P$ (the maximum transmitted power at the Base Station), $W = [w_1, w_2, , w_k]$ is the $N \times K$ precoding matrix with $|w_k|_2 = 1$ for k = 1, 2, $\cdot \cdot \cdot$, K, and v is the is the noise vector following the distribution $\mathscr{CN}(0, \delta^2 I_k)$. Finally, $H = [h_1, h_2, , h_k]$ of size N × K is the channel matrix, where h_k of size N × 1 denotes the spatial channel vector between the BS and the k_{th} user. Particularly, in this paper, we consider the widely used Sahel-Valenzuela channel model for mm-Wave communications (Zeng & Zhang, 2016), so h_k can be represented as

$$h_k = \beta_k^{(0)} a(\theta_k^{(0)}) + \sum_{l=1}^{L} \beta_k^{(l)} a(\theta_k^{(l)}) \quad (3.2)$$

where $\beta_k^{(0)} a(\theta_k^{(0)})$ is the LoS component of the k_{th} user, in which $\beta_k^{(0)}$ denotes the complex gain and $a(\theta_k^{(0)})$ represents the spatial direction.$\beta_k^{(l)} a(\theta_k^{(l)})$ for 1≤ l≤ L is the l_{th} NLoS component of the k_{th} user, where L is the total number of NLoS components. $a(\theta)$ is the N × 1 array steering vector.

Note that at mm-Wave frequencies, the amplitudes $|\beta_k^{(l)}|_{l=1}^{N}$ of NLoS components are typically 5 to 10dB weaker than the amplitude $|\beta_k^{(0)}|$ of the LoS component(Brady & Sayeed, 2015).

To address this issue, in mm-Wave massive MIMO systems, the notion of BS-MIMO has recently been presented, which can use lens antenna array to greatly reduce the number of needed RF chains without obviously sacrificing performance. As shown in as shown in 3.1 (a), by employing lens antenna array, The BS channel in the equation may be created from the channel in the spatial domain 3.2. Specifically, the mathematical function of the lens antenna array is to realize the spatial discrete Fourier transformation with the N × N transform matrix U (Gao, Dai, Chen, Wang, & Zhang, 2016), It includes an assortment of steering vectors in N directions, spanning the whole space, as follows:

$$\mathbf{U} = [a(\vartheta_1), a(\vartheta_2), , a(\vartheta_N)]^H \quad (3.3)$$

$\vartheta_N = \frac{1}{N}(n - \frac{N+1}{2})$ for n = 1, 2, $\cdots$, N are the predefined spatial directions. Then, the received signal vector $\bar{Y}$ in BS-MIMO systems can be represented as

$$\bar{Y} = H^H U^H W P_s + v = \bar{H}^H W P_s + v \quad (3.4)$$

where the BS channel matrix $\bar{H}$ is defined as

$$\bar{H} = UH = [Uh_1, Uh_2, , , , Uh_k] = [\bar{h}_1, \bar{h}_2, , , , \bar{h}_k] \quad (3.5)$$

where $\bar{h}_k = Uh_k$ is the BS channel vector between the BS and the k_{th} user, which is the Fourier transformation of the spatial channel vector h_k in equation 3.2.

As for the BS channel matrix$\bar{H}$ defined in equation 3.5, each row of $\bar{H}$ corresponds to one beam, and all N rows correspond to N beams with spatial directions $\bar{\theta_1}, \bar{\theta_2}, , , , \bar{\theta_N}$, separately. Since only a few number of dominating scatters are present in mm-Wave communications, When compared to the number of beams N, the number of NLoS components L is substantially lower (Amadori & Masouros, 2015). Therefore, the number of dominating components in each BS channel vector $\bar{h}_k$ is much smaller than N, namely, the BS channel matrix $\bar{H}$ has a sparse nature. Dimension-reduced BS design It is feasible to implement MIMO systems employing this sparse structure without clearly illuminating performance loss due to beam selection. Specifically, according to the sparse BS channel matrix, only a small number of beams can be selected to simultaneously serve K users. Then, the received signal vector in equation 3.4 can be rewritten as

$$\bar{Y} = \bar{H}_r^H W_r P_s + v, \tag{3.6}$$

where $\bar{H}_r = \bar{H}(i,:)$ of size $|\gamma| \times k$ is the dimension reduced BS channel matrix including selected beams, and γ is the index set of selected beams. W_r of size $|\gamma| \times k$ is the dimension-reduced precoding matrix. Since the row dimension of W_r has a considerably smaller than N (the row dimension of the original precoding matrix W), the quantity of RF chains needed may be greatly decreased, and we have $N_{RF} = |\gamma|$.

However, in the existing BS-MIMO systems, one beam can only support a maximum of one user. Therefore, The number of RF chains equals the maximum number of concurrent users that the time-frequency resources can serve i.e., $K \leq N_{RF}$ This is the fundamental BS-MIMO system limit that was taken into account, either explicitly or implicitly, in all articles that have been published on BS-MIMO (Gao et al., 2016). The reason is that, The DoF offered by the RF chains must exceed or be comparable to the DoF needed by users, otherwise signal for different users cannot be separated by linear operation. To break this limit, In the next paragraph, we propose a model mm-wave transmission system that combines NOMA with BS-MIMO.

3.8 Non-orthogonal Multiple Access Technology

The wireless research community's attention are shifting toward 5G as LTE networks are developed and 4G standards are complemented. In order to offer widespread connectivity with a variety of strict criteria, wireless networks need have capabilities that go much beyond those of earlier generations of wireless communications. These features will include enormous system capacity, large data speeds at all times and locations, extremely low latency, ultra-high dependability, extremely cheap device cost, and energy-efficient ways. These rigorous requirements will be too much for the present mobile networks to manage, necessitating the use of several disruptive technologies. Recently, NOMA has been suggested as a critical strategy to attain high SE and significant system throughput performance increases. In addition to the greater SE achieved in NOMA, it is adaptable to apply with other technologies that are being suggested for 5G and beyond networks, providing an additional gain in frequency reuse that will help wireless communication systems function even better. In non-orthogonal access, all users can use the total transmission bandwidth regardless of their channel conditions, in contrast to OMA, which restricts the bandwidth assignment to the weaker users in order to obtain a greater throughput. The core idea behind NOMA is the non-orthogonality of user access caused by sharing the same wireless resources across different users in the code or power domain. This scheme applies SC which is a summation of all users'signal to superpose multiple user at the transmitter. Multi-user detection and SIC are used to differentiate multi-user signals at the receiver end by depending on receivers that are equipped with processors that have varied capabilities (S. R. Islam et al., 2016).

3.8.1 Superposition Coding with Successive Interference Cancellation

According to the channel circumstances, several users' signals are multiplexed across various power levels using power domain multiplexing, while sharing the same time-frequency-code resources. This method uses SIC to decode multi-user signals at the receiver after applying SC to encode signals from many users at the transmitter. The SC scheme is an effective way to boost NOMA system capacity since it has the ability to reach channel capacity. In the following, NOMA will refer to the power-domain NOMA scheme because the focus of this thesis has been on a NOMA scheme in the power domain (S. R. Islam et al., 2016).

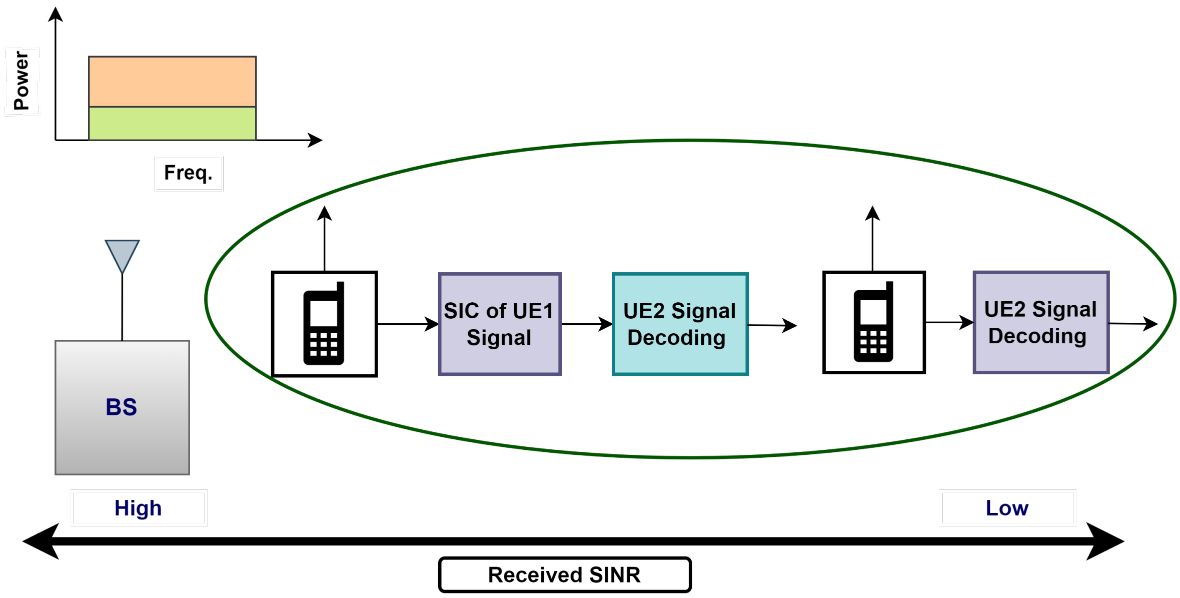


Figure 3.2: SC and SIC receiver

In NOMA, In Given that they are already dealing with poor channel conditions, it is assumed that the weaker users would be given a greater transmit power allocation than the strong users. In other words, Without harming the performance of the weaker user, a stronger user may utilize the slot that is now occupied by a weaker user. They utilize the same radio resources, The signal relating to the weaker user received at the strong user has a greater SINR than that at the weaker user. Hence, The weaker user's signal is decoded and removed by the strong user before it can utilize SIC to decode its own signal. On the other hand, Since the strong user's signal is hardly detectable at the lesser user due to the strong user's higher transmit power, the weaker user decodes its own signal without the aid of SIC.

Here, an example is provided to further exemplify the basic concepts of SC and SIC as shown in Figure 3.2. Assume that a BS is providing downlink transmission to two consumers while using the same channel. The users are geographically separated, with one being a nearby user and the other being a distant user. h1 and h2 stand for the channel gains to two users from the BS. The near user is considered as user 2, U2, which has a better channel condition than that of the far user, i.e., user 1, U1, hence, $\| h1 \| \leq \| h2 \|$. The user with a bad channel condition receives a higher transmit power allocation under NOMA, whereas the user with a good channel condition receives a lower transmit power allocation. Assume that x1 and x2 are signals that are aimed at U1 and U2, respectively. At the transmitter, The BS transmits to two users a superposition coded information that is the total of their signals, i.e., x = x1 + x2. Hence, The signals at U1 and U2 that were received can be written as

$$y_1 = h_1 x + n_1, \quad (3.7)$$

$$y_2 = h_2 x + n_2, \quad (3.8)$$

where n_k is Additive White Gaussian Noise (AWGN) for U_k, k = 1, 2, with zero mean and variance σ_k^2.

3.9 Proposed Beamspace(BS) MIMO-NOMA

We propose to use NOMA in BS mm-Wave massive MIMO systems to significantly increase spectrum efficiency and connection density. As shown in figure 3.1 (b), The suggested BS-MIMO NOMA system allows for simultaneous service of several users inside each chosen beam, in contrast to current BS-MIMO systems.

In particular, one beam may be chosen for each user, and each RF chain corresponds to one beam, using beam selection methods such maximum magnitude (MM) selection and maximization of the signal-to-interference-plus-noise ratio (SINR) selection. (Pal, Srinivas, & Chaitanya, 2018).

Note that different users are likely to select the same beam, which are called “conflicting users” in this thesis. Particularly, for a typical mm-Wave massive MIMO system with K = 32 users, N = 256 antennas, and a uniformly distributed set of spatial directions, the likelihood of people choosing the same beam is 87 % (Gao et al., 2016). In contrast to current BS-MIMO systems, where user scheduling is used to choose just one user from among those that are in conflict, (Gao et al., 2016), In the proposed BS-MIMO NOMA system, competing users can be supplied concurrently utilizing the same RF chain.

Although the number of selected beams is equal to N_{RF}, the number of simultaneously served users K can be larger than N_{RF}, i.e., $K \geq N_{RF}$. Let S_n for n = 1, 2, $\cdots$, N_{RF} denote the set of users served by the n_{th} beam with $S_i \cap S_j = \phi$ for $i \neq j$ and $\sum_{n=1}^{N} RF|S_n| = K$. The $N_{RF} \times 1$ BS channel vector after beam selection between the BS and the m_{th} user in the nth beam is denoted by $h_{m,n,}$ and wn of size $N_{RF} \times 1$ denotes the uniform precoding vector for users in the n_{th} beam. Without loss of generality, we assume that $||h_{1,n}^H w_n||_2 \geq ||h_{2,n}^H w_n||_2 \geq$,....,$||h_{|Sn|,n}^H w_n||_2$ for n = 1, 2, $\cdots$, N_{RF}. The received signal ym,n at the m_{th} user in the nth beam (n = 1, 2, $\cdots$, N_{RF}, and m = 1, 2, $\cdots$, $|S_n|$) can be expressed as

$$y_{m,n} = h_{m,n}^H \sum_{j=1}^{N_{RF}} \sum_{i=1}^{|S_j|} W_j \sqrt{P_{i,j} S_{i,j}} + v_{m,n}$$

$$
\begin{aligned}
&= h^H_{m,n} W_n \sqrt{P_{m,n} S_{m,n}} \text{ [desired signal]} \\
&+ h^H_{m,n} \sum_{i=1}^{m-1} W_n \sqrt{P_{i,n} S_{i,n}} + h^H_{m,n} \sum_{i=m+1}^{|S_n|} W_n \sqrt{P_{i,n} S_{i,n}} \text{ [intra beam interferences]} \\
&+ h^H_{m,n} \sum_{j \neq 1} \sum_{i=1}^{|S_j|} W_j \sqrt{P_{i,j} S_{i,j}} + v_{m,n} \text{ [inter beam interferences and noise]}
\end{aligned} \tag{3.9}
$$

where $S_{m,n}$ and $P_{m,n}$ are the transmitted signal and transmitted power for the m_{th} user in the nth beam, and $v_{m,n}$ is the noise following the distribution $C\mathcal{N}(0, \delta^2)$.

Note that in existing BS-MIMO systems, only one user can be supported in each selected beam, i.e., $|S_n|$ = 1 (n = 1, 2, $\cdots N_{RF}$), while $|S_n|$ (n = 1, 2, $\cdots$ N_{RF}) can be larger than one in the proposed BS-MIMO NOMA system.

In the second equation of equation 3.9, The intended signal is the first term, followed by the terms for intra- and inter-beam interference, inter-beam interference, noise, and the fourth term. Particularly, the precoding vectors $(w_n)_{n=1}^{N_{RF}}$ should be carefully planned to limit inter-beam interference; this topic will be covered in more detail in the section on precoding in the downlink system. By doing SIC in the ascending order of corresponding channel gains, it is possible to decrease the intra-beam interference brought on by superposition coding in NOMA (S. R. Islam et al., 2016), i.e., the m_{th} interference can be eliminated by the user in the nth beam from the i_{th} user (for all i ¿ m) in the nth beam by performing SIC.

When NOMA is used in BS-MIMO systems, many users can be serviced concurrently inside each beam, allowing the total number of supported users to exceed the number of beams, i.e., $K \geq N_{RF}$. However, Users in the proposed BS-MIMO NOMA system experience interference from other beams in addition to intra-beam interference brought on by superposition transmission. Thus, Precoding and power allocation should be created to minimize interferences by maximizing the feasible sum rate since a simple combination of NOMA and BS-MIMO is unable to ensure the dependable performance in practice.

3.10 Achievable Sum Rate

As discussed in the previous section, in the nth beam using NOMA with SIC, the i_{th} (i ¿ m) user's signal is detectable at the m_{th} user, provided that it is detectable at itself (Liu, Li, Cheng, Gao, & Zhang, 2020), as the equivalent channel gain of the m_{th} user is larger than that of the i_{th} user, i.e.,$||h^H_{1,n} w_n||_2 \geq ||h^H_{2,n} w_n||_2 \geq$,....,$||h^H_{|Sn|,n} w_n||_2$ for n = 1, 2, $\cdots$, N_{RF} as assumed before. Therefore, the m_{th} user can detect the i_{th} user's signals for $1 \leq m < i \leq |S_n|$, and then remove the detected signals from its received signals, in a successive manner. Then, the remaining received signal at the m_{th} user in the nth beam can be rewritten as

$$\begin{aligned}\bar{y}_{m,n} &= h_{m,n}^{H} W_n \sqrt{P_{m,n} S_{m,n}} \text{ [desired signal]} \\ &+ h_{m,n}^{H} \sum_{i=1}^{m-1} W_n \sqrt{P_{i,n} S_{i,n}} \text{ [intra beam interferences]} \\ &+ h_{m,n}^{H} \sum_{j \neq 1} \sum_{i=1}^{|S_j|} W_j \sqrt{P_{i,j} S_{i,j}} + v_{m,n} \text{ [inter beam interferences and noise]}\end{aligned} \tag{3.10}$$

Then, according to (Gao et al., 2016), the SINR at the m_{th} user in then_{th} beam can be presented as

$$\gamma_{m,n} = \frac{\left\| h_{m,n}^{H} w_n \right\|_2^2 P_{m,n},}{\xi_{m,n}} \tag{3.11}$$

where,

$$\xi_{m,n} = \left\| h_{m,n}^{H} w_n \right\|_2^2 \sum_{i=1}^{m-1} P_{i,n} + \sum_{j \neq n} \left\| h_{m,n}^{H} w_n \right\|_2^2 \sum_{i=1}^{|S_j|} P_{i,j} + \sigma^2 \tag{3.12}$$

As a result, the achievable rate at the m_{th} user in the n_{th} beam is

$$R_{m,n} = \log_2(1 + \gamma_{m,n}) \tag{3.13}$$

Finally, the achievable sum rate of the proposed BS-MIMO NOMA scheme is

$$R_{sum} = \sum_{n=1}^{N_{RF}} \sum_{m=1}^{|S_j|} R_{m,n}, \tag{3.14}$$

which can be improved by carefully designing the precoding $(w_n)_{n=1}^{N_{RF}}$ and power allocation $(P_{m,n})_{m=1,n=1}^{|Sn|,N_{RF}}$.

3.11 Precoding in Downlink System

In existing BS MIMO systems, where only one user can be served in each beam (i.e., $K \leq N_{RF}$), To eliminate inter-beam interferences, the traditional linear ZF precoding with low complexity can be used (Zeng & Zhang, 2016), This is easily realizable for all users using the pseudo-inverse of the BS channel matrix. However, The number of users in the proposed BS-MIMO NOMA system exceeds the number of beams, i.e., $K \geq N_{RF}$, This denotes the inverse of the pseudo-inverse of the BS channel matrix of size $N_{RF} \times K$ does not exist. As a result, direct usage of the traditional ZF precoding is not possible.

This issue may be solved by finding an analogous channel for each beam and using that information to create the precoding vector. Specifically, We provide two techniques for creating the corresponding channel for every beam, i.e., the most effective The Strongest User-Based Equivalent Channel, This is covered in the subsections as follow.

3.11.1 The Strongest User-Based Equivalent Channel

As mentioned before, the amplitudes of NLoS components are typically 5 to 10 dB weaker than the amplitude of the LoS component (Rappaport, Ben-Dor, Murdock, & Qiao, 2012). Therefore, In mm-Wave communications, the multipath channel may be essentially described by the LoS component (Liu et al., 2020). The fact that the BS channel matrix has a sparse structure that represents the directions of many users is also its most significant characteristic. As a result, The sparse BS channel vectors of several users in the same beam are strongly coupled if the LoS component is present. That is to say, The corresponding channel vector for the nth beam may be thought of as one of the BS channel vectors for multiplexed users in the nth beam.

Particularly, Considering that the first user in each beam should conduct SIC to decode all of the other users' signals in this beam, We utilize the first user's BS channel vector in each beam as the analogous channel vector. Specifically, the equivalent channel matrix of size $N_{RF} \times N_{RF}$ for all N_{RF} beams can be written as

$$\bar{H} = [\bar{h}_{1,1}, \bar{h}_{1,2}, \ldots.., \bar{h}_{1,N_{RF}}] \tag{3.15}$$

Then, the precoding matrix of size $N_{RF} \times N_{RF}$ can be generated by

$$\bar{W} = [\bar{w}_1, \bar{w}_2, \ldots.., \bar{w}_{N_{RF}}] = (\bar{H})^{\dagger} = \bar{H}(\bar{H}^H \bar{H})^{-1} \tag{3.16}$$

After normalizing the precoding vectors, the precoding vector for the n_{th} beam (n = 1, 2, $\cdots$, N_{RF}) can be written as

$$w_n = \frac{\bar{w_n}}{\|\bar{w_n}\|_2} \tag{3.17}$$

With this precoding method, the initial user in each beam may totally eliminate inter Beam interferences, i.e.,

$$\frac{h_{1,j}^{H} w_n}{\left\| h_{1,j}^{H} w_n \right\|_2} = \begin{cases} 0, & j \neq n, \\ 1, & j = n, \end{cases} \tag{3.18}$$

where $1 \leq j, n \leq N_{RF}$. Thus, after performing SIC, the SINR at the first user in the n_{th} beam can be rewritten as

$$\gamma_{1,n} = \frac{\left\| h_{1,n}^{H} w_n \right\|_2^2 P_{1,n},}{\xi^2} \tag{3.19}$$

3.12 Dynamic Power Allocation

In NOMA systems, the multiplexing gains can be converted from the channel gain differences between users through superposition coding. Therefore, The system performance is significantly impacted by power distribution. In fact, Numerous research have been conducted to design power allocation in the current MIMO-NOMA systems in order to reduce inter-user interferences and enhance the achievable total rate. The integration of NOMA and MIMO was investigated in (Chung, 2020), When fixed power allocation algorithms were used at the BS and two users were taken into account in each beam with random beamforming. In addition, fixed power allocation strategies have also been considered in (Iswarya & Jayashree, 2021). A coordinated frequency block-dependent inter-beam power allocation was proposed in to generate distinct power levels for different beams (Iswarya & Jayashree, 2021) considered equal power allocation for different groups, and intra-group power allocation has been optimized to maximize the achievable sum rate, where each group only included two single-antenna users. The intra-group power optimization has also been studied in, where the closed-form power allocation solution was obtained using a convex optimization technique. For MIMO-NOMA systems, where just two users have been taken into account, a non-convex power allocation issue was defined. Sub-optimal solutions were offered, studied coupled beamforming and power allocation optimization, where channel uncertainties have been taken into account to maximize the worst-case possible total rate. In the simulations, the performance with just two users in each group was assessed.

$$
\begin{aligned}
&max_{(p_{m,n})} \sum_{n=1}^{N_{RF}} \sum_{m=1}^{|S_n|} R_{m,n} \\
s.t. C_1 :&P_{m,n} \geq 0, \forall_{m,n}, \\
C_2 :&\sum_{n=1}^{N_{RF}} \sum_{m=1}^{|S_n|} P_{m,n} \leq P, \\
C_3 :&R_{m,n} \geq R_{min}, \forall_{n,m},
\end{aligned}
\tag{3.20}
$$

where $R_{m,n}$ is the user's potential rate inside the n_{th} beam as defined in equation 3.13, the constraint C_1 indicates that the power allocated to each user must be positive, C_2 is the transmission power restriction, where P is the maximum amount of power that the BS can send at once, and C_3 is the data rate constraint for each user with R_{min} being the minimum data rate for each user. By substituting equation 3.11-3.13 into the constraint C_3 in equation 3.20, we have

$$
\left\|h_{m,n}^H w_n\right\|_2^2 P_{m,n} - \eta \left\|h_{m,n}^H w_n\right\|_2^2 \sum_{i=1}^{m-1} P_{i,n} - \eta \sum_{j \neq n} \left\|h_{m,n}^H w_n\right\|_2^2 \sum_{i=1}^{|S_j|} P_{i,j} \geq \omega, \tag{3.21}
$$

where,$\eta = 2^{R_{min}} - 1$ and $\omega = \eta \sigma^2$ In this way, the non-linear constraint C_3 has been transformed into linear constraint. Then, the optimization problem equation 3.20 can be rewritten as

$$
\begin{aligned}
&max_{(p_{m,n})} \sum_{n=1}^{N_{RF}} \sum_{m=1}^{|S_n|} \log_2(1 + \gamma_{m,n}) \\
s.t. C_1 :&P_{m,n} \geq 0, \forall_{m,n}, \\
C_2 :&\sum_{n=1}^{N_{RF}} \sum_{m=1}^{|S_n|} P_{m,n} \leq P, \\
C_3 :&\left\|h_{m,n}^H w_n\right\|_2^2 P_{m,n} - \eta \left\|h_{m,n}^H w_n\right\|_2^2 \sum_{i=1}^{m-1} P_{i,n} - \eta \sum_{j \neq n} \left\|h_{m,n}^H w_n\right\|_2^2 \sum_{i=1}^{|S_j|} P_{i,j} \geq \omega, \forall_{m,n},
\end{aligned}
\tag{3.22}
$$

We can see from equation 3.22 that all constraints, i.e., C_1, C_2, and C_3, are linear inequality constraints, while the objective function is non-convex. Therefore, this optimization problem is NP-hard, and it is very difficult to obtain the closed-form solution to the optimal power allocation problem equation 3.22.

To solve this difficult non-convex problem equation 3.22, To achieve power allocation, we provide an iterative optimization approach. Specifically, according to the extension of the Sherman Morrison-Woodbury formula equation (Chen, Wen, Wang, Liu, & Hanzo, 2020), i.e.,

$$(A+BCD)^{-1} = A^{-1} - A^{-1}B(I+CDA^{-1}B)^{-1}CDA^{-1} \tag{3.23}$$

we have

$$(1+\gamma_{m,n})^{-1} = 1 - \left\|h_{m,n}^{H}w_n\right\|_2^2 P_{m,n}(\left\|h_{m,n}^{H}w_n\right\|_2^2 P_{m,n} + \xi_{m,n}) \tag{3.24}$$

where n = 1, 2, $\cdots$, $N_{RF}$and m = 1, 2, $\cdots$, $|S_n|$.
We can find that the expression in equation 3.24 has the same form as the MMSE. Specifically, if MMSE detection is used to solve $S_{m,n}$ from $\bar{y}_{m,n}$ in equation 3.10, this detection problem can be formulated as

$$\mathbf{C}_{m,n}^{o} = \mathbf{arg}_{min_{c_{m,n}}}\mathbf{e}_{m,n}, \tag{3.25}$$

where,

$$e_{m,n} = E\left\{ \ \|s_{m,n} - c_{m,n}\bar{y}_{m,n}\|^2 \ \right\}. \tag{3.26}$$

is the mean square error (MSE), $c_{m,n}$ is the channel equalization coefficient, and $c_{m,n}^{o}$ is the optimal value of $c_{m,n}$ to minimize the MSE. Substituting in equation 3.10 into in equation 3.26, we have

$$\begin{aligned} e_{m,n} &= 1 - 2Re(C_{m,n}\sqrt{P_{m,n}}h_{m,n}^{H}w_n) + |c_{m,n}|^2(P_{m,n}\left\|h_{m,n}^{H}w_n\right\|_2^2 P_{m,n}) \\ &= |1 - C_{m,n}\sqrt{P_{m,n}}h_{m,n}^{H}w_n)|^2 + |c_{m,n}|^2 + \left\|h_{m,n}^{H}w_n\right\|_2^2 \sum_{i=1}^{m-1} P_{i,n} \\ &+ |c_{m,n}|^2 \sum_{j\neq n} \left\|h_{m,n}^{H}w_j\right\|_2^2 \sum_{i=1}^{|S_j|} P_{i,j} + |c_{m,n}|^2\sigma, \end{aligned} \tag{3.27}$$

Then, by solving in equation 3.25 based on equation 3.27, the optimal equalization coefficient $c^o_{m,n}$ can be calculated by

$$\begin{aligned}
&\frac{\delta e_{m,n}}{\delta c_{m,n}}|_{c_{m,n}} = 0, \\
\Rightarrow & e_{m,n} = -\sqrt{P_{m,n}} h^H_{m,n} w_n + |c^o_{m,n}|^* (P_{m,n} \left\| h^H_{m,n} w_n \right\|_2^2 + \xi_{m,n}) = 0, \\
\Rightarrow & |c^o_{m,n}|^* = (\sqrt{P_{m,n}} h^H_{m,n} w_n)^* (P_{m,n} \left\| h^H_{m,n} w_n \right\|_2^2 + \xi_{m,n})^{-1} = 0,
\end{aligned} \tag{3.28}$$

Substituting in equation 3.28 into equation 3.27, we obtain the MMSE as,

$$\begin{aligned}
e^o_{m,n} &= 1 - 2Re(C^o_{m,n} \sqrt{P_{m,n}} h^H_{m,n} w_n) + |c^o_{m,n}|^2 (P_{m,n} \left\| h^H_{m,n} w_n \right\|_2^2 P_{m,n}) \\
&= 1 - 2Re((\sqrt{P_{m,n}} h^H_{m,n} w_n)^* (P_{m,n} \left\| h^H_{m,n} w_n \right\|_2^2 + \xi_{m,n})^{-1} \sqrt{P_{m,n}} h^H_{m,n} w_n) \\
&+ |(\sqrt{P_{m,n}} h^H_{m,n} w_n)^* (P_{m,n} \left\| h^H_{m,n} w_n \right\|_2^2 + \xi_{m,n})^{-1}|^2 \times (P_{m,n} \left\| h^H_{m,n} w_n \right\|_2^2 + \xi_{m,n}), \\
&= 1 - 2P_{m,n} \left\| h^H_{m,n} w_n \right\|_2^2 (P_{m,n} \left\| h^H_{m,n} w_n \right\|_2^2 + \xi_{m,n})^{-1} + P_{m,n} \left\| h^H_{m,n} w_n \right\|_2^2 (P_{m,n} \left\| h^H_{m,n} w_n \right\|_2^2 + \xi_{m,n})^{-1} \\
&= 1 - P_{m,n} \left\| h^H_{m,n} w_n \right\|_2^2 (P_{m,n} \left\| h^H_{m,n} w_n \right\|_2^2 + \xi_{m,n})^{-1}
\end{aligned} \tag{3.29}$$

which is equal to $(1+\gamma_{m,n})^{-1}$ in 3.24, i.e., we have

$$(1+\gamma_{m,n})^{-1} = min_{c_{m,n}} e_{m,n} \tag{3.30}$$

Then, the achievable rate of the m_{th} user in the n_{th} beam can be written as

$$R_{m,n} = \log_2(1+\gamma_{m,n}) = min_{c_{m,n}}(-\log_2 e_{m,n}) \tag{3.31}$$

To remove the log function in equation 3.31, we introduce the following proposition (Chen et al., 2020).

Proposition 1: Let $f(a) = -\frac{ab}{\ln 2} + \log_2 a + \frac{1}{\ln 2}$ and a be a positive real number, we have

$$max_{a>0} f(a) = -\log_2 b, \tag{3.32}$$

where the optimal value of a is $a^o = \frac{1}{b}$.

Proof: The function f(a) is concave, and thus the maximum value of f(a) can be obtained by solving

$$\frac{\delta f(a)}{\delta a}|_{c_{m,n}} = 0, \tag{3.33}$$

Then, we have $a^o = \frac{1}{b}$. By instituting ao into f(a), the maximum value of f(a) is -$\log_2 b$. Using Proposition 1, equation 3.31 can be rewritten as

$$R_{m,n} = max_{c_{m,n}} max_{a_{m,n}>0} = (-\frac{a_{m,n}e_{m,n}}{\ln 2} + \log_2 a_{m,n} + \frac{1}{\ln 2}) \tag{3.34}$$

As a result, the objective function for the optimization problem equation 3.22 has been transformed into quadratic programming function, and equation 3.22 can be reformulated as

$$\begin{aligned}
& max_{(p_{m,n})} \sum_{n=1}^{N_{RF}} \sum_{m=1}^{|S_n|} max_{c_{m,n}} max_{a_{m,n}>0} = (-\frac{a_{m,n}e_{m,n}}{\ln 2} + \log_2 a_{m,n} + \frac{1}{\ln 2}) \\
& s.t. C_1 : P_{m,n} \geq 0, \forall_{m,n}, \\
& C_2 : \sum_{n=1}^{N_{RF}} \sum_{m=1}^{|S_n|} P_{m,n} \leq P, \\
& C_3 : \left\|h_{m,n}^H w_n\right\|_2^2 P_{m,n} - \eta \left\|h_{m,n}^H w_n\right\|_2^2 \sum_{i=1}^{m-1} P_{i,n} - \eta \sum_{j \neq n} \left\|h_{m,n}^H w_n\right\|_2^2 \sum_{i=1}^{|S_j|} P_{i,j} \geq \omega, \forall_{m,n},
\end{aligned} \tag{3.35}$$

To solve the reformulated optimization problem equation 3.35, we propose to iteratively optimize $c_{m,n}$, $a_{m,n}$, and $p_{m,n}$. Specifically, given the optimal power allocation solution $(p_{m,n}^{t-1})$ in the $(t-1)_{th}$ iteration, the optimal solution of $(c_{m,n}^t)$ in the t_{th} iteration can be obtained according to equation 3.28, i.e.,

$$c_{m,n}^t = (\sqrt{P_{m,n}^{(t-1)}} h_{m,n}^H w_n)^* (P_{m,n}^{(t-1)} \left\|h_{m,n}^H w_n\right\|_2^2 + \xi_{m,n}^{(t-1)})^{-1} \tag{3.36}$$

where

$$\xi_{m,n}^{(t-1)} = \left\|h_{m,n}^H w_n\right\|_2^2 \sum_{i=1}^{m-1} P_{i,n}^{(t-1)} + \sum_{j \neq n} \left\|h_{m,n}^H w_n\right\|_2^2 \sum_{i=1}^{|S_j|} P_{i,j}^{(t-1)} + \sigma^2, \tag{3.37}$$

and the corresponding MMSE denoted by in equation 3.29 in thet_{th} iteration can be expressed as

$$e_{m,n}^{o(t)} = 1 - P_{m,n}^{(t-1)} \left\|h_{m,n}^H w_n\right\|_2^2 P_{m,n}^{(t-1)} (\left\|h_{m,n}^H w_n\right\|_2^2 P_{m,n}^{(t-1)} + \xi_{m,n}^{(t-1)})^{-1} \tag{3.38}$$

Then, the optimal solution of $\{a_{m,n}^{(t)}\}$ in the t_{th} iteration can be obtained by

$$a_{m,n}^{(t)} = \frac{1}{e_{m,n}^{o(t)}} \tag{3.39}$$

After obtaining the optimal $\{c_{m,n}^{(t)}$ and $\{a_{m,n}^{(t)}$ in the t_{th} iteration, the optimal$\{p_{m,n}^{(t)}$ in the t_{th} iteration can be obtained by solving the following problem:

$$\begin{aligned}
& max_{\{p_{m,n}^{(t)}\}} \sum_{n=1}^{N_{RF}} \sum_{m=1}^{|S_n|} a_{m,n}^{(t)} e_{m,n}^{(t)} \\
s.t.C_1 \, & :P_{m,n}^{(t)} \geq 0, \forall_{m,n}, \\
C_2 & : \sum_{n=1}^{N_{RF}} \sum_{m=1}^{|S_n|} P_{m,n}^{(t)} \leq P, \\
C_3 & : \left\| h_{m,n}^H w_n \right\|_2^2 P_{m,n}^{(t)} - \eta \left\| h_{m,n}^H w_n \right\|_2^2 \sum_{i=1}^{m-1} P_{i,n}^{(t)} - \eta \sum_{j \neq n} \left\| h_{m,n}^H w_n \right\|_2^2 \sum_{i=1}^{|S_j|} P_{i,j}^{(t)} \geq \omega, \forall_{m,n},
\end{aligned} \tag{3.40}$$

where

$$\begin{aligned}
e_{m,n}^{(t)} = & |1 - c_{m,n}^{(t)} \sqrt{p_{m,n}^{(t)}} h_{m,n}^H w_n)|^2 + |c_{m,n}^{(t)}|^2 + \left\| h_{m,n}^H w_n \right\|_2^2 \sum_{i=1}^{m-1} p_{i,n}^{(t)} \\
& + |c_{m,n}^{(t)}|^2 \sum_{j \neq n} \left\| h_{m,n}^H w_j \right\|_2^2 \sum_{i=1}^{|S_j|} p_{i,j}^{(t)} + |c_{m,n}^{(t)}|^2 \sigma,
\end{aligned} \tag{3.41}$$

To solve the convex optimization problem in equation 3.40, we define the Lagrange function as

$$L(p, \lambda, \mu) = \sum_{n=1}^{N_{RF}} \sum_{m=1}^{|S_n|} a_{m,n}^{(t)} e_{m,n}^{(t)} + \lambda \left(\sum_{n=1}^{N_{RF}} \sum_{m=1}^{|S_n|} p_{m,n}^{(t)} - p \right) + \sum_{n=1}^{N_{RF}} \sum_{m=1}^{|S_n|} \mu_{m,n} \theta_{m,n}, \tag{3.42}$$

where

$$\theta_{m,n}^{(t)} = \eta \left\| h_{m,n}^H w_n \right\|_2^2 \sum_{i=1}^{m-1} P_{i,n}^{(t)} + \eta \sum_{j \neq n} \left\| h_{m,n}^H w_n \right\|_2^2 \sum_{i=1}^{|S_j|} P_{i,j}^{(t-1)} - \left\| h_{m,n}^H w_n \right\|_2^2 P_{i,n}^{(t)} + \omega, \tag{3.43}$$

$\lambda \geq 0$, and $\mu_{m,n} \geq 0$ (n = 1, 2, $\cdots$, N_{RF}, m = 1, 2, $\cdots$, $|S_n|$). Then, the Karush-Kuhn-Tucker (KKT) (Boyd, Boyd, & Vandenberghe, 2004) conditions of in equation 3.40 can be obtained by the following three equations 3.44 - 3.46 :

$$\frac{\delta L_{m,n}}{\delta p_{m,n}} = a_{m,n}^{(t)}(|c_{m,n}^{(t)}|^2 \left\|h_{m,n}^H w_n\right\|_2^2 - Re(C_{m,n}\sqrt{P_{m,n}^{(t)}} h_{m,n}^H w_n)) + \sum_{u=m+1}^{|S_j|} a_{u,n}^{(t)}|c_{u,n}^{(t)}|^2 \left\|h_{u,n}^H w_j\right\|_2^2$$
$$+ \sum_{v\neq n}\sum_{u=1}^{|S_v|} a_{u,v}^{(t)}|c_{u,v}^{(t)}|^2 \left\|h_{u,v}^H w_j\right\|_2^2 + \lambda - \mu_{m,n}\left\|h_{m,n}^H w_n\right\|_2^2 + \sum_{u=m+1}^{|S_j|} \mu_{m,n}\eta \left\|h_{u,n}^H w_j\right\|_2^2$$
$$+ \sum_{v\neq n}\sum_{u=1}^{|S_v|} \mu_{m,n}\eta \left\|h_{u,v}^H w_j\right\|_2^2 = 0, \tag{3.44}$$

$$\lambda(\sum_{n=1}^{N_{RF}}\sum_{m=1}^{|S_n|} p_{m,n}^{(t)} - p) = 0, \tag{3.45}$$
$$\mu_{m,n}\theta_{m,n} = 0, \forall_{n,m}.$$

$$\mu_{m,n}\theta_{m,n} = 0, \forall_{n,m}. \tag{3.46}$$

From equation 3.44, we can obtain the optimal solution of $p_{m,n}$ as follows:

$$P_{m,n}^{(t)} = \frac{Re(C_{m,n}P_{m,n}^{(t)}h_{m,n}^H w_n)}{\tau} \tag{3.47}$$

where

$$\tau = \sum_{u=m}^{|S_j|} a_{u,n}^{(t)}|c_{u,n}^{(t)}|^2 \left\|h_{u,n}^H w_j\right\|_2^2 + \sum_{v\neq n}\sum_{u=1}^{|S_v|} a_{u,v}^{(t)}|c_{u,v}^{(t)}|^2 \left\|h_{u,v}^H w_j\right\|_2^2 + \lambda - \mu_{m,n}\left\|h_{m,n}^H w_n\right\|_2^2$$
$$+ \sum_{u=m+1}^{|S_j|} \mu_{m,n}\eta \left\|h_{u,n}^H w_j\right\|_2^2 + \sum_{v\neq n}\sum_{u=1}^{|S_v|} \mu_{m,n}\eta \left\|h_{u,v}^H w_n\right\|_2^2, \tag{3.48}$$

Since equation 3.25, $f(a)$ in equation 3.32, and equation 3.40 are convex (*concave*), the obtained $\{c_{m,n}^{(t)}\}$, $\{a_{m,n}^{(t)}\}$, and $\{p_{m,n}^{(t)}\}$ are optimal solutions in the t_{th} iteration. Therefore, iteratively updating $\{c_{m,n}\}$, $\{a_{m,n}\}$, and$\{p_{m,n}\}$ will increase or maintain the value of the objective function in equation 3.35 (Chen et al., 2020). With the constraint of the maximum transmitted power P, we will obtain a monotonically non decreasing sequence of the objective value in equation 3.35 with a upper bound, i.e., the global maximum. As a result, the proposed iterative optimization algorithm for power allocation will converge to a stationary solution to the problem equation 3.35.

3.13 Spectral efficiency

The network's throughput performance was addressed in the analysis up to this point. In this chapter, we analyze the Energy Efficiency (EE) of NOMA systems in addition to the Spectral Efficiency (SE) of NOMA systems. In our analysis, In addition to the power used for the information waveform, we also account for the network's static power consumption caused by the power amplifiers. The total of the power used by the circuits and the information signal power may be used to calculate the transmitter's overall power consumption (mainly by power amplifiers). The total power used by the BS may be expressed as after taking into account the downlink.

$$P = P_T + P_{static} \tag{3.49}$$

where P_T is the total signal power as mentioned earlier and P_{static} is the power consumed by the circuitry.

Therefore, based on the celebrated formula attained by Shannon [147], the SE is defined as

$$SE = log_2(1 + \frac{p|h|^2}{\sigma^2})(bits/s/Hz) \tag{3.50}$$

where σ^2 denotes the noise power, p represents the transmit power, and $|h|^2$ denotes the channel gain.

Energy efficiency (EE) is defined as the sum rate over the total consumed power of the base station

$$EE = \frac{R_T}{P_{Total}} = SE\frac{W}{P_{Total}}(\frac{bits}{joule}) \tag{3.51}$$

where SE is the spectral efficiency ($\frac{R_T}{W}$) in terms of bps/Hz. is defined in as the amount of data bandwidth that can be obtained from a given technology per unit frequency spectrum used.

Since the circuit's power consumption is not taken into account, the connection between energy efficiency and spectral efficiency (EE-SE) in Shannon theory is monotonic, with a greater SE always translating into a lower EE. When the circuit power is taken into account, the EE rises in the low SE and falls in the high SE regions.

CHAPTER FOUR
RESULTS AND DISCUSSIONS

4.1 Simulation Results

In this chapter, we present the simulation results that show how well the proposed BS-MIMO-NOMA system works. We specifically examine a typical downlink mm-Wave MIMO system with a ULA of N = 256 antennas and K users that the base station interacts with.
The total transmitted power is set as$P = 32mW(15dBm)$ (Gao et al., 2016).
One LoS component and L = 2 NLoS components are assumed for all users' channels.
In the simulations, we consider the following two typical mm-Wave MIMO schemes for comparison:

1 "MIMO-OMA" (Ali, Tabassum, & Hossain, 2016) with $N_{RF} \leq K$, where OMA is performed for conflicting users, and users in the same beam are allocated with orthogonal frequency resources;

2 The "proposed beamspace (BS) MIMO NOMA" with $N_{RF} \leq K$, which integrates NOMA and BS-MIMO. The normalized method designed in this research work to overcome the challenges of previous techniques.

Both the strongest user-based equivalent channel and SVD-based equivalent channel introduced in chapter 3 are considered, and the power allocation(PA) algorithm proposed in is performed to alleviate interferences. Particularly, ZF precoding is considered in BS-MIMO. In the following subsections, the performance of the proposed BS-MIMO NOMA scheme will be evaluated in terms of spectrum efficiency.

4.2 Performance analysis of spectral efficiency by varying number of antennas and users

Conventional OMA models are characterized by the allocation of radio resources to users in a way that ensures orthogonality in the time, frequency, or coding domain. This orthogonality eliminates interference between the users, making it possible to separate their signals using simple single-user detection in an ideal world. However, it is theoretically impossible for OMA to fully utilize the sum-rate capacity of wireless systems supporting many users.
Figure 4.1 and Figure 4.2 demonstrates the outcomes of spectral efficiency. As shown in

both Figure 4.1 and Figure 4.2, the spectral efficiency increases as the amount of users and antenna increasing for MIMO-NOMA scheme.

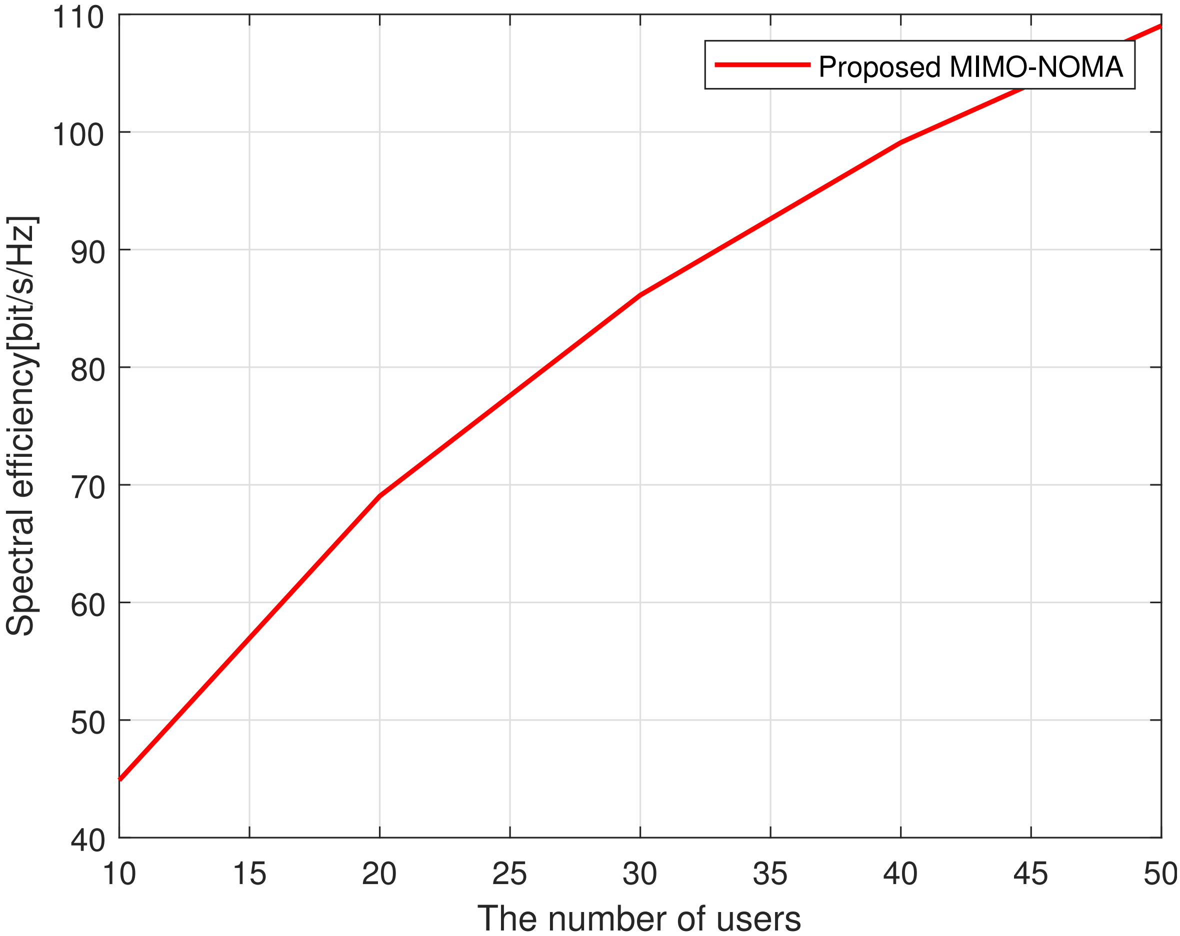


Figure 4.1: Spectrum efficiency against the number of users K, where SNR = 10 dB.

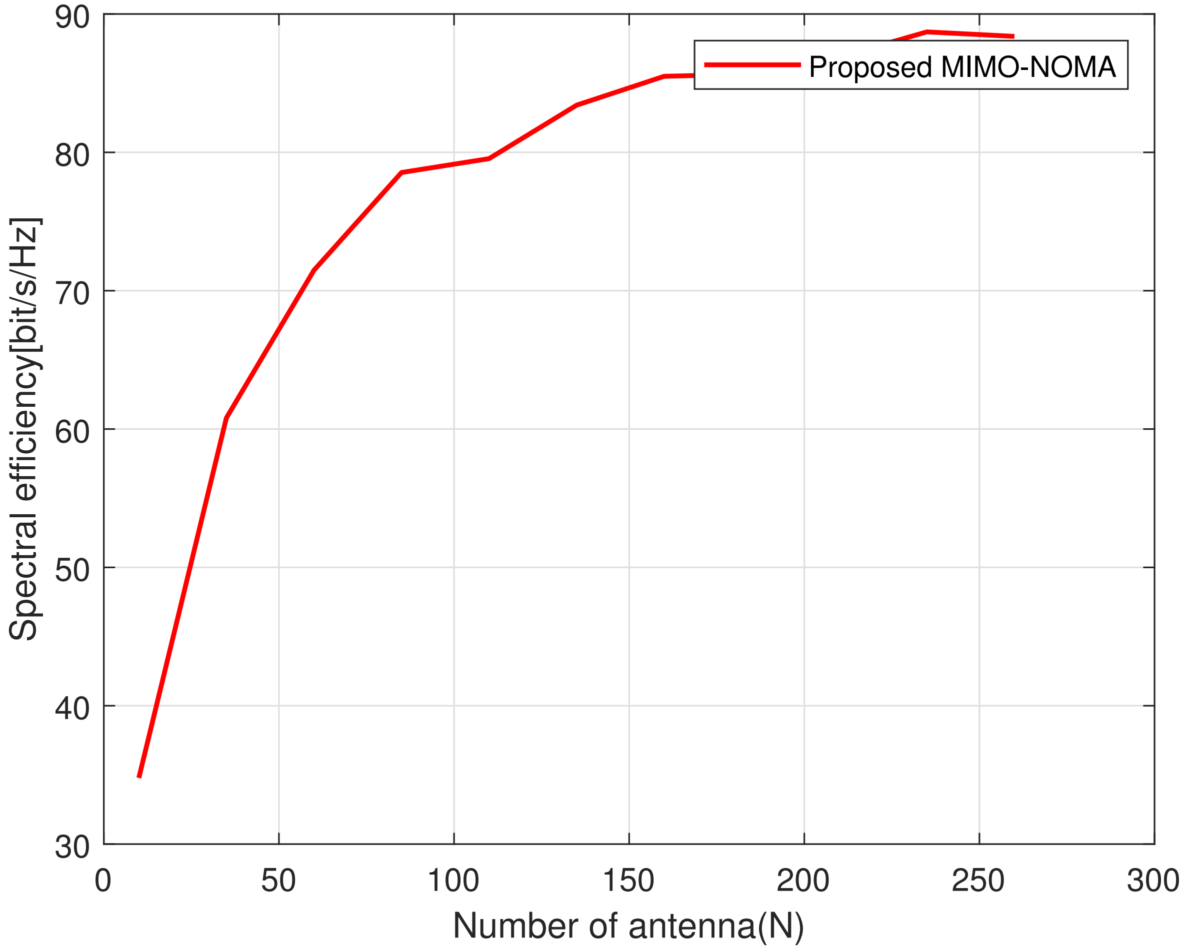


Figure 4.2: Spectrum efficiency against the number of antenna N, where SNR = 10dB.

By introducing NOMA into BS-MIMO, where intra-beam superposition coding and SIC are considered, multiple users can be served in one beam concurrently, which is fundamentally different from conventional BS-MIMO, which uses one beam to serve only one user. This is because NOMA allows for the superposition of multiple users' signals on the same beam, which can then be decoded by the receiver using SIC. This allows for more efficient use of the spectrum and can improve the capacity of the network.

Therefore, the number of supported users in the proposed BS-MIMO NOMA approach may be more than the amount of RF chains at the same time-frequency resources. The equivalent channel vector is generated for each beam in the proposed BS-MIMO NOMA system in order to implement precoding based on the ZF principle, which minimizes inter-beam interferences.

4.3 Performance analysis of spectral efficiency by varying SNR

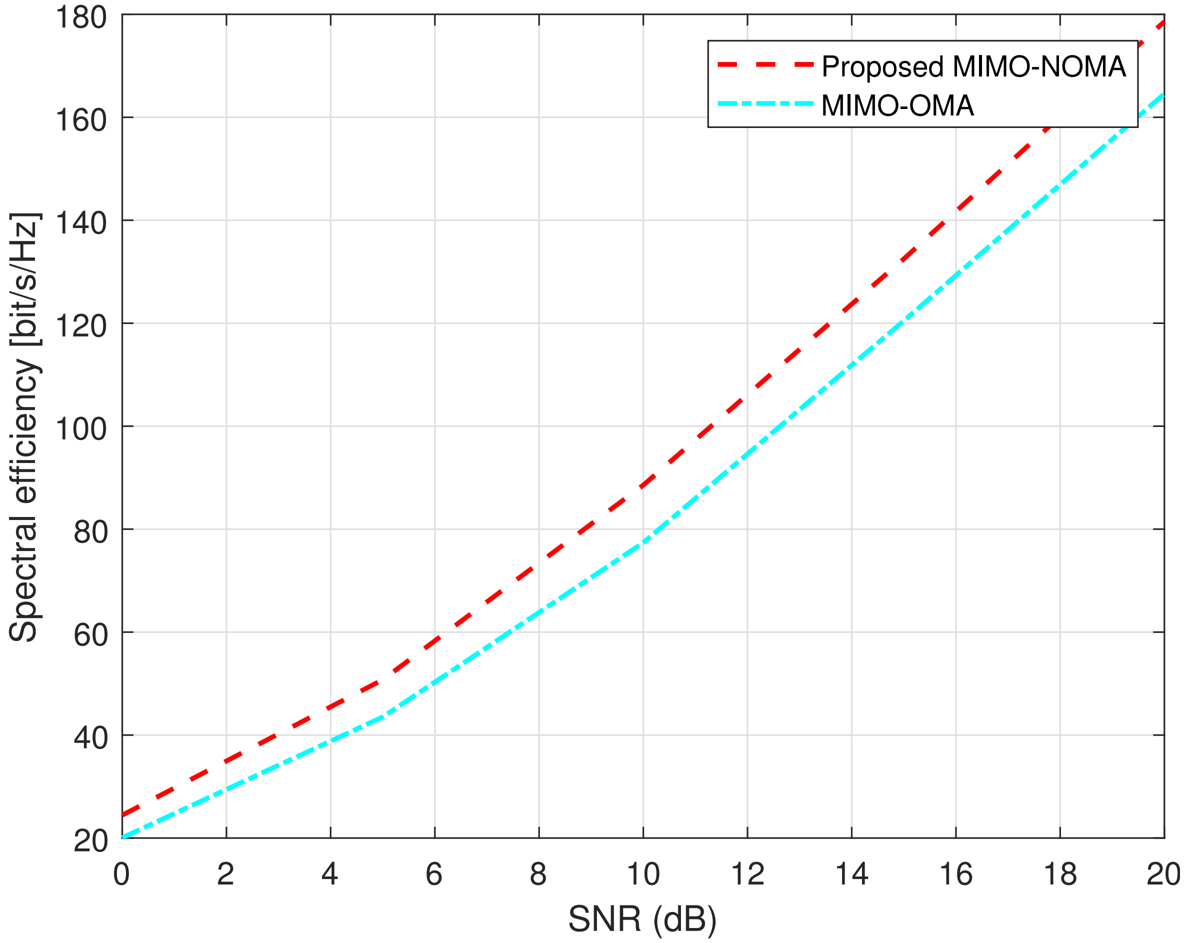


Figure 4.3: Spectrum efficiency against the SNR.

Figure 4.3, Figure 4.4 and Figure 4.5 shows the spectrum efficiency of the proposed BS-MIMO NOMA scheme is compared with that of the MIMO-OMA scheme for different values of SNR, number of users, and number of antennas. The results show that the BS-MIMO NOMA scheme can achieve higher spectrum efficiency than the MIMO-OMA scheme (Ali et al., 2016). Specifically, the proposed BS-MIMO NOMA scheme benefits from the use of NOMA to serve multiple users in each beam and has an approximately 3 dB SNR improvement over the BS-MIMO OMA scheme.

4.4 Performance comparison of spectral efficiency by varying number of antenna

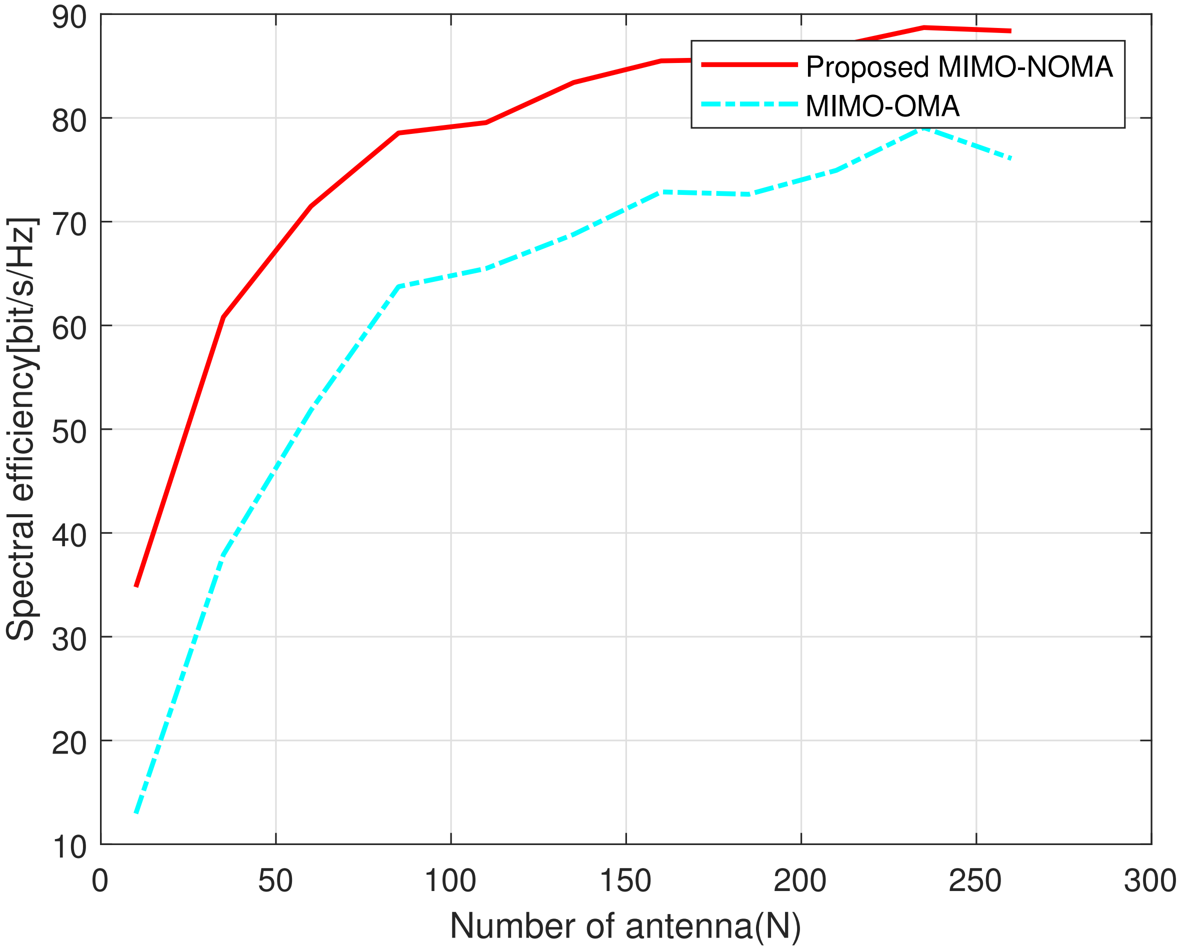


Figure 4.4: Spectrum efficiency against the number of antenna N, where SNR = 10 dB.

Table 4.1: Spectrum efficiency against Number of antenna N, where the number of users is K = 32, and SNR = 10dB

Methods	Spectrum efficiency(bits/sec/Hz) with number of antenna(N)			
	N=30	N=60	N=100	N=150
MIMO-OMA	40.63	54.14	62.04	75.42
MIMO-NOMA	62.6	72.53	79.66	85.98

The results of the simulation reveal an increasing performance difference between the proposed BS-MIMO NOMA and BS-MIMO, as demonstrated by the growth of K and N parameters for users and antennas, respectively. This is due to the possibility of multiple users being assigned to the same beam with more users. The use of NOMA allows the proposed

BS-MIMO NOMA to maintain high performance levels while standard BS-MIMO experiences a noticeable decline in performance.

4.5 Performance comparison of spectral efficiency by varying number of users

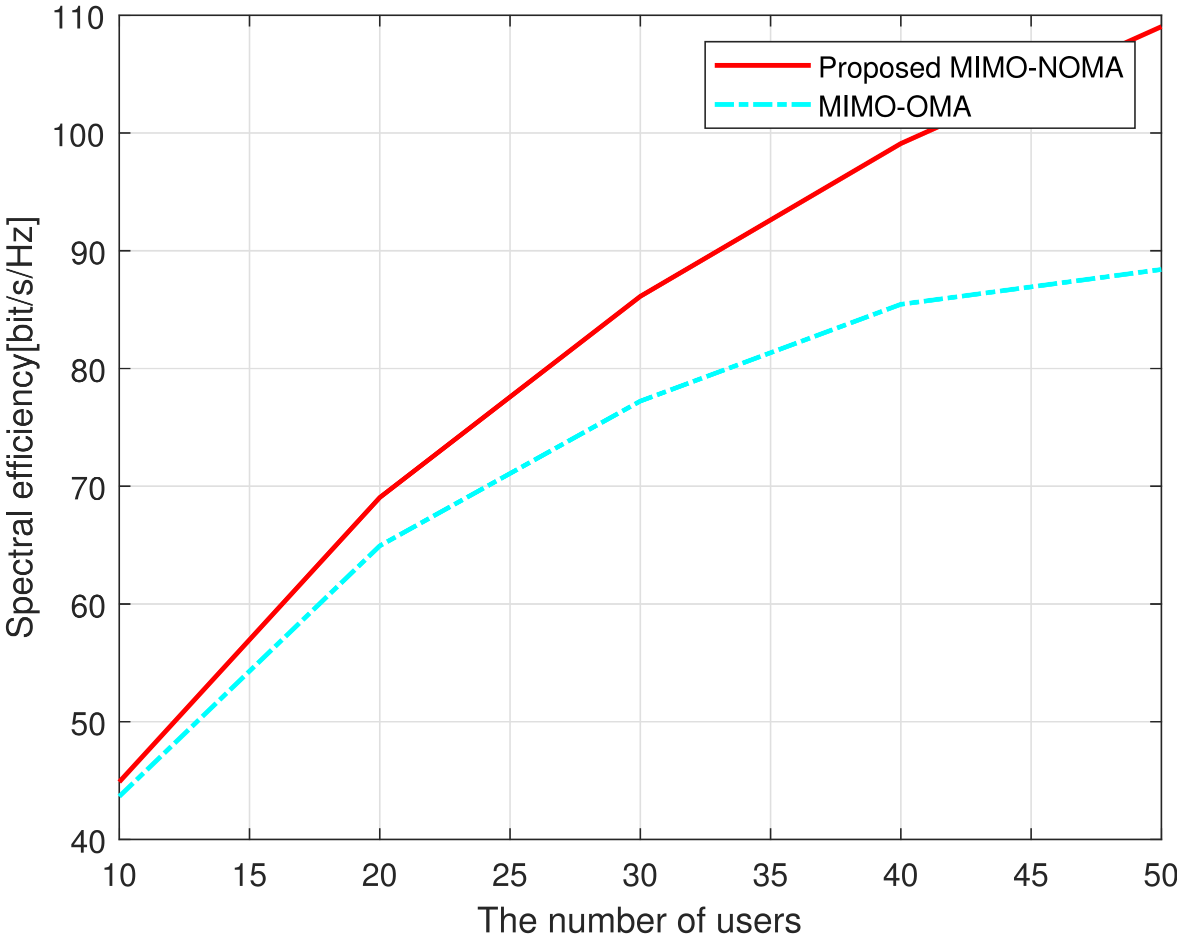


Figure 4.5: Spectrum efficiency against the number of users K, where SNR = 20 dB.

In addition, the proposed BS-MIMO NOMA also outperforms MIMO-OMA, since NOMA can achieve higher spectrum efficiency than that of OMA (S. R. Islam et al., 2016). It is intuitive that the fully digital MIMO can achieve the best spectrum efficiency as shown in figure 4.3, since there is not beam selection in the fully digital MIMO, and N_{RF} = N RF chains are used to serve all users. However, the fully digital MIMO suffers from the worst energy efficiency as shown in 4.6, which will be discussed later.

4.6 Performance comparison of energy efficiency by varying number of users

The energy efficiency ε is defined as the ratio between the achievable sum rate R_{sum} and the total power consumption [6], i.e.,

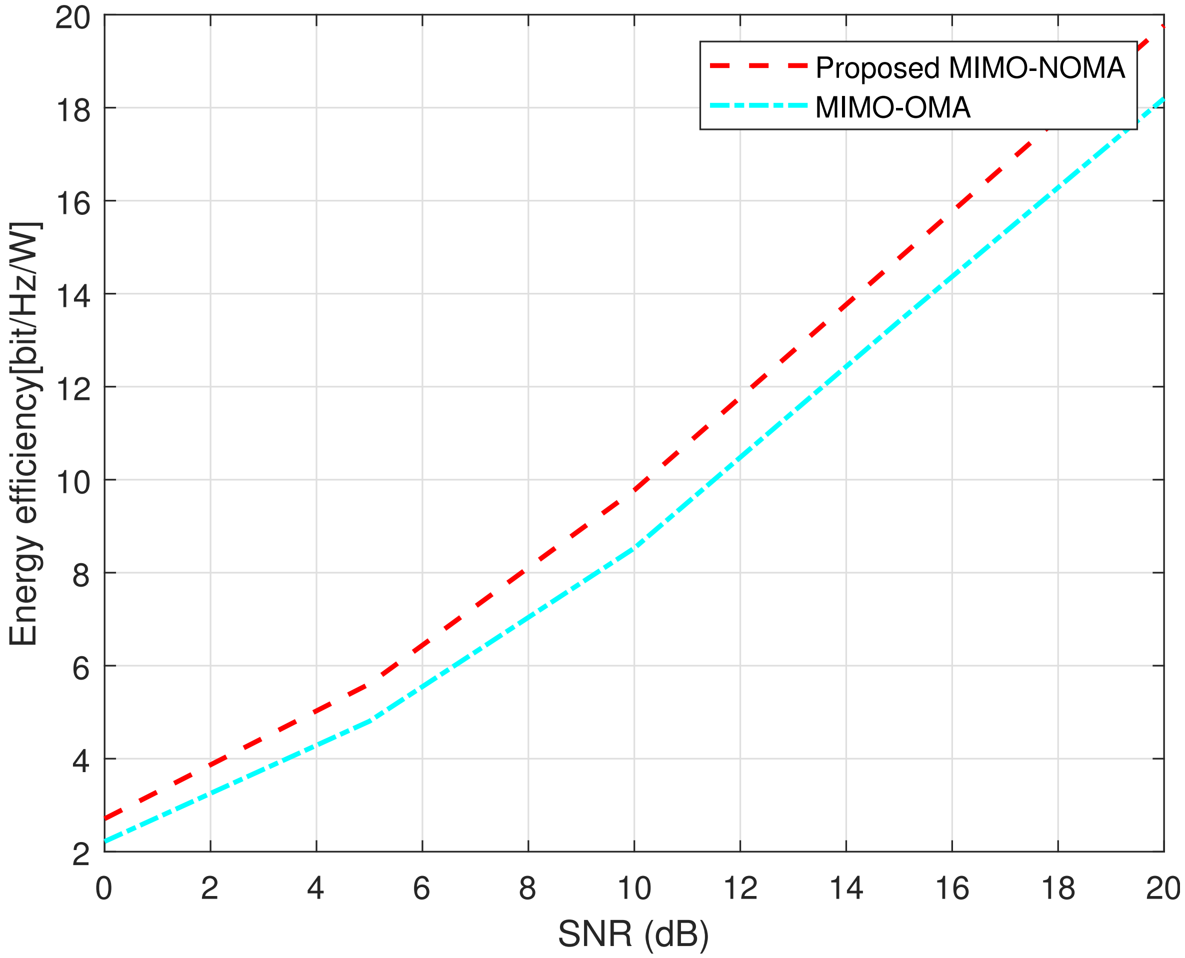


Figure 4.6: Energy efficiency against varying SNR values.

Figure 4.6 and Figure 4.7 shows In the study, energy efficiency was evaluated against SNR with K=32 users and against the number of users. The results indicate that the proposed BS-MIMO NOMA outperforms other schemes in terms of energy efficiency. Notably, the proposed BS-MIMO NOMA demonstrated a 25% improvement in energy efficiency compared to the existing BS-MIMO. This improvement is attributed to the use of NOMA to serve multiple users in each beam.

The proposed BS-MIMO NOMA architecture has the potential to achieve significantly higher energy efficiency, with a potential savings of 300 mW per RF chain. This is in contrast to the proposed BS-MIMO NOMA architecture, which has fewer RF chains than antennas. Consequently, the energy consumption caused by the RF chains may be reduced compared to a fully digital MIMO system.

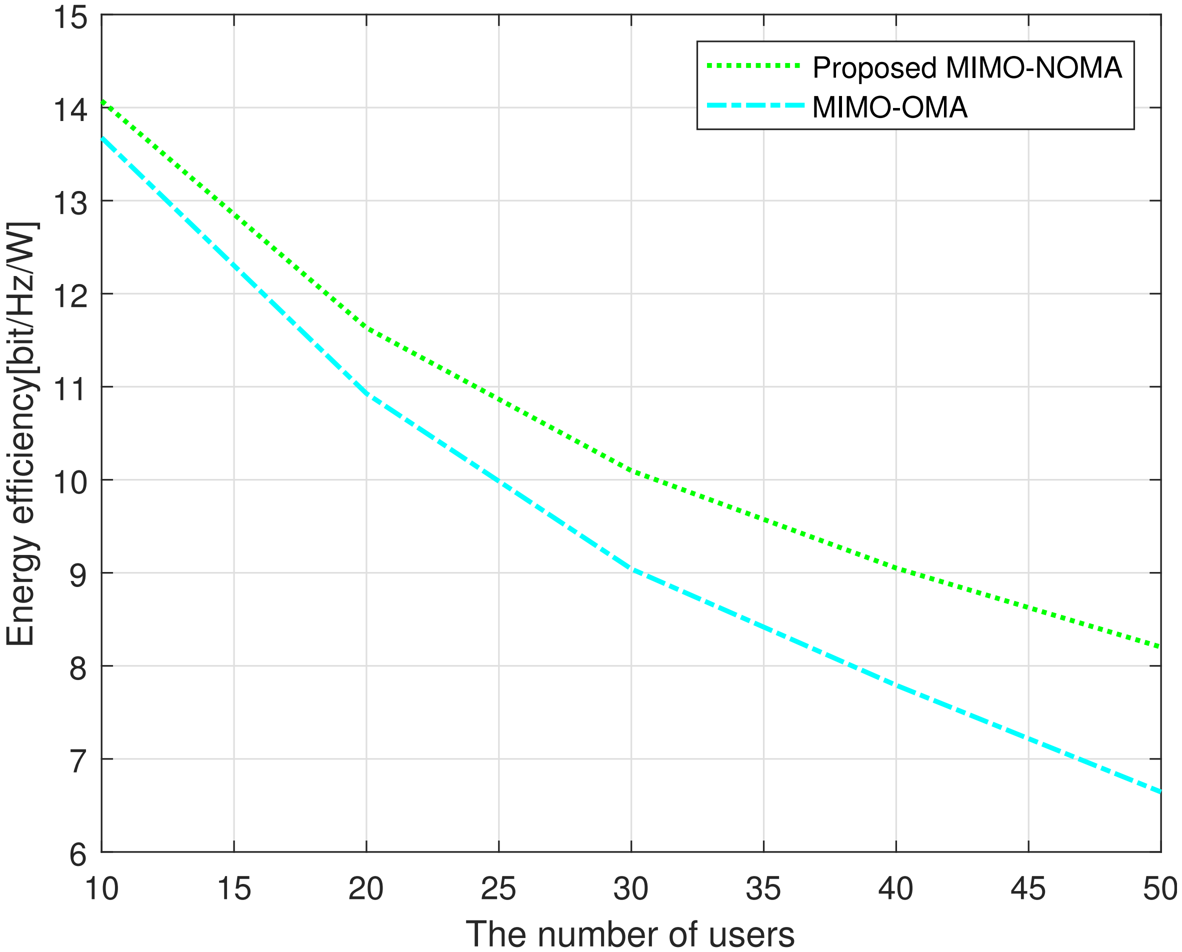


Figure 4.7: Energy efficiency against the number of users K.

The performance comparison in terms of energy efficiency against the number of users is shown in Figure 4.7, where SNR is set as $10dB$. We can see that the energy efficiency of the proposed BS-MIMO MOMA scheme is higher than all of other three schemes even the number of users is very large (e.g., 50 users are simultaneously severed).

4.7 Convergence of Power Allocation

In this subsection, we evaluate the convergence of the proposed iterative dynamic power allocation(PA) algorithm in Section, where the number of users is set as K = 32, and SNR = $10dB$. As shown in Figure 4.8, the spectrum efficiency tends to be stable after 10 times of iteration, which verifies the convergence of the proposed power allocation.

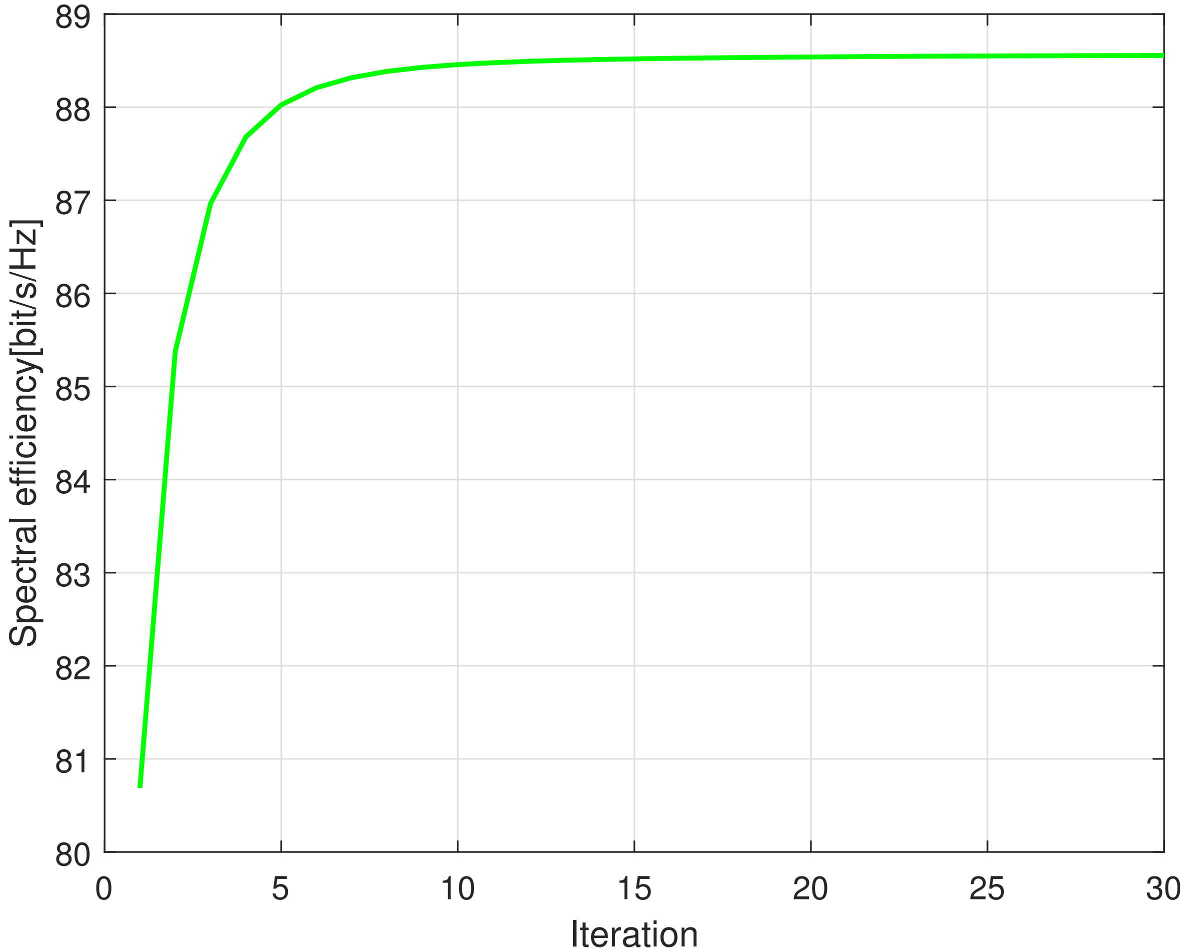


Figure 4.8: Spectrum efficiency against the number of iterations for power allocation.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

This thesis proposes a transmission technique called BS-MIMO NOMA, which combines NOMA with BS-MIMO to overcome the limited ability of current BS-MIMO systems to serve only one user in each beam at the same time-frequency resources. The proposed BS-MIMO NOMA technology allows for a larger user count than the number of RF chains and boosts capacity by utilizing NOMA to establish strong connections. To reduce inter-beam interferences, a precoding technique based on the zero forcing principle is employed, taking into account the strong correlation between users in a single beam at mm-wave frequencies. Power allocation is jointly optimized for all users by maximizing the total rate potential to reduce both inter-beam and intra-beam interferences using an iterative optimization method. Simulation results show that the proposed BS-MIMO NOMA outperforms current BS-MIMO OMA in terms of spectrum efficiency.

Future Work

In this thesis, the proposed BS-MIMO NOMA system. The future scope is:

- For the proposed BS-MIMO NOMA system in the extremely dense network, in the future we will take into account advanced user pairing/clustering(UDN).
- Cooperative transmission is crucial for NOMA since, in contrast to OMA, consumers who are currently experiencing bad channel conditions may experience some performance loss. By using cooperative NOMA, It is possible to increase these users' reception dependability.
- Network MIMO has recently received a lot of attention, thus cell borders are blurred and cooperation between base stations from various cells is promoted.

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