# Performance Analysis of Optimized Particle Filter Precoding for Multi User Massive MIMO System

Terefe Abebe Beyene

A Thesis Submitted to the Department of Electronics and Communication Engineering
School of Electrical Engineering and Computing
Presented in Partial Fulfilment of the Requirement for the Degree of Master's in Communication Engineering

Office of Graduate Studies
Adama Science and Technology University

July, 2023

Adama, Ethiopia

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Co-advisor: Mr. Tadesse Hailu

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# DECLARATION

I hereby declare that this Master Thesis entitled "Performance Analysis of Optimized Particle Filter Precoding for Multi User Massive MIMO System" is my original work. That is, it is 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.

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## RECOMMENDATION OF ADVISORS

We, the advisors of this, hereby certify that we have read the revised version of the thesis entitled "Performance Analysis of Optimized Particle Filter Precoding for Multi User Massive MIMO System" prepared under our guidance by Terefe Abebe submitted in partial fulfillment of the requirement for the degree of Masters of Science in Communication Engineering. Therefore, we recommend the submission of revised version of the thesis is to the department following the applicable procedures.

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| Co-advisor | Signature | Date |

## APPROVAL PAGE OF M.Sc. THESIS

We, the advisors of the thesis entitled "Performance Analysis of Optimized Particle Filter Precoding for Multi User Massive MIMO System" and developed by Terefe Abebe, 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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## APPROVAL OF BOARD OF EXAMINERS

We, the undersigned members of the Board of Examiner of the thesis by Terefe Abebe have read and evaluated the thesis entitled "Performance Analysis of Optimized Particle Filter Precoding for Multi User Massive MIMO System" and examined the candidate during open defense. That is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Communication Engineering.

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## ACRONCYMS

| | |
|---|---|
| 1G | First Generation |
| 2G | Second Generations |
| 3G | Third Generations |
| 3GPP | Third Generations Partnership Project |
| 4G | Fourth Generations |
| 5G | Fifth Generations |
| 6G | Sixth Generations |
| AMP | Approximates Message Passing |
| CD | Cholesky Decomposition |
| CE | Constant Envelop |
| CG | Conjugate Gradient |
| CI | Chebyshev Iteration |
| CSI | Channel States Information |
| DPC | Dirty Paper Coding |
| GS | Gauss-Seidel |
| IEEE | Institute of Electrical and Electronics Engineers |
| IoT | Internets of Things |
| JI | Jacobi Iteration |
| LED | Light Emitting Diode |
| LR | Lattice Reduction Aided |
| M2M | Machines to Machine |
| MATLAB | Matrix Laboratory |
| MIMO | Multi Input Multi Output |
| MMSE | Minimum Mean Squares Error |
| MRT | Maximum Ratio Transmission |
| MU-MIMO | Multi User Multi Input Multi Output |
| NI | Newton Iteration |
| NSA | Neumann Series Approximations |
| OPF | Optimized Particle Filter |
| PAPR | Peak Average Power Ratio |

| | |
|---|---|
| QAM | Quadrature Amplitude Modulations |
| QP | Quantized Precoding |
| RF | Radio Frequency |
| SOR | Successive Over Relaxation |
| SU-MIMO | Single User Multi Input Multi Output |
| TH | Tomlinson-Harashima |
| TPE | Truncated Polynomial Expansion |
| UE | User Equipment |
| VLC | Visible Light Communications |
| VP | Vector Perturbation |
| ZF | Zero Forcing |

# *ABSTRACT*

*Due to globalization, the demands of network subscribers for different services and the total number of users in the communication industry is growing day to day. To address the demand of these users, the communication industry needed to be upgraded in a way to support the growing demand. To address the growing demands of users, higher spectral efficiency, higher data rates (HDR), and higher throughput with low latency are required. However, getting higher spectral efficiency, higher data rates (HDR), and higher throughput with low latency in the transmission medium is a very difficult challenge. Due to the above-mentioned and more factors the current network systems are unable to deliver the required spectral efficiency (SE). Precoding is* essential *in massive MIMO systems because it* optimizes *throughput while reducing the impacts of path loss and interference. Massive MIMO systems gain greatly from the precoding approach, but adding more computations, also makes the system's total computations more difficult. With more antennas, the computational complexity rises as well. Therefore, it is more practicable to employ simple and effective precoders for massive MIMO systems. For this issue to be solved different researchers have suggested different linear and non-linear precoding techniques. In this thesis work optimized particle filter non-linear precoding technique is proposed to mitigate this issue. The computational complexity analysis of TH, DPC, and VP and proposed optimized particle filter precoding techniques. From the analysis result optimized particle filter has less execution time than others non-linear precoding techniques. Signal-to-noise ratio versus bit error rate, Signal-to-noise ratio versus spectral efficiency, the number of transmit antennas versus average sum spectral efficiency, and other were used to analyze the results. The simulation result shows that the proposed optimized particle filter precoding outperforms the existing non-linear precoding those are, Tomlinson- Harashima (TH), Dirty Paper Coding (DPC) and Vector Perturbation (VP) precoding techniques in average sum spectral efficiency and bit error rate performance on different modulation techniques.*

***Keywords:*** Optimized Particle Filter Precoding, Linear Precoding, Non-Linear Precoding, Spectral Effeciency ,SNR, BER, Massive MIM

# CHAPTER ONE

# 1. INTRODUCTION

## 1.1. Background of the Study

The number of network subscribers in the communication industry is growing day to day. To address the demand of these users, the communication industry needed to be upgraded in a way to support the growing demand. To address the growing demands of users, it is necessary to have higher throughput, higher data rates, and improved spectral efficiency with less delay. It is a very challenging task to achieve larger spectral efficiency, greater data rate, and higher throughput in the transmission medium with low latency. Because there is a limited spectrum to satisfy these needs in cellular technology. Massive MIMO technology, which employs many antennas at both the transmitters (Tx) and receptions (Rx) portion, is seen to be one of the main study areas nowadays. since it can help to mitigate this problem (Babu et al., 2015).

Due to its ability to significantly increase the system throughput, the massive MIMO transmission system has recently attracted a lot of attention (Hasegawa et al., 2018). The most appealing wireless access solution that can accommodate the requirements of 5G and future networks is the massive MIMO system. It is a development of massive MIMO technology that boosts throughput and spectral efficiency through the connection of hundreds or even thousands of antennas to a base station (BS) (Chataut & Akl, 2020).

Due to the world wide bandwidth bottleneck in the wireless communication sector, massive MIMO wireless access technology has been researched and evaluated. Massive MIMO is an important technology for 5G and future networks. Massive MIMO systems employ several antennas at the transmitter and receiver to achieve remarkable spectrum and energy efficiency with very small or no processing. It is essential to have a deeper understanding of the massive MIMO system for the effective rollout of the 5G and beyond network and to realize a variety of applications for intelligent systems (Chataut & Akl, 2020).

Technological advancement brought different services like online gaming, video calling, and social media application like Twitter, Facebook, and WhatsApp and these services have transformed our life significantly. The demand for traffic on today's network systems is considerable due to globalization and the rise in network customers seeking these and other services. Additionally, the present network systems are unable to provide the necessary spectral efficiency due to the advent of new ideas like; Machine to Machine (M2M) communications, the Internet of Things (IoT), virtual reality, and augmented reality (Chataut & Akl, 2020).

Many enabling technologies have been put out in recent years by several researchers to accomplish 5G and future networks. The visible light spectrum, small cells, full duplex technology, Terahertz waves, device-centric architecture, beamforming, and millimeter waves are among them. However, the massive MIMO concept has emerged as the most hotly debated issue in wireless communication systems because of its significant benefits in the standardization of 5G (Chataut & Akl, 2020).

It has been demonstrated that massive MIMO systems perform well in both indoor and outdoor settings. Simple baseband and radio frequency circuits are used, and it also delivers dependable operation. It is feasible to develop low-complexity, low-cost hardware for both digital baseband and analog RF chains as part of the hardware implementation of a massive MIMO. Many precoding, detection, scheduling, and equalization methods have been developed to further reduce costs and power consumption (Chataut & Akl, 2020).

Massive MIMO technology goes beyond simple MIMO technology advancement. There are still a lot of problems and difficulties that need to be solved before it can become a reality. Precoding, channel estimation, signal detection, pilot contamination, hardware impairment, and user scheduling are the core problems in massive MIMO systems that need to be solved. Precoding techniques are emphasized in this thesis work to handle the difficulties of a massive MIMO system.

## 1.2. Statement of the Problem

Due to globalization, the number of network subscribers is increasing. The demands of network subscribers for different services like online gaming, video calling, and social media application like Twitter, Facebook, and WhatsApp is greatly increasing. The implementation of new concepts like a machine to machine (M2M) and Internet of Things (IoT) communications, virtual reality, augmented reality, and more requires more spectral efficiency than the current network system behaves. Due to the above-mentioned and more factors the current network systems are unsuitable for offering the needed spectral efficiency. To solve this issue different researchers are focusing on different enabling technologies.

Network technologies that support 5G and beyond include millimeter waves, device-centric architecture, beamforming and small cells, full duplex technology, Terahertz wave, massive MIMO, and visible light spectrum most researchers are attracted by massive MIMO system, due to its enormous benefits in the standardization. However, massive MIMO system has fundamental challenges like precoding, channel estimation, signal detection, pilot contamination, hardware impairment, and user scheduling needed to be addressed. Different researchers are working on different massive MIMO challenges to solve its challenge and realize a massive MIMO system. In this thesis work, the precoding technique is focused on.

In massive MIMO systems, precoding is essential because it increases throughput while minimizing the effects of path loss and interference. In massive MIMO systems, the base station calculates the CSI using uplink pilot signals or user terminal feedback. Due to various environmental conditions on the wireless channel, the received CSI at the base station is not uncontrollable and not perfect (Fatema et al., 2018). Although the base station does not always get error-free CSI, the estimated CSI still has a significant impact on the base station's downlink performance. To reduce interference and improve spectral efficiency, estimated CSI and the precoding technique were employed at the base station. The performance of downlink massive MIMO depends upon the accurate estimation of CSI and the precoding technique employed.

Although the precoding technique provides immense benefits to massive MIMO systems, it also increases the computational complexity of the overall system by adding extra computations. The computational complexity increases along with the number of antennas. Thus, low complex and efficient precoders are more practical to use for massive MIMO systems. In this thesis work, optimized particle filters are proposed to mitigate this issue.

## 1.3. Objectives

### 1.3.1. General Objective

The general objective of this thesis is performance analysis of optimized particle filter precoding techniques for multi user massive MIMO System.

### 1.3.2. Specific Objectives

Specific objectives of the study are:

- To analyze the performance of the proposed optimized particle filter precoding technique in channel state information (CSI) perspective to reduce Bit Error Rate.

- To compare the complexity of the Proposed Optimized Particle Filter (OPF) precoding technique with other precoding techniques.
- To assess the spectral efficiency for a multi-user massive MIMO system by employing Tomlinson- Harashima (TH), Dirty Paper Coding (DPC), Vector Perturbation (VP), and Proposed Optimized Particle Filter (OPF) precoding techniques.

## 1.4. Contribution of the Study

An organized and well-studied research report on precoding techniques provides strong information to address the challenges of multi-user massive MIMO Systems. By adding additional computations, the majority of precoding approaches raise the computational complexity of the system as a whole. As there are more antennas, the computation becomes more complicated. Therefore, for multiuser massive MIMO systems, using low complexity and efficient precoding algorithms is more realistic. By analyzing the computational complexity of non linear precoding techniques, it is possible to design algorithms that can operate in real-time, thereby improving system performance.

This thesis provide high-quality voice and video communication, reliable data transmission, and efficient control of systems in communication industry. Also provides a detailed assessment of precoding techniques and proposes the optimized particle filter precoding technique to realize a multi-user massive MIMO system.The optimized particle filter precoding technique is not used by any researcher for multi user massive MIMO systems.

## 1.5. Scope of the Study

This thesis mainly focuses on the way and system of realizing the 5G and beyond wireless Technology. Most researchers agree on the following enabling technologies of 5G and beyond wireless networks like millimeter waves, device-centric architecture, beamforming, small cells, full-duplex (FD) technology, Terahertz wave, massive MIMO, and visible light (VL) spectrum. But most of them prefer massive MIMO systems to realize future networks according to the demand of the users. However, massive MIMO system has fundamental challenges like precoding, channel estimation, signal detection, pilot contamination, hardware impairment, and user scheduling needed to be addressed.

Different researchers are working on different massive MIMO challenges to get a mitigation way and realize a massive MIMO system. In this thesis work, the precoding technique is focused on. The majority of precoding approaches include additional calculations, which raises the system's total computational complexity. With more antennas, the computational complexity rises as well. Therefore, it is more practicable to adopt simple and effective precoding algorithms for multiuser massive MIMO systems.

## 1.6. Limitations of the Study

This thesis is limited to the simulation of the system which is done using application software called MATLAB and simulation is undertaken on multi-user massive MIMO scenarios, by assuming all the available resource is used by multi-user massive MIMO. The implementation of the real system is difficult because of the availability of the component.

## 1.7. Thesis Outline

The outline of this thesis is summarized as follows:

Chapter 1 Introduction: The main topic raised in this chapter is listed as follows: background of the study, statement of the problem, objectives, contribution of the study, scope of the study, and limitation of the study.

Chapter 2 Literature Review: The main topic raised in this chapter is listed as follows: 5G and beyond Wireless Communication, Enabling Technologies of 5G and Beyond Network, Why Massive MIMO System? Massive MIMO Challenges, Precoding Techniques and Review of Related Works.

Chapter 3 Methodology: The main topics that are raised in this chapter are materials and methods, precoding techniques, and performance metrics.

Chapter 4 Result and Discussion; in this chapter, a detailed analysis of the result is discussed. The result is simulated under acceptable parameters. The Signal Noise Ratio versus Bit Error Rate, Signal Noise Ratio versus Outage Probability, and Average Achievable Rate analysis are used to check the improvement of the system.

Chapter 5 Conclusion and Recommendation:

# CHAPTER TWO

# 2. LITERATURE REVIEW

## 2.1. Chapter Overview

In this chapter, 5G and beyond wireless communication, the requirement of 5G and beyond (6G) wireless communication, enabling technologies of 5G and beyond network, the reason for the need for massive MIMO system, massive MIMO challenges and mitigation, precoding techniques and review of related works according to the objective of the thesis reviewed.

## 2.2. Future Wireless Communication

In wireless communication systems data is transmitted without the need for wire, cable, or other electrical conductor. The development of mobile communication technology began in the 1980s. Numerous improvements in mobile communication technology have been made since 1980. Technology for cellular networks has progressed from 1G to 5G and beyond. Cellular networks primarily consist of base stations, user equipment (phones), and core networks (Chataut & Akl, 2020).

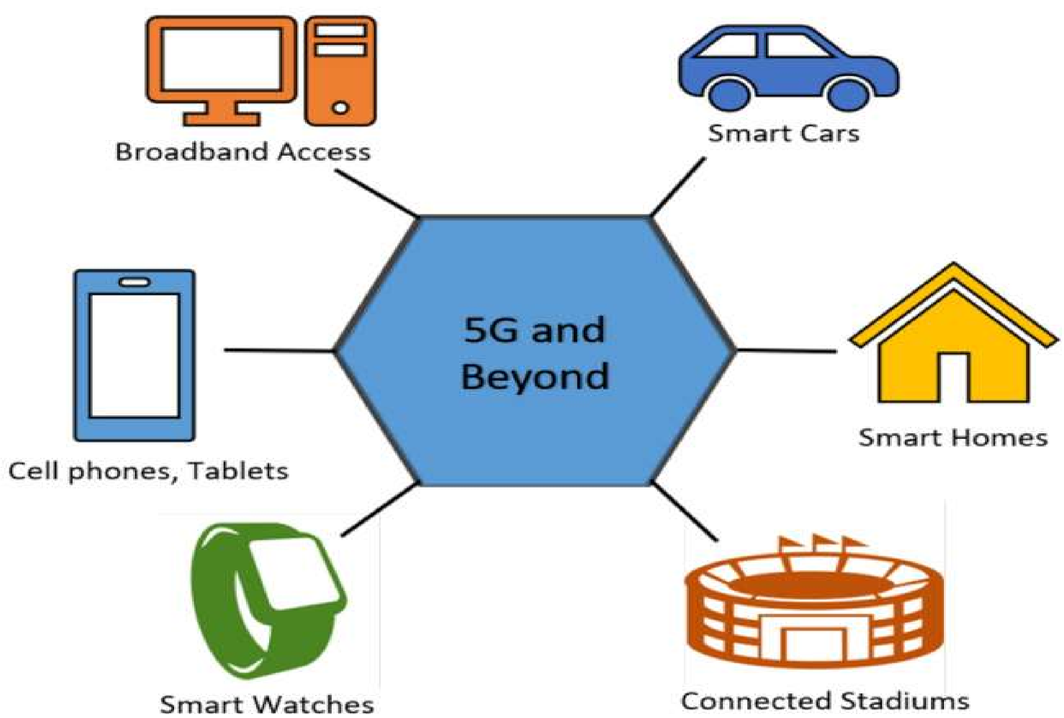


Figure 2. 1 5G and beyond Technology (Chataut & Akl, 2020)

The increasing need for high data rates across an increasing number of devices from consumers is the primary driver of wireless technology advancement. However, it is becoming increasingly crowded daily since there is a limited amount of spectrum available for mobile communications. Current networks like 2G, 3G, and 4G sometimes struggle to provide the connection and data rates needed, especially when demand is strong. Users may experience poor data speeds, sluggish connectivity, delays, or a total loss of services during periods of peak demand. Therefore, there is a significant demand for wireless technology to evolve constantly to increase the quality of communication (Agyapong et al., 2014).

The first mobile phone was introduced to users as part of first-generation technology. Users could only access voice services on the analog network infrastructure. Data services were nonexistent during the 1G period. At that time, service providers charged their clients a hefty price for technology. The users' access to coverage and capacity was constrained (Santhi et al., 2003).

Digital networks were introduced in the 2G period. Data services are now available to end customers as a result of digital technology advancement. To make the phone more affordable for end customers, the system's coverage was increased (Santhi et al., 2003).

Data and voice were both available on the 3G network. This technique made mobile internet available. The advent of the internet made it feasible to browse videos and send emails online. With the advent of smartphones, consumers could now use their phones instead of PCs for both work and play. The need for data rates has grown as a result.

Genuine mobile broadband with higher data rates has been made possible by fourth-generation technology, which may be used for streaming music and live video, mobile data apps, online gaming, and many other things. To connect with other devices, 4G has provided a variety of data plans and mobile devices (Mshvidobadze, 2012). Each generation's progress brought about improvements of its own.

The implementation of the fifth-generation wireless communication systems, which will be quicker than the 1G to 4G systems, is now underway. This generation will provide up to 10Gbps of data throughput, minimal latency, and higher dependability. It supports several Internet of Things devices and intelligent cars (Dumari et al., 2023).

The 6G mobile technology is anticipated to have fewer restrictions. It is presently under construction and is anticipated to transmit data at amazing rates of Tb/s. A huge optical network, smart antenna, and mobile phones with enormous memory are required for sixth-generation wireless technology. The wireless network will support artificial intelligence and be cell-free. Although the frequency range that 6G networks will use is unknown, a much higher frequency band would certainly be needed to increase the data capacity necessary for 6G networks. Although the frequency range for 6G is significantly higher in THz bands, the frequency range for 5G is projected to be between 30 GHz and 300 GHz (millimeter waves).

Commercial 6G terahertz spectrum usage is anticipated to be available within the next 5-7 years. A few examples of applications for 6G networks include tactile internet, industrial internet, networked robotics and autonomous systems, deep-sea tourism, networked robots and autonomous systems, networked robots and autonomous systems, multi-sensory extended reality, and block chain technology.

## 2.3. Enabling Technologies of 5G and Beyond Network

The commonly accepted 5G objectives include fast data speeds, minimal latency, more connected devices, longer battery life, and extra ordinarily high traffic volumes. Not just a tweak to 4G, the switch to 5G represents a fundamental change in every facet of the network. A variety of cutting-edge technology proposals have been put out to fulfill the cutting-edge requirements of 5G and other technologies.

To build networks for 5G and beyond, many innovative ideas have been proposed. The key significant enabling technologies that have been taken into account for 5G and 6G systems are millimeter waves, small cells, beamforming, device-centric architecture, full-duplex technology, massive MIMO, Terahertz wave, and visible light spectrum (Chataut & Akl, 2020).

### 2.3.1. Millimeter Waves

When compared to other applications, such as radio astronomy, medical imaging, microwave remote sensing, amateur radio, terahertz computing, and amateur radio, cellular communication frequently takes place at frequencies below 6 GHz. Frequency spectrum congestion is mostly caused by the sharp increase in data traffic. The network became slower and less trustworthy as a result of inadequate bandwidth. To alleviate the aforementioned problem, the bulk of research suggests utilizing a frequency greater than 6 GHz. The term "millimeter wave" describes radio waves with a frequency range of 30 GHz to 300 GHz and a length range of 1 to 10 mm. Different researchers have studied millimeter wave technology and raised the main challenges in it (Chakraborty et al., 2018; Rangan et al., 2014; X. Wang et al., 2018). The bandwidth of millimeter waves can be 10 times greater than that of the whole 4G cellular spectrum. Millimeter Waves are not suitable for long-distance range applications because it has a lower wavelength. Millimeter

Waves are unable to pass through walls and other obstructions and frequently get absorbed by rain.

### 2.3.2. Sub Millimeter or Terahertz Band

The need for wireless communication has expanded as a result of globalization. A greater spectrum will soon be required for 6G technology. The wave band for 6G wireless communication technology is anticipated to be in the higher frequency range that is greater than the millimeter wave band (30 GHz-300 GHz). Between 300 GHz and 3THz, the terahertz frequency range is a currently active research field and a crucial one for the wireless communication sector. Terahertz band has several advantages, scalable deployment, improved security, access to green field spectrum, low power consumption, a front-haul boost for wireless networks, minimal antenna size, and focused beams (Singh et al., 2019).

Applications including imaging, spectroscopy, holographic telepresence, and large-scale communications would all benefit from terahertz technology. However, there are some difficulties and pressing problems with terahertz band deployments, incorporating complex antenna design for higher antenna gain, deployment and specification of access points, complex circuit design, high propagation loss, and advanced mobility management (Singh et al., 2019).

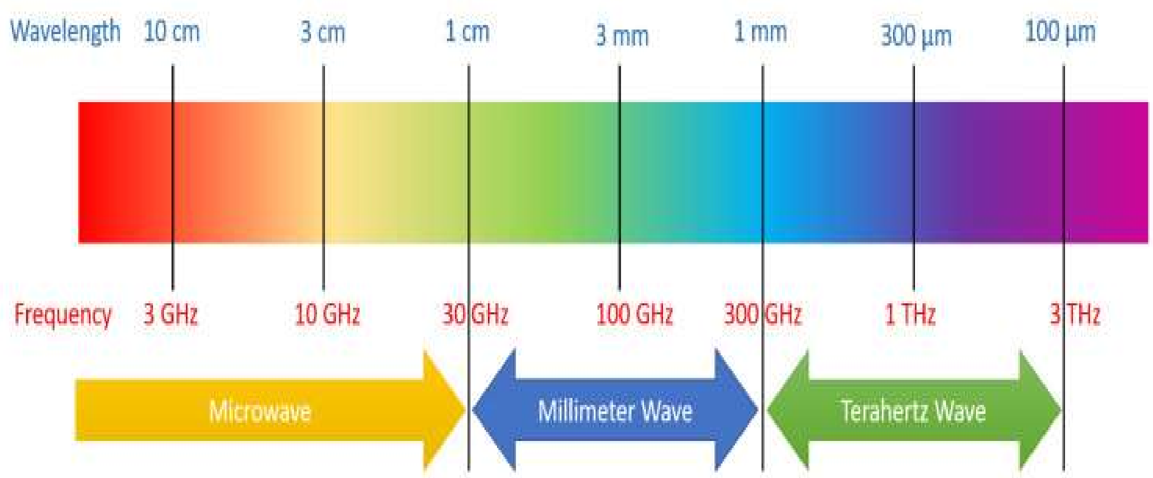


Figure 2. 2 Sub-Millimeter or Terahertz Band (Chataut & Akl, 2020)

### 2.3.3. Small Cells or Heterogeneous Networks

Small cells are discrete, low-power base stations that may be placed every 100 meters to cover constrained, localized regions. These low-power base stations keep the signal from dropping in areas with a lot of people. Due to their modest size, small cells may be positioned everywhere. The small cells will be necessary for future technologies like 5G to provide extremely low latency and fast mobile internet. Microcells, femtocells, and picocells are additional classifications of small cells based on their coverage areas and user capacity (Chataut & Akl, 2020).

### 2.3.4. Beamforming

The method through which a base station may change an antenna's emission pattern is called beamforming (Molisch, 2017). It aids in choosing the best path for delivering info to the consumer. In addition to providing a suitable pathway, it lessens obstruction from other users on the path (Yang et al., 2018). Beamforming offers several benefits for networks running on 5G and in the future.  In 5G and future networks, beamforming technology may be used in several different ways. In massive MIMO systems, the base station may transmit data to the user via several channels, and in millimeter wave systems, it is utilized to increase data rate but does not spread to farther distances since a shorter wavelength also helps to deliver focused beams towards the users. So, beamforming makes it possible for a user to receive a strong signal that is free from outside interference.

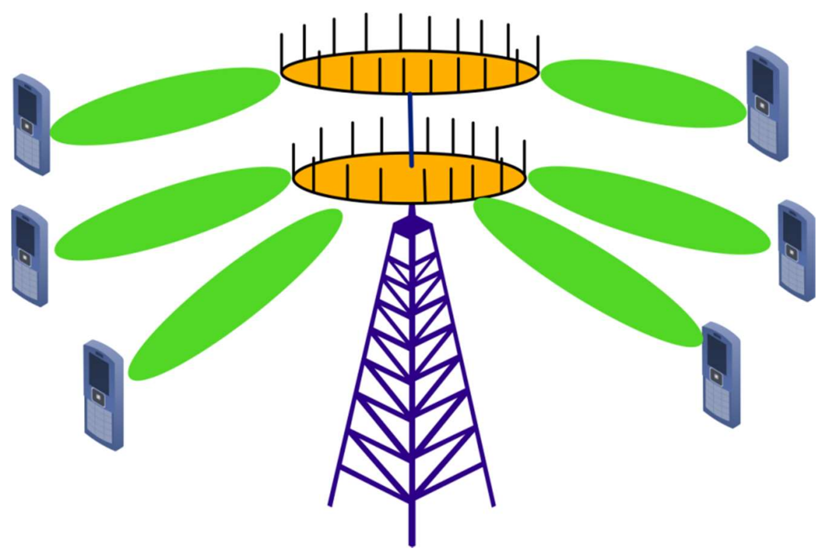

Figure 2. 3 Beamforming (Chataut & Akl, 2020)

### 2.3.5. Device Centric Architecture

The base station-centric architecture is the foundation of the 4G network infrastructure. It features an uplink and downlink connection as well as a control mechanism to access the base station's services. Cell or base station density rises in tandem with the number of users. System incapability results from the additional density. As a result, it has to be improved further for 5G and future networks. The coexistence of several frequency bands with vastly differing propagation properties will be made possible by millimeter waves. To solve problems like network densification and expanded frequency bands, future networks are expected to transit from a base station-centric design to a device-centric design (Boccardi et al., 2014). A user device would exchange information across several heterogeneous nodes to communicate in a device-centric design (Biswash et al., 2014; Mishra et al., 2016).

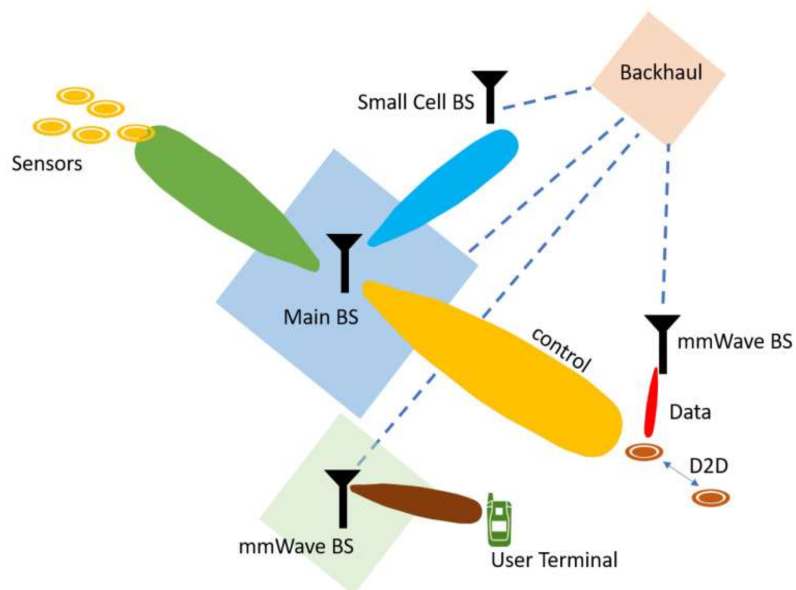


Figure 2. 4 Device-centric architecture (Chataut & Akl, 2020)

### 2.3.6. Full Duplex Technology

Half-duplex wireless communication is the norm, which implies that transmission and reception take place at various times. Full duplexing is a new concept that has been brought by technology in the 5G era and beyond. In full duplexing, transmission, and reception happen simultaneously throughout the same period. This method doubles the gain in spectral efficiency. Self-interference between a sent and received signal is the main obstacle to full-duplex communication (Yang et al., 2018).

Wireless transmission and reception frequently do not occur in the same frequency range to avoid interference. To have orthogonal signals, every bidirectional system needs a distinct downlink channel or frequency domain from the uplink channel. Full duplex, however, exhibits concurrent transmission and reception across the same frequency range. 5G and future technologies are anticipated to utilize full-duplex technology to quadruple network capacity during signal transmission (Mahmood et al., 2017).

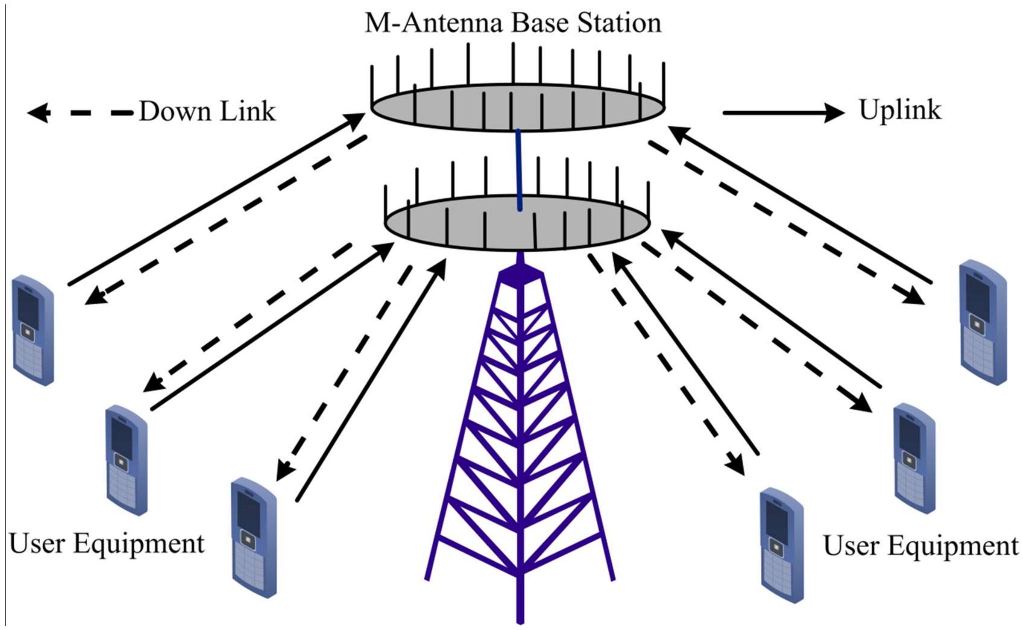


Figure 2. 5 Full duplex Technology (Chataut & Akl, 2020)

### 2.3.7. Visible Light Communication

The performance of optical fiber can help networks of the future since it communicates via visible light. With a visible light spectrum between 400 and 800 THz, it uses LEDs and fluorescent lights to transmit the signal over a shorter distance. VLC can be made with really inexpensive hardware and unlicensed frequencies. VLC is not exposed to any radiation from the outside since it emits no electromagnetic radiation on its own. IEEE 802.15.7 defines a VLC standard, however, the 3rd Generation Partnership Project (3GPP) has not considered it for cellular networks (Giordani et al., 2020). VLC has been acknowledged as one of the essential enabling technologies for 6G networks, and it would be particularly beneficial for applications related to smart cities.

### 2.3.8. Massive MIMO

To achieve great spectrum efficiency and energy efficiency, MIMO systems are a crucial component of today's wireless communication systems. The majority of systems were single-input, single-output, which had a relatively poor throughput and could not serve a large number of users with great dependability. Single-user MIMO (SU-MIMO), among other novel MIMO technologies, have been developed to meet this enormous user demand (Fatema et al., 2018), network MIMO and multi-user MIMO (MU-MIMO) were created. These new technologies, nevertheless, are also insufficient to meet the rising needs. Massive MIMO technology is present in the 5G and beyond network as a potential solution to the issue brought on by high user density and data traffic (Adnan et al., 2016). Massive MIMO has been the subject of several research (Björnson et al., 2017).

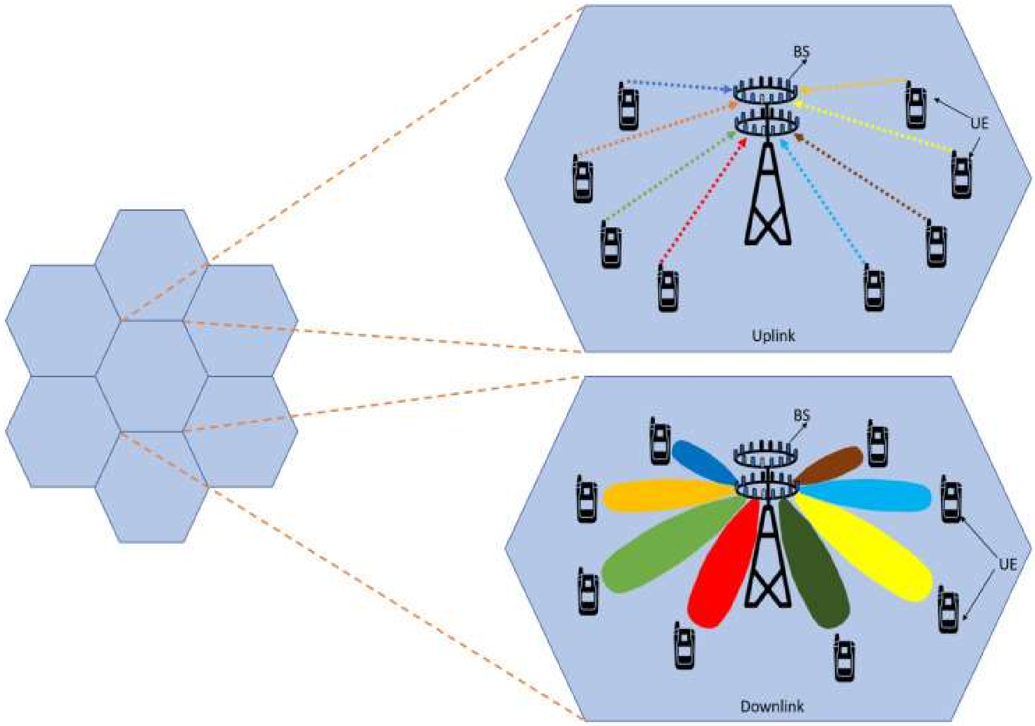


Figure 2. 6 Massive MIMO uplink and down link system (Chataut & Akl, 2020)

Massive MIMO is the most attractive technology for wireless access and beyond 5G. Massive MIMO is an advancement of the existing MIMO technologies now in use in wireless networks. These systems are capable of concurrently serving tens of users by merging hundreds or even thousands of antennas at the base station (Xiang et al., 2016). In a massive MIMO system, as the number of antennas increases, the emitted beams become narrower and more spatially focused on the user. Thanks to these spatially focused antenna beams, the throughput for the targeted user is boosted while the interference to the surrounding user is reduced. There are several benefits when comparing massive MIMO to the traditional MIMO system (Chataut & Akl, 2020).

## 2.4. Why Massive MIMO system?

Massive MIMO has initially proposed a few years ago, but because of its significant benefits in the standardization of 5G, it has emerged as the most popular research topic in the wireless industry. The available MIMO systems have been influenced by the dramatic rise of wireless data traffic. Current technologies are unable to provide enough spectral efficiency in light of the rise of ideas like the Internet of Things, machine-to-machine communication, virtual reality, and augmented reality. Recent research on the massive MIMO system has revealed unprecedented spectrum efficiency, proving its worth. 22 users employing 256-Quadrature Amplitude Modulation (256-QAM) modulation were able to achieve 145.6 bits/s/Hz spectral efficiency across a shared 20 MHz radio channel at 3.51GHz using 128 antennas at the base station in a research conducted in 2015 by Lund University and Bristol University (Malkowsky et al., 2017).

The current MIMO systems are unable to handle the enormous growth in wireless data traffic. With the development of concepts like the Internet of Things, machine-to-machine communication, virtual reality, and augmented reality, the current system is unable to attain the required spectral efficiency. It has been demonstrated that massive MIMO systems can function dependably with a basic baseband and radio frequency circuit. A large MIMO system's hardware implementation has also undergone successful testing, showing that both the digital baseband and analog RF chains can be built using very basic, low-cost technology (Malkowsky et al., 2017).

Numerous indoor and outdoor scenarios have shown that massive MIMO systems perform well. Furthermore, it has been proven that the massive MIMO system provides dependable operation using just a basic baseband and radio frequency circuit. Massive MIMO systems have also been successfully tested in terms of their hardware implementation, and it has been demonstrated that both the digital baseband and analog RF chains of these systems can be built using incredibly basic, low-cost hardware (Chataut & Akl, 2020; Malkowsky et al., 2017).

Numerous precoding, detection, scheduling, and equalization techniques have been developed to further reduce costs and power consumption. Massive MIMO has seen a number of recent innovations and improvements that support its enticing deployment as an essential component of 5G and other future wireless networks.

Massive MIMO has already been implemented in China and Japan for usage with 4G LTE. 2016 saw the deployment of massive MIMO on the network of Japan's SoftBank Group Corp. In 2017, Vodafone and Huawei successfully tested massive MIMO systems in the real world and were able to reach a speed of 717 Mbps. As a small and power-efficient chipset for a massive MIMO antenna design, Nokia developed the ReefShark chipset in 2018. This chipset has been recognized as one of the most promising technologies for implementing big MIMO since it may reduce the size of the massive MIMO antenna in half. Samsung also demonstrated the ability of large MIMO to simultaneously transmitter high-speed video without lag in a crowded setting by testing at a jam-packed stadium in South Korea. Utilizing 2.5 GHz and Massive MIMO on the 3GPP 5G New Radio commercial Network, Sprint Mobile made the first-ever 5G data call in the globe in January 2019 (Chataut & Akl, 2020).

The potential number of base station antennas in massive MIMO systems is infinite. However, 64 to 128 have been practically used in the majority of scenarios with a large MIMO base station. Sprint Network recently unveiled 128 antenna massive MIMO systems (64 for receiving and 64 for sending a signal), working with industry heavy weights Ericsson, Nokia, and Samsung Electronics. The fact that the UE only requires a single antenna and a simple antenna design is one of the main advantages of massive MIMO, whereas the base station requires specialized gear. Therefore, a bigger number of antennas are only required at the base station and not at the user equipment for massive MIMO. Two to four antennas are present in modern cellphones. Although most smartphones now have two to four antennas, massive MIMO will only require one antenna at the UE (Chataut & Akl, 2020).

## 2.5. Massive MIMO Challenges

Massive MIMO is one of enabling technology of 5G and beyond wireless networks. It has several advantages in increasing the spectral efficiency of 5G and beyond the network. Besides its advantages, there are some challenges in the massive MIMO system (Lu et al., 2014). These are pilot contamination, channel estimation, precoding, user scheduling, signal detection, hardware impairment, and energy efficiency. But the focus of this thesis work is on one challenge of the massive MIMO technique namely the precoding technique (Chataut & Akl, 2020).

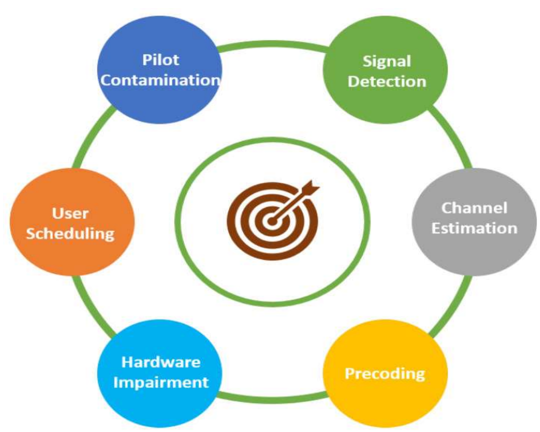


Figure 2. 7 Challenges in massive MIMO deployment (Chataut & Akl, 2020)

## 2.6. Precoding Techniques Massive MIMO

Precoding is a beamforming concept that permits multi-stream transmission in systems with multiple antennas. In massive MIMO systems, precoding is essential because it optimizes throughput while minimizing the effects of path loss and interference. With the use of uplink pilot signals or input from the user terminal, the base station in massive MIMO systems determines the CSI. The received CSI at the base station is not uncontrolled or perfect because of a variety of environmental factors on the wireless channel (Albreem et al., 2021; Ma et al., 2020). Even though the base station doesn't always get perfect CSI, the downlink performance of the base station is heavily reliant on the estimated CSI. As a result, the base station employs the precoding approach and approximated CSI to minimize interference and improve spectral efficiency. Both the precoding method used and an accurate assessment of CSI are necessary for downlink massive MIMO to work as intended. Massive MIMO systems benefit greatly from the precoding process, but it also adds more computations to the system, which makes it more computationally demanding. As there are more antennas, the computation becomes more complicated. For massive MIMO systems, it is therefore more practicable to employ low complexity and efficient precoders.

To reduce the issue of precoding, many precoding methods are recommended by various researchers. We primarily categorize precoding approaches as linear (Albreem et al., 2021; Fatema et al., 2018) and nonlinear precoding (Albreem et al., 2021), peak average power ratio precoding (Albreem et al., 2021), and machine learning precoding (Albreem et al., 2021) techniques.

## 2.7. Review of Related Works

Overview of Massive MIMO Precoding Techniques is studied in (Albreem et al., 2021). Precoding approaches in this study are divided into four groups: linear precoding, non-linear precoding, peak average power ratio (PAPR) precoding, and machine learning precoding. The linear precoding methods may also be divided into fixed point iteration-based algorithms (GS, SOR, CG, JI, QR, and CD), matrix inversion approximation precoders (TPE, NSA, NI, and CI), and basic linear precoders (MRT, ZF, and MMSE). Unfortunately, using a lot of antennas and radio frequency chains (RF) greatly increases the complexity of enormous MIMO systems. The non-linear precoding methods include TH, VP, DPC, and LR. The three precoding methods for PAPR are CE, AMP, and QP. To identify the best precoding algorithm with the least amount of complexity, research is crucial. The primary goal of this work is to educate a wireless communications generalist on such precoding strategies. The researchers made no mention of the (OPF) optimized particle filter precoding approach, in their work.

Technology is described in Massive MIMO Systems for 5G and Beyond Networks: Overview, Recent Trends, Challenges, and Future Research Direction (Chataut & Akl, 2020). In this paper precoding technique is raised as a challenge for implementation of a massive MIMO system. And also provided mitigation techniques form linear and non-linear precoders. But, did not categorize precoding techniques. Optimized particle filter precoding technique is another solution or mitigation technique for precoding technique in massive MIMO system implementation.

Performance Analysis of Linear and Nonlinear Precoding in MIMO Systems is studied in (Babu et al., 2015). The objective of this study is to examine the linear and non-linear precoding methods for MIMO systems, such as Channel Inversion, Block Diagonalization, Dirty paper Coding, and TH precoding. The complexity of linear precoding methods is modest, and they have a respectable capacity. With a sophisticated receiver, nonlinear precoding can access additional capacity. According to simulation studies, Dirty Paper Coding (DPC), a nonlinear precoding approach, performs better than any other precoding method. Another form of precoding approach for more sophisticated systems, like massive MIMO, is not demonstrated in the paper.

The use of a large number of antennas in massive MIMO makes the estimation of channel state information very challenging. Accurate channel state information is essential in capitalizing the advantages of the massive MIMO technology. This paper proposes the application of the Ensemble Square Root Filter (ESRF) and a variant of ESRF, namely a Particle wise Update version of the Ensemble Square Root Filter (PUESRF) to estimate the time-selective frequency-flat fading channel coefficients in the massive MIMO scenario. Simulation results clearly indicate the remarkably superior accuracy and filter convergence of PUESRF estimates as compared to the conventional particle filters (S.,A.T.,& Raveendran, T,2022).

Based on a decision-directed Kalman filter, a new particle filtering framework for data transmission receivers was proposed on the basis of its local symbol-by-symbol hard decisions. This architecture gives distinct particles the freedom to make various decisions, giving the receiver the opportunity to investigate various transmission symbol sequences. The weight of the particle will be high for people that made the right judgments in the past, while it will be low for those that made the bad ones. High-weight particles will survive during the resampling process, while low-weight particles will be eliminated, creating room for the resampling of new particles from the surviving ones.The choice of the importance distribution is a key factor in importance sampling, and the fundamental innovation is the suggestion of an importance distribution that transforms the particle-based Kalman filters into decision-directed ones. One significant advantage of our suggested solution is that since it is not data-aided, it does not require pilot symbols, preserving transmission rate. The MIMO systems influenced by phase noise, where the channel state vector consists of several parameters, were described and developed as an important application example. License. (Spalvieri, A., Reggiani, L., & Dossi, L, 2022).

RF beamforming matrix construction algorithm design and implementation study for mobile situations. Accordingly, to lessen the computational complexity of building an RF beamforming matrix, this study provides a mixture particle filter that takes use of the temporal continuity of beam clusters in a mobile mm Wave channel. Additionally, the parallel processing architecture of this beam-tracking particle filter supports the tracking of numerous beam clusters in the mm Wave channel. Finally, the hybrid beamforming system for mm Wave MIMO systems was used to verify the beam-tracking particle filter, which had been constructed on a field-programmable gate array platform. (Huang, H. Z., Wang, Y. C., & Huang, Y. H, 2020).

This study developed a suboptimal particle filter that uses swarm behavior in particle propagation to overcome the limitations of the prior importance density and noise uncertainty (Hoang, H. H., & Kwan, B. W,2013). A MIMO wireless communication system operating in a Rayleigh flat fading channel will use the proposed method to estimate channel state information and detect transmitted symbols. For wireless communications, particle filters have been used to successfully track MIMO flat fading channels. A particle filter's performance cannot always be improved by finding the ideal importance density. The anticipated particles are moved to the low-error zone by a class of suboptimal particle filters, which employ the prior distribution as the important density.

Rayleigh fading channel performance of huge multiple input multiple output uplink system was proposed by ( Al-Rawi, M., & Al-Rawi, M,2016). Utilizing the maximum-ratio-combining, minimum mean-square error, and linear detection techniques, the performance is evaluated in terms of spectral and energy efficiency. According to the simulation results, adding more base station antennas boosts spectral and energy efficiency. Additionally, the spectrum and energy efficiency of the receiver with least mean-square error is superior to the receiver with zero forcing, and the latter is superior to the receiver with maximum ratio-combining. Additionally, as spectral efficiency increases, energy efficiency declines.

With both perfect and imperfect channel state information, the performance of the spatially correlated Rayleigh fading channel's multicellular DL system is examined (CSI). Intra-cell interferences are reduced by precoding, and the PC effect is decreased by PRF by allocating orthogonal pilots to nearby cells. Maximum ratio transmitter (MRT), zero forcing (ZF), and minimum mean square error (MMSE) precoding techniques are combined with PRF to examine the SE performance of a multi-cell Ma-MIMO system. MMSE provides the best SE performance for both CSI and has the highest SE at PRF of four when the number of antennas is varied, according to a performance comparison of precoding approaches. System performance with perfect CSI is better than system performance with imperfect CSI when both the number of users and antennas are raised at the same time and $M > K$ (Admassu, G (2022).

# CHAPTER THREE

# 3. MATERIALS AND METHODS

## 3.1. Introduction

This chapter mainly focuses on materials and methods used to accomplish the research work, precoding techniques, and simulation parameters.

## 3.2. Materials

Software materials used in this thesis are MATLAB R2021a, Math Type 6.0, Microsoft Word, and Concept Draw Office. Concept Draw Office is used to draw block diagrams and figures. MATLAB R2021a, which is computing software that consists of an Editor, which is used to write code for the entire system. Microsoft Word is an integrated writing environment. It is a writing tool that is user-friendly to write.

## 3.3. Methods

First different literatures are reviewed and the research gap is identified. Then the data that are directly related to the research problem is collected. The collected data are studied and analyzed. Then by understanding the concept, the MATLAB code is written on MATLAB R2021a. From the simulation result the best solution for a particular and specified case according to the scientific research method is recommended.

## 3.4. Precoding Techniques

Precoding is a beamforming technique that enables multi-stream transmission using several antenna systems. (Acheampong et al., 2019). Precoding is a critical approach in massive MIMO systems because it boosts throughput while helping to minimize the impacts of interference and path loss. The CSI estimation is done with the help of the feedback sent from the user terminal or the uplink pilot signal sent by the user terminal in a massive MIMO system. Due to several environmental barriers on the wireless channel, the received CSI at the BS is poor and uncontrolled.The massive MIMO's BS utilizes precoding techniques and the anticipated CSI to decrease interference and increase spectral efficiency. Massive MIMO systems benefit substantially from precoding techniques. Unfortunately, these benefits are offset by a high level of computing complexity that is inversely proportional to the number of antennas. Consequently, it is essential to use low-complexity precoders in massive MIMO systems.

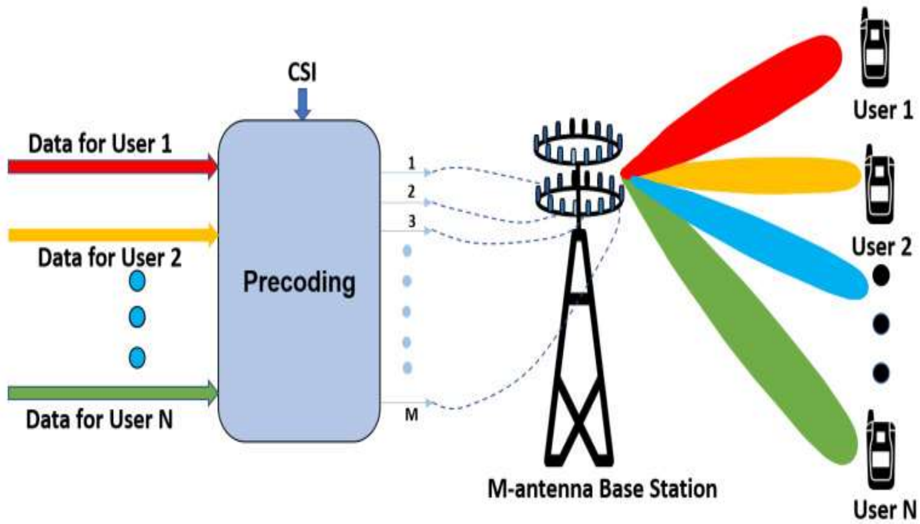


Figure 3. 1 Precoding in a massive MIMO system with M antennas at the base station communicating with N users (Chataut & Akl, 2020)

Many precoding methods, including linear precoding, nonlinear precoding, peak average power ratio (PAPR) precoding, and machine learning precoding, have been suggested for large MIMO systems. In big antenna systems or huge MIMO systems, all precoding approaches other than linear precoding techniques offer superior performance but have very high computational complexity. Maximal Ratio Combining (MRC), Zero-Forcing (ZF), Water Filling (WF), and MMSE are examples of linear precoders that have reduced computing costs and can perform close to optimally. (Albreem et al., 2021).

One of the important concepts in massive MIMO systems is a precoding approach that shifts the complexity system from the side of receiving terminals to the side of BS by using a potent signal processing technique at the transmitter side. In a genuine wireless propagation situation, where the accuracy of DL transmission significantly relies on CSI, it might be difficult to get a reliable CSI. CSI that isn't perfect can be handled with precoding technology.

By guiding the beams in a certain direction toward the receiving terminal, massive MIMO precoding technology has been shown in several tests to be essential in reducing the bottleneck that is restricting the system's performance. When the number of antennas approaches infinity, the use of precoding technology in massive MIMO systems results in the elimination or cancellation of the effects of interference and fading, enhancing throughput, and increasing capacity (Bjornson et al., 2014). Although there are several other types of precoding algorithms, non-linear precoding approaches are the major emphasis of this thesis. These include non-linear precoding, PAPR precoding, and machine learning-based precoding algorithms.

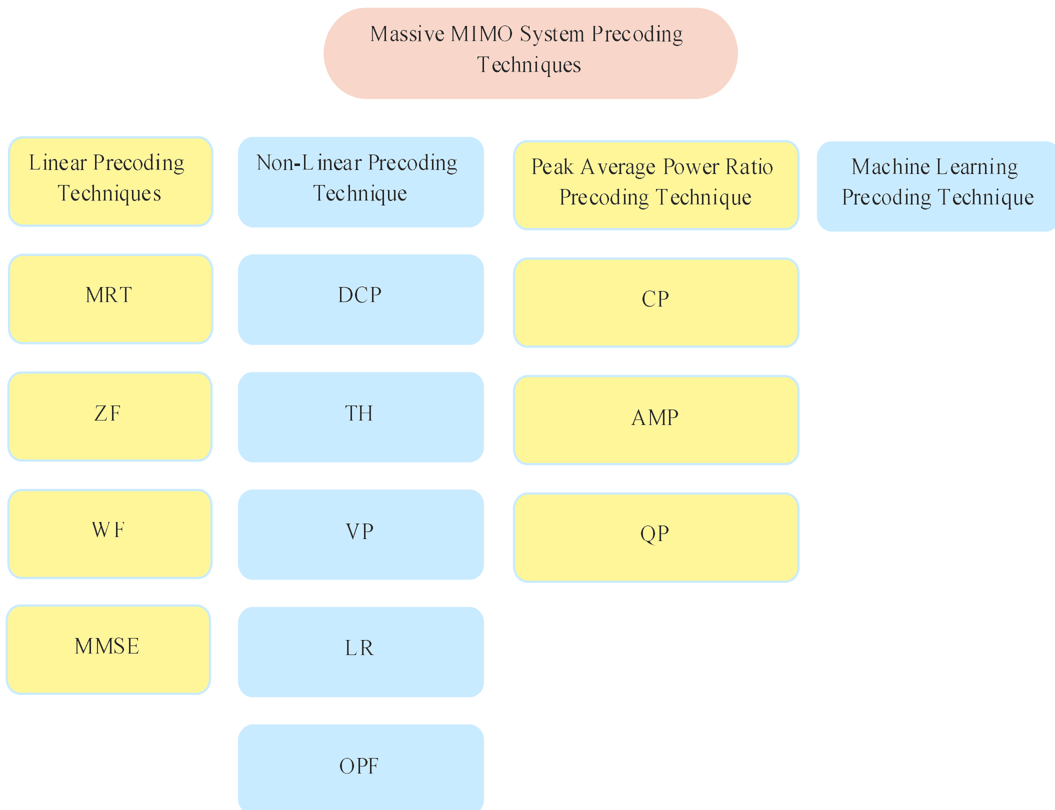


Figure 3. 2 Massive MIMO Precoding Techniques (Albreem et al., 2021)

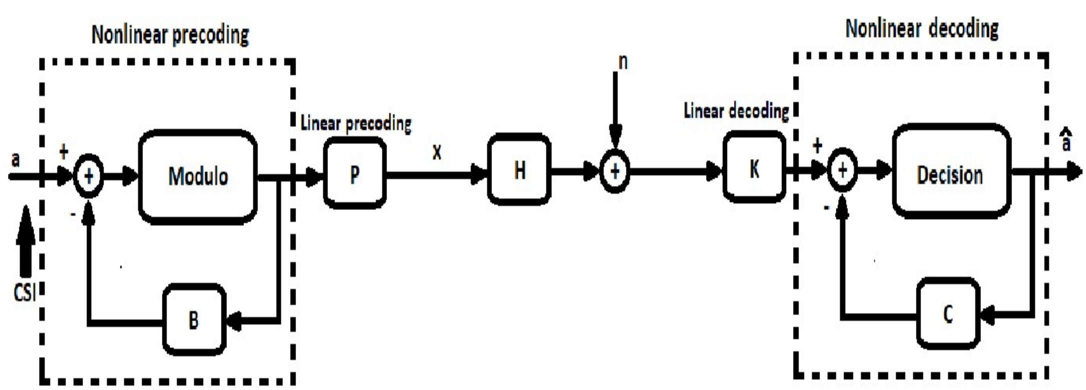


Figure 3. 3 Generalized block diagram of communication systems with precoding and decoding techniques (Albreem et al., 2021)

### 3.4.1. Linear Precoding

A feed-forward matrix for linear precoding is called P, a feedback matrix for linear precoding is called B, a feed-forward matrix for linear decoding is called K, and a feed-forward matrix for non-linear precoding is called C. These matrices describe whether a hybrid, linear, or non-linear precoding approach is needed. For example, the generalized precoding approach functions as the linear precoding technique when B = 0 (Albreem et al., 2021). The average power is changed using modulo arithmetic (Pappa et al., 2017). It is believed that a single BS is providing service to N single antenna receiving terminals, where N ≤ M, using M transmitted antennas. Considered is a frequency-flat channel, which displays coefficients across N receiving terminals and M transmitting antennas. Due to the channel reciprocity in the TDD mode, the DL transmission shares the same channel matrix H as the UL transmission throughout the channel coherence time (Lu et al., 2014). It is possible to describe the channel matrix H ∈ C $^{M\times N}$ as:

$$\mathrm{H} = \begin{bmatrix} h_{11}, h_{12} \dots\dots h_{1N} \\ \cdot \\ \cdot \\ h_{M1}, h_{M2} \dots\dots h_{MN} \end{bmatrix} \mathrm{H}\ \hat{I}\ \mathcal{E}^{MN} \tag{3.1}$$

In the DL transmission, where M > N, the sent signal for the N users can be expressed as

$$\mathrm{X} = \sqrt{r}\ p_{a,}\ x\ \hat{I}\ \mathcal{E}^{M.N} \tag{3.2}$$

Where P is an M × N linear precoding matrix, a denotes an N × 1 transmitted vector before precoding and is then transmitted average power. P, the precoding matrix, and H are connected. The N ×1 vector at N-received terminals transforms into the DL channel in the TDD mode, which is the transpose of the H (Albreem et al., 2021).

$$\mathrm{y} = H^T \mathrm{x} + \mathrm{n},$$

$$\sqrt{r}\ H^T P_a + \mathrm{n}, \quad \mathrm{y}\hat{I}\ \mathcal{E}^{N\ 1} \tag{3.3}$$

The P matrix of basic precoding schemes often includes a matrix inversion operation, which raises the cost of computation, according to (Pappa et al., 2017). This is especially true if N and M are not sufficiently different. Depending on how the matrix inversion process is handled, the linear precoding approach may be classified into four categories: basic linear precoding, linear precoders based on the matrix inversion approximation, linear precoders based on fixed-point iterations, and linear precoders based on matrix-decomposition.

The precoding matrix P is primarily multiplied by the transmitted signal by the fundamental linear precoders. The computational complexity of the fundamental linear precoders is O (N3), which is equivalent to the complexity of accurate matrix inversion (Albreem et al., 2021)

## 1. Maximum Ratio Transmission (MRT)

The goal of the MRT is to increase the signal gain into a specific receive terminal. It is the reverse of matched filtering (MF) and conjugate beamforming (CB). The MRT precoding matrix's formula is

$$P_{MRT}=\sqrt{b}\,(H^{*}) \tag{3.4}$$

Where b is a scaling power factor and the matrix H*' is a complex conjugate of the H matrix are both given. Consequently, the signal that was received becomes (Albreem et al., 2021).

$$y_{MRT} \quad \sqrt{b}\sqrt{r}\ H^{T}H^{*}a+n, \qquad \text{y}\ \hat{I}\ \mathcal{E}^{\,N\,1} \tag{3.5}$$

## 2. Zero Forcing (ZF)

A common algorithm used in fundamental precoding techniques is the ZF algorithm. It is the polar opposite of a channel inversion. A ZF algorithm lessens the interference caused by other users by guiding the signal beam toward the targeted user while blocking the other directions where other users are located (Fatema et al., 2018). This nulling is created by multiplying the user data by the following ZF precoding matrix:

$$P_{ZR=}\sqrt{b}\ H^{*}(G^{-1})\ \text{, Where G=}H^{T}H^{*} \tag{3.6}$$

Where G is a Gram matrix whose non-diagonal components represent the mutual correlations among the channels and whose diagonal components represent the power imbalance along the channel. In huge MIMO systems, the number of transmit antennas can increase indefinitely, but G eventually turns into an identity matrix, simplifying the calculations for matrix inversion. The ZF algorithm's received signal may be represented as

$$y_{ZF=}\ \sqrt{b}\sqrt{r}\ H^{T}H^{*}\ (G^{-1})\ a+n, \qquad \text{y}\hat{I}\ \pounds^{\,N\,1} \tag{3.7}$$

## 3. Minimum Mean Square Error (MMSE)

By using their benefits, the MMSE algorithm creates a balance between the MRT and ZF algorithms. As a result, it operates effectively in systems with moderate interference and noise (System et al., 2015). The eigenvalue-based beamforming, transmitting Wiener filtering, regularized ZF (RZF), signal-to-leakage and-interference ratio (SLNR), and transmitting Wiener filtering (Fatema et al., 2018) are the alternatives to the MMSE approach. The mean square error technique is used in the signal by the MMSE algorithm to decrease error filtering between the transmission symbols from the BS and the receiving terminal. The MMSE's precoding matrix is expressed as

$$P_{MMSE=}\ \sqrt{b}\ H^{*}(G+V+\lambda I_N)^{-1} \tag{3.8}$$

Where, λ is a positive regularizing factor that relies on the size of the system, the variance of the noise, and the transmitter's channel uncertainty. The matrix V is a non-negative Hermitian N × N deterministic matrix. When V = 0, there is an equilibrium between reducing the IUI (at a high value of b) and increasing the channel gain toward the intended receiving terminals (at a small value of b ). At b → 0, and as the MF algorithm at b → ∞, the MMSE algorithm acts as the ZF algorithm, respectively (Busari et al., 2018). The MMSE algorithm's received signal is

$$y_{\ MMSE=}\ \sqrt{r}\sqrt{H}\ H^{T}H^{*}\ \ (G+V+l\ I_N\ )^{-1}\ a+n \tag{3.9}$$

### 3.4.2. Non- Linear Precoding

For massive MIMO systems, there are two main types of signal precoders: linear precoders and non-linear precoders. Although linear precoding techniques are simple, their lack of precoding precision cannot be overlooked, especially when M/N is close to or equal to one (Busari et al., 2018). The ML precoders are the best signal precoders. Unfortunately, the complexity of the ML precoder exponentially grows with M, making huge MIMO systems impossible to build (You et al., 2020). The most popular nonlinear massive MIMO signal precoding techniques are introduced in this section, along with any associated benefits and drawbacks.

### 1. Dirty-Paper Coding (DPC) precoding

Costa proposed the DPC technique in 1983, and it is shown that when the interference is known at the transmitter side, it is possible to offer the theoretical channel's capacity and eliminate interference (You et al., 2020). The interference from the first up to (n-1) the received terminals are regarded as canceled in MU-MIMO systems when the precoding matrix is created for the nth received terminal. The sum-rate of the DPC algorithm can be presented (Albreem et al., 2021)

$$Y_{DPC=}maxW\log_2 det\,(I_N+H^{*}WH^{T}) \tag{3.10}$$

Furthermore, the DPC algorithm may give superior performance without consuming more power on the transmission side or sharing CSI with the receiving side. Although the DPC approach requires advanced signal processing and an endless number of code words, it is not feasible (Minango et al., 2018; Z. Wang, 2020).

## 2. Tomlinson-Harashima (TH) Precoding

The TH precoding method, which combines the DPC algorithm and modulo arithmetic, is a poor implementation of the DPC algorithm (Belmekki et al., 2020; Stankovic & Haardt, 2008). According to (Thakor and Sathvara 2016), Tomlinson and Harashima first introduced the TH algorithm in 1972. To replace the ISI, an equalization procedure called the TH algorithm was first developed. Additionally, in MIMO systems, the TH method may be utilized to remove interference from sub-channels (Chen, 2019). Although the TH method performs less well than the DPC algorithm, it can still be used in real-world applications. When compared to linear precoding techniques, the TH algorithm is more complex, but it effectively avoids noise amplification (Chen, 2019). The feed-forward filter, feedback filter, and modulo arithmetic are the three main parts of the TH algorithm (Chen, 2019; Yan et al., 2012).

TH algorithm can be carried out by decomposing $H^T$ to the multiplying of a lower triangular matrix L and a unitary matrix Q as

$$H^T = LQ \tag{3.11}$$

## 3. Vector Perturbation (VP) Precoding

Vector Perturbation Precoding (VP) is a precoding technique used in wireless communication systems to improve the performance of multi-antenna systems. It was introduced as an extension of the classic linear precoding technique, where a precoding vector is applied to the data symbols before transmission. In VP, the transmitted signal is perturbed by a random vector, which is designed to spread the signal power across multiple antennas at the receiver. This spreading effect helps to improve the diversity of the system, which in turn improves its reliability and robustness to fading.

The mathematical representation of vector perturbation precoding can be expressed as:

$$S=W(X + dx) \tag{3.12}$$

Where s is the transmitted signal, W is the precoding matrix, x is the original data vector, and δx is the perturbation vector. The perturbation vector δx is added to the original data vector x before being multiplied by the precoding matrix W and transmitted through the MIMO channel.

One way to design the perturbation vector is to use a lattice-based quantization scheme, such as the so-called "MIMO-BCQ" technique. This scheme involves quantizing the complex-valued perturbation vector using a lattice codebook, and then applying a rotation matrix to the resulting quantized vector to ensure that it has a uniform distribution over all possible directions. Another approach is to use a random perturbation vector, such as a Gaussian or uniform distribution. In this case, the perturbation vector is chosen randomly from a prescribed distribution, and the precoding vector is designed to exploit the resulting statistical properties of the perturbation vector.

Overall, the VPP technique is a powerful tool for improving the performance of multi-antenna systems, particularly in environments with high levels of multi-path fading and interference. Its effectiveness depends on the choice of perturbation vector and the specific implementation details, which can vary depending on the application and system requirements.

## 4. Proposed Optimized Particle Filter (OPF) Precoding

The core idea behind particle filtering, which employs a sequential Monte Carlo method, is the recursive computation of relevant probability distributions. This methodology combines the concepts of significance sampling and approximating probability distributions using discrete random measures (Djuri et al., 2003). Particle filtering is an emergent method for getting the posterior probability density function (pdf) in the Bayesian framework. The sequential Monte Carlo approach is used in particle filters. The channel estimates provided are optimum in the sense that all available statistical information has been employed since the genuine posterior pdf incorporates all available statistical information about the state.

Particle filters, commonly referred to as sequential Monte Carlo approaches, are a set of Monte Carlo algorithms used to approximate solutions for filtering problems in nonlinear state-space systems such as signal processing and Bayesian statistical inference. Particle filtering uses a collection of particles (also known as samples) to represent the posterior distribution of a stochastic process given noisy and/or incomplete input.

The optimized particle filter precoder (OPFP) is a signal processing technique used in wireless communication systems to optimize the transmission rate and reliability of data transmission. It is particularly useful in systems with multiple antennas, such as MIMO (multiple-input multiple-output) systems, where the precoding technique is used to improve signal quality and reduce interference between antennas.

The OPFP is based on a Bayesian filtering method known as the particle filter, which is used to infer the state of a dynamic system from noisy observations. In the OPFP, the particle filter is used to estimate the channel state information (CSI) of the wireless channel, which is then used to optimize the precoder for data transmission.

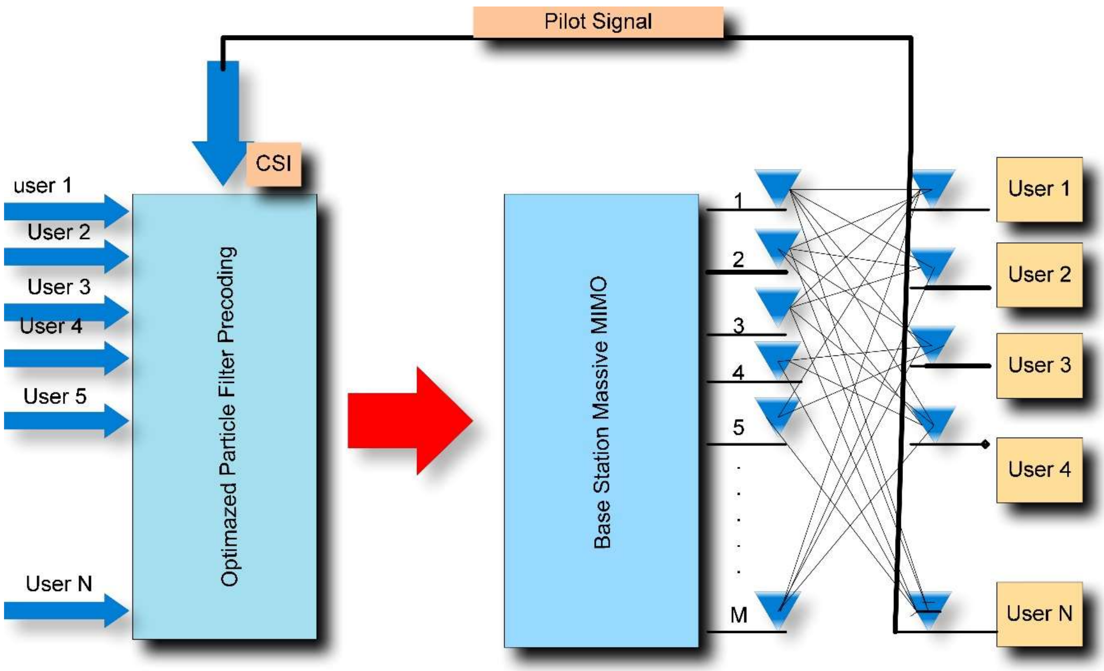


Figure 3. 4 System model of OPF precoding  multi user massive MIMO system

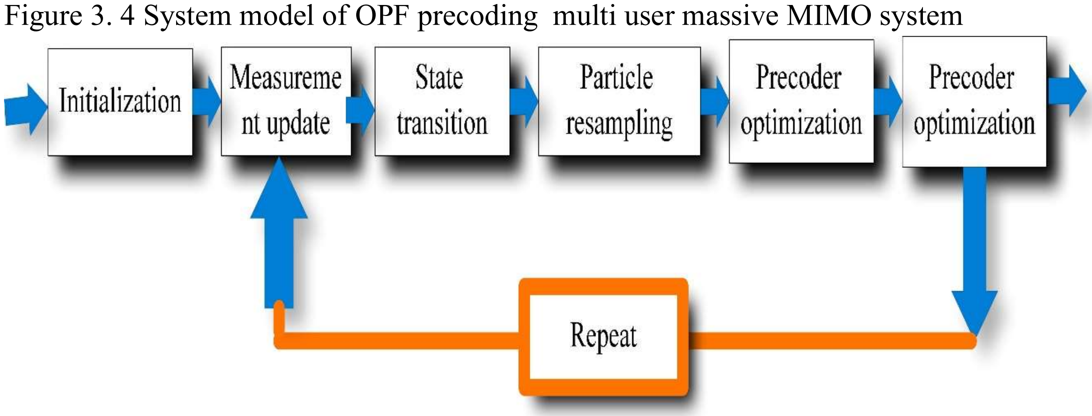


Figure 3. 5The OPFP algorithm

The OPFP algorithm consists of the following steps:

1. Initialization: The algorithm initializes the particle filter with a set of particles that represent the possible values of the channel matrix. The number of particles is determined by the system parameters, such as the number of antennas and the channel conditions.

2. Measurement update: In each time slot, the algorithm receives a set of noisy observations from the channel. The particle filter uses these observations to update the weights of the particles and estimate the CSI.
3. State transition: The algorithm predicts the state of the system in the next time slot based on the estimated CSI and the precoder used in the current time slot.
4. Particle resampling: The algorithm resamples the particles based on their weights to improve the accuracy of the estimation. The resampling process is designed to increase the number of particles that represent the most likely values of the channel matrix.
5. Precoder optimization: Based on the estimated CSI and the system parameters, the algorithm optimizes the precoder for data transmission to maximize the transmission rate and reliability. The optimization process uses the estimated CSI to minimize the interference between antennas and maximize the signal quality at the receiver.
6. Data transmission: The optimized precoder is used to transmit data in the current time slot.
7. Repeat: The algorithm repeats steps 2 to 6 in each time slot to continuously estimate the CSI and optimize the precoder for data transmission.

The OPFP algorithm is computationally intensive, as it involves the estimation of the CSI using the particle filter and the optimization of the precoder in each time slot. However, it has been shown to significantly improve the performance of wireless communication systems, especially in MIMO systems with multiple antennas and high interference.

The OPFP algorithm can be implemented using MATLAB or other programming languages, and it requires knowledge of signal processing, wireless communication, and Bayesian filtering. It is commonly used in the research and development of advanced wireless communication systems, such as 5G and beyond.

Let H be the channel matrix between the transmitter and receiver, x be the transmitted signal, and y be the received signal. The particle filter precoding technique involves the following steps:

- Generate a set of particles ($x_1$, $x_2$, . . . , $x_N$ ) that represent possible transmitted signals.
- For each particle $x_i$, calculate the corresponding precoding vector $w_i$ as:

$$w_i = H^H \left(HH^H + d^2 I\right)^{-1} Hx_i \tag{3.13}$$

Where $H^H$ is the conjugate transpose of H, $HH^H$ is the Hermitian of H, $d^2$ is the noise variance, and I is the identity matrix.

- Calculate the weight of each particle as:

$$w_i = \left|y + Hw_i\right|^2 \tag{3.14}$$

- Normalize the weights such that they sum to one:

$$w_i = \frac{w_i}{\sum_j w_j} \tag{3.15}$$

- Update the particles based on their weights using a resampling step, such as the systematic resampling algorithm.
- Transmit the particle with the highest weight as the final transmitted signal.

These equations represent the basic steps involved in the particle filter precoding technique. The specific implementation may vary depending on the application and system requirements.

## 3.5. Simulation Parameters

Simulation parameters are important parameters used to test the performance of precoding techniques. There are different types of simulation parameters. The most general and common parameters used by different researchers to test the performance of the system are computational complexity, signal-to-noise ratio and spectral efficiency. These parameters are not the only parameters. In this thesis work to test the performance of precoding techniques computational complexity analysis, spectral efficiency versus signal-to-noise ratio analysis is used.

### 3.5.1 Computational Complexity

Computational complexity is a computer science concept concerned with the amount of computing resources required for specific tasks. The symbol T represents channel coherence time. N and M represent the number of users and the number of BS antennas for the Downlink massive MIMO system.The study of computational complexity focuses on the resources required to solve computational problems. It is a fundamental concept in computer science and is essential to understanding the limits of what can be computed efficiently. In this response, we will cover the basics of computational complexity, including the definition of complexity classes, the role of algorithms, and the implications of the P versus NP problem.The most common way to measure the complexity of a problem is by the amount of resources it requires to solve it. These resources can include time, space, and other factors such as energy and communication. The most commonly used resource is time, which is measured in terms of the number of basic operations or steps required to solve the problem.

Big O notation is typically used to define an algorithm's time complexity since it gives an upper constraint on the number of steps the algorithm must take about the size of the input. For instance, an algorithm with O(n) time complexity has a linear increase in the number of steps needed as n increases. The study of computational complexity is concerned with the classification of problems into complexity classes. These classes are defined based on the amount of resources required to solve the problem, usually in terms of time complexity. The most well-known complexity classes are P and NP.

All issues that can be resolved in a polynomial amount of time are included in the class P. Accordingly, the amount of time needed to address the issue rises no faster than a quadratic function of the input size. An algorithm with O(n^2) time complexity, for instance, is in P, but one with O(2^n) time complexity is not.All problems for which a suggested solution can be verified in a polynomial amount of time belong to the class NP. This means that given a solution to the problem, there exists an algorithm that can verify its correctness in polynomial time. On the other hand, it could take more than a polynomial time to solve an NP issue. The knapsack problem, the traveling salesman issue, and the Boolean satisfy ability problem are examples of NP problems.

The P vs NP problem, which asks if P is equivalent to NP, is one of the most significant open problems in computer science. In other words, the question examines whether it is possible to solve in polynomial time any issue that can be proved in that unit of time. The solution to this issue has significant ramifications for several domains, including cryptography, optimization, and artificial intelligence.If P is equal to NP, then many important problems that are currently considered intractable could be solved efficiently using algorithms that currently only exist in theory. On the other hand, if P is not equal to NP, then there exist problems for which no efficient algorithm exists.

Computational complexity also plays an important role in the design and analysis of algorithms. A good algorithm should be not only correct but also efficient, meaning it should be able to solve the problem in a reasonable amount of time or with a reasonable amount of resources. The study of computational complexity provides a framework for analyzing the efficiency of algorithms and comparing different algorithms for the same problem.

One way to design efficient algorithms is by using heuristic techniques, which trade off the quality of the solution for the amount of resources required. Heuristic algorithms frequently deliver an accurate approximation of the ideal outcome in a respectable period, but they cannot ensure ideality. For example, the traveling salesman problem can be solved approximately using heuristic algorithms such as the nearest neighbor algorithm.

The concept of completeness is another important concept in computational complexity. A problem is said to be complete for a complexity class if every problem in that class can be reduced to it in polynomial time. For instance, every NP-complete problem, including the Boolean satisfy ability problem, may be reduced to it in polynomial time since it is NP-complete. NP-complete problems are considered to be among the hardest problems in computer science, and no efficient algorithm is known for them.In addition to P and NP, many other complexity classes have been defined, such as NP-hard, co-NP, and PSPACE. These classes provide a more nuanced understanding of the complexity of different problems and their relationships to each other.

In summary, computational complexity is a fundamental concept in computer science that is concerned with the resources required to solve computational problems. The most commonly used resource is time, and problems are classified into complexity classes based on their time complexity. The study of computational complexity provides a framework for analyzing the efficiency of algorithms and comparing different algorithms for the same problem. The P versus NP problem is an important open problem in computer science that has far-reaching implications for many fields. Computational complexity also plays a crucial role in the design and analysis of algorithms, and heuristic techniques are often used to trade off solution quality for the amount of resources required. Finally, the notion of completeness and other complexity classes provide a more nuanced understanding of the complexity of different problems and their relationships to each other.

### 3.5.2 Spectral Efficiency

Spectrum efficiency, also known as bandwidth efficiency or spectrum efficiency, refers to the information rate that may be carried over a specific bandwidth in a communication system. Spectral efficiency is required for achieving unreasonable data rate needs. A crucial performance indicator for wireless communication systems is spectral efficiency, which quantifies how much data can be sent across a specific bandwidth. It is a key aspect in determining the capacity and overall performance of a wireless communication system and is defined as the number of bits per second that can be sent per unit of bandwidth.

In modern wireless communication systems, precoding techniques are often used to improve spectral efficiency. Precoding is a signal processing technique that is applied at the transmitter to optimize the transmission of data over a wireless channel. It involves manipulating the transmitted signal to exploit the spatial diversity of the channel, which can improve the quality and reliability of the received signal.Several different types of precoding techniques can be used in wireless communication systems, including linear precoding, nonlinear precoding, and multi-user precoding. Linear precoding is the simplest form of precoding, which involves applying a linear transformation to the transmitted signal to optimize its transmission over the channel.

One of the key advantages of linear precoding is that it can be easily implemented in real-time communication systems, and does not require complex algorithms or hardware. However, it may not always be the most effective precoding technique, as it is limited by the linear nature of the transformation, and may not be able to fully exploit the spatial diversity of the channel.

Nonlinear precoding techniques, on the other hand, are designed to overcome the limitations of linear precoding by using more complex transformations that can better exploit the spatial diversity of the channel. These techniques typically involve nonlinear functions, such as logarithmic or exponential functions, which can better approximate the optimal transformation for the given channel.While nonlinear precoding can offer superior performance compared to linear precoding, it can also be more complex to implement and may require more processing power and hardware. In addition, the nonlinearity of the transformation can make it more difficult to analyze or optimize the performance of the system. Multi-user precoding techniques are another type of precoding that is designed to optimize the transmission of data from multiple users over a shared wireless channel. These techniques can be used to improve the spectral efficiency of wireless communication systems by reducing interference between users and increasing the overall capacity of the system.

One of the key challenges in designing multi-user precoding techniques is to balance the conflicting goals of maximizing the capacity of the system while minimizing interference between users. This requires sophisticated algorithms and optimization techniques, as well as careful modeling and analysis of the wireless channel and the user traffic. Overall, the use of precoding techniques in wireless communication systems can significantly improve spectral efficiency and overall performance. However, the choice of precoding technique will depend on several factors, such as the complexity of the system, the quality of the channel, and the requirements of the application.

In addition to precoding, several other techniques can be used to improve spectral efficiency in wireless communication systems. These include adaptive modulation and coding, which adjusts the modulation and coding scheme based on the quality of the channel, and multiple-input multiple-output (MIMO) techniques, which use multiple antennas to exploit the spatial diversity of the channel.

An approach called adaptive modulation and coding modify the modulation and coding method used to transmit data over a wireless channel according to the channel's quality. This enables the system to employ higher modulation and coding schemes during periods of good channel quality and lower schemes during periods of poor channel quality. By enabling the system to utilize the available bandwidth more effectively, can considerably increase spectral efficiency.

MIMO techniques, on the other hand, use multiple antennas at the transmitter and receiver to exploit the spatial diversity of the channel. By transmitting multiple signals over the same frequency band, MIMO can significantly improve the capacity and spectral efficiency of wireless communication systems. MIMO techniques can be used in conjunction with precoding techniques to further improve performance.

In summary, spectral efficiency is a crucial performance metric in wireless communication systems, which measures the amount of data that may be delivered across a specific bandwidth. Precoding methods, such as multi-user precoding, nonlinear precoding, and linear precoding, are frequently used to increase spectral efficiency by making use of the spatial diversity of the channel. Other techniques, such as adaptive modulation and coding and MIMO, can also be used to improve spectral efficiency. The choice of technique will depend on several factors, like the complexity of the system, the quality of the channel, and the requirements of the application.

### 3.5.3 Signal-to-Noise Ratio

In wireless communication systems, the signal-to-noise ratio (SNR) is a crucial performance indicator that compares the strength of the received signal to the strength of the channel's noise. It plays a significant role in influencing the dependability and quality of the received signal and is taken into account when designing and putting precoding techniques into practice in wireless communication systems.

In wireless communication systems, the performance of the system is often limited by the presence of noise in the channel, which can distort the transmitted signal and degrade its quality. The SNR measures the quality of the received signal relative to the noise and is a key factor in determining the overall performance of the system. Precoding techniques are often used in wireless communication systems to optimize the transmission of data over the channel and can be used to improve the SNR of the received signal. Precoding involves manipulating the transmitted signal to exploit the spatial diversity of the channel and can be used to reduce the impact of noise and interference on the received signal.

One of the key advantages of precoding techniques is their ability to improve the SNR of the received signal. By exploiting the spatial diversity of the channel, precoding can improve the quality and reliability of the received signal and can reduce the impact of noise and interference on the system. To design and optimize precoding techniques, it is important to have a good understanding of the SNR in the system. The SNR depends on several factors, including the power of the transmitted signal, the distance between the transmitter and receiver, the bandwidth of the channel, and the level of noise and interference in the channel.

The power of the transmitted signal is a critical factor in determining the SNR of the received signal. The higher the power of the transmitted signal, the higher the SNR of the received signal, and the more resistant it is to noise and interference. However, increasing the power of the transmitted signal can also increase the interference and noise in the channel, which can degrade the quality of the received signal.

Another crucial element in determining the SNR of the received signal is the distance between the transmitter and receiver. The strength of the received signal declines as the distance between the transmitter and receiver rises, and the channel's noise and interference become more pronounced. This may lower the signal-to-noise ratio (SNR) of the received signal and make it more difficult to retrieve the original signal.

The SNR of the received signal is significantly influenced by the channel's bandwidth. Wider bandwidths can boost the quantity of data that can be transferred over a channel while simultaneously raising its noise and interference levels. This may lower the signal-to-noise ratio (SNR) of the received signal and make it more difficult to retrieve the original signal. Finally, a significant component in affecting the SNR of the received signal is the amount of noise and interference present in the channel. Other wireless devices, atmospheric conditions, and technological interference are a few examples of the many causes of noise and interference. The quality of the channel might be greatly diminished by noise and interference. The presence of noise and interference in the channel can significantly degrade the quality of the received signal and can make it more challenging to recover the original signal.

To optimize the performance of precoding techniques, it is important to consider the impact of these factors on the SNR of the received signal. By understanding the SNR in the system, it is possible to design and implement precoding techniques that can effectively improve the quality and reliability of the received signal.

One common approach to improving the SNR in wireless communication systems is to use multiple antennas at the transmitter and receiver, which can be used to exploit the spatial diversity of the channel. By transmitting multiple signals over the same frequency band, MIMO techniques can significantly improve the capacity and spectral efficiency of wireless communication systems and can be used in conjunction with precoding techniques to further improve performance.

Another approach to improving the SNR in wireless communication systems is to use adaptive modulation and coding techniques, which adjust the modulation and coding scheme used to transmit data over the channel based on the quality of the channel. By adjusting the modulation and coding scheme based on the SNR of the received signal, adaptive modulation, and coding can significantly improve the efficiency and reliability of wireless communication systems.

In summary, signal-to-noise ratio (SNR) assesses the relationship between the strength of the received signal and the strength of the channel noise and is a crucial performance parameter for wireless communication systems. The SNR of the received signal can be increased by using precoding techniques, which are frequently employed in wireless communication systems to maximize the transmission of data across the channel. The SNR is influenced by several variables, including as the broadcast signal's strength, the separation between the transmitter and receiver, the channel's bandwidth, and the amount of noise and interference present. It is achievable to create and employ precoding procedures that can significantly raise the caliber and dependability of the received signal by comprehending these aspects. To further enhance performance, precoding techniques can be used with methods like MIMO and adaptive modulation and coding to increase the

SNR in wireless communication systems. These approaches' ultimate objective is to enhance wireless communication systems' spectral efficiency and overall performance to enable dependable and effective data transfer over the channel.

### 3.5.4 Bit Error Rate

The amount of bit mistakes that take place in a communication system is measured by the bit error rate (BER). It is determined by dividing the total number of bits transferred by the number of bits that are wrongly received. The quality of the received data is directly impacted by BER, making it a crucial parameter in wireless communication systems. In wireless communication systems, noise, interference, fading, and attenuation are just a few of the variables that can impair the transmission of data. These elements may result in incorrect information in the data that is received, which may lead to the loss of critical data and a decline in system efficiency. BER is used to measure these elements' effects on system performance and assess how well error-correction methods work.

The importance of BER in a wireless communication system can be understood by considering its impact on the quality of the received data. A high BER indicates that a significant number of errors are occurring in the transmission, which can lead to a loss of information and a reduction in the system performance. Therefore, it is important to keep the BER as low as possible to ensure the reliable transmission of data. To achieve a low BER, various techniques can be used such as error correction coding, modulation schemes, diversity techniques, and power control. These techniques are designed to minimize the impact of noise, interference, and other factors that can cause errors in the transmission. By using these techniques, the BER can be reduced to a level that is acceptable for the particular application.

In summary, BER is an important parameter in wireless communication systems as it is used to quantify the impact of various factors on the system performance and to evaluate the effectiveness of error correction techniques. By minimizing the BER, the quality of the received data can be improved, leading to a more reliable and efficient communication system.

# CHAPTER FOUR

# 4. RESULT AND DISCUSSION

## 4.1. Overview

In this chapter, a detailed analysis of the result is discussed. The result is simulated under acceptable parameters. The Signal Noise Ratio versus Bit Error Rate, Signal Noise Ratio versus Outage Probability, and Average Achievable Rate analysis is used to check the improvement of the system.

Table 4. 1 Parameters for simulation

| Parameters | Numerical Value | Remark |
|---|---|---|
| Number of Symbols (M) | 64/256 | $M=2^K$ where k= Integer |
| Number of Bits | $10^6$ | Can Vary |
| Number of Users | 2 | Can Vary |
| Distance between Transmitters in meter | 5 | Can Vary |
| Transmit power in watts | 0.01 | Can Vary |
| Carrier Frequency in Hertz | 2.4x10^(9) | ITU Standard |
| Bandwidth | 1x10^(6) | Can Vary |
| Number of Tx Antenna | 4 | Can Vary |
| Power Splitting Ratio (rho) | 0.1-0.9 | Can Vary |
| Time Fraction for EH | 0.1-0.9 | Can Vary |
| Path-loss Exponent | 3 | Can Vary |
| Energy Conversion Coefficient | 0.7 | Can Vary |
| EbNo | 0:2:50 | Can Vary |
| M-QAM | 4/16/64/128/256 | Can Vary |
| Communication Channel Model | Rayleigh Fading | ITU Standard |

## 4.2. Signal to Noise Ratio versus Bit Error Rate Analysis

Precoding is a wireless communication technique that improves the quality of the signal being transmitted. It involves manipulating the signal before transmission to maximize the signal-to-noise ratio (SNR) at the receiver end, thereby reducing the bit error rate (BER). SNR and BER are two important parameters that are used to evaluate the performance of the precoding techniques in this context. The signal-to-noise ratio (SNR) is a measure of the strength of the signal relative to the noise present in the system. It is defined as the ratio of the power of the signal to the power of the noise. A higher SNR indicates a stronger signal and less noise, which results in a better quality of the received signal. In the context of precoding, the goal is to maximize the SNR at the receiver end by manipulating the transmitted signal.

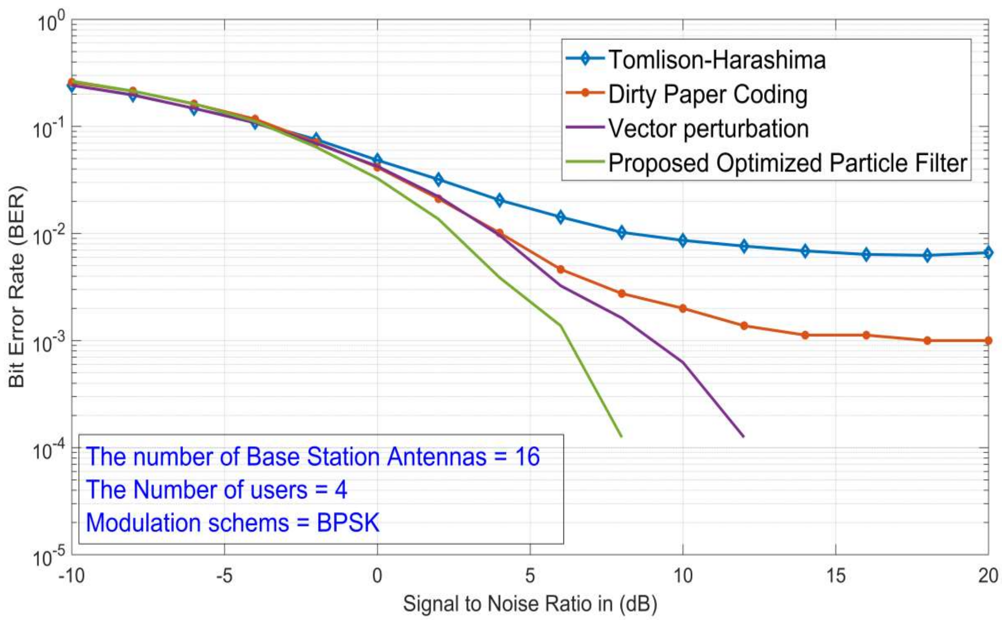


Figure 4. 1 Signal Noise Ratio (SNR) versus Bit Error Rate (BER) Analysis on TH, DPC, VP, and Proposed OPF precoding techniques using BPSK modulation scheme.

The accuracy of the signal received at the receiver is measured by the bit error rate (BER). It represents the probability that a bit in the received signal is corrupted due to noise or other factors. A lower BER indicates a more accurate received signal, which is important for reliable communication. In the context of precoding, the goal is to minimize the BER by maximizing the SNR at the receiver end. In the analysis of precoding techniques, SNR and BER are used to evaluate the performance of the system. The SNR is used to measure the strength of the signal relative to the noise, while the BER is used to measure the accuracy of the received signal. Precoding can be used to manipulate the transmitted signal and increase SNR, which reduces BER and improves system performance.

Figure 4.1 simulated using 16, number of base station antenna 4, number of users, and modulation scheme BPSK. The analysis is carried out for the non-linear precoding methods Tomlinson-Harashima, Dirty Paper Coding, Vector Perturbation, and Proposed Optimized Particle Filter, as shown in Figure 4.1.

The simulation result shows that the bit error rate value of the Proposed Particle Filter is minimum compared to Tomlinson- Harashima, Dirty Paper Coding, and Vector Perturbation precoding techniques because the graph of the Proposed Optimized particle Filter found below all other precoding techniques graph. This is because the proposed optimized particle filter's graph is located below the graphs of all other precoding techniques. From this, it is concluded that having a minimum bit error rate value is essential for ensuring the quality and reliability of wireless communication systems. Therefore the Proposed Optimized Particle Filter can provide high-quality voice and video communication, reliable data transmission, and efficient control of systems.

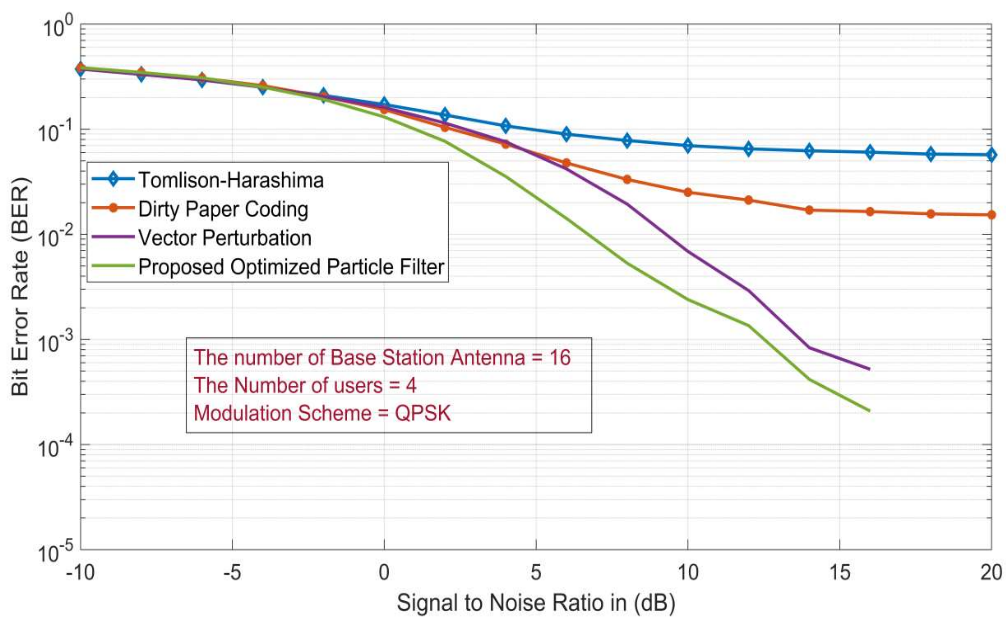


Figure 4. 2 Signal Noise Ratio versus Bit Error Rate Analysis on TH, DPC, VP, and Proposed OPF Precoding Techniques Using QPSK Modulation Scheme.

Figure 4.2 shows the signal-to-noise ratio in decibels on the X-axis and the bit error rate on the Y-axis. The accuracy of the received signal is measured by the bit error rate (BER), which is well-known. It represents the probability that a bit in the received signal is corrupted due to noise or other factors. A lower BER indicates a more accurate received signal, which is important for reliable communication. And also it is known that the signal-to-noise ratio (SNR) is a measure of the strength of the signal relative to the noise present in the system. It is defined as the ratio of the power of the signal to the power of the noise. A higher SNR indicates a stronger signal and less noise, which results in a better quality of the received signal.

Figure 4.2 is simulated using 16 numbers of base station antennas, 4 numbers of users, and modulation scheme QPSK. QPSK stands for Quadrature Phase Shift Keying. It is a digital modulation scheme used to transmit digital information over a radio frequency carrier signal. In QPSK, two bits of digital information are combined to represent a single symbol, and the phase of the carrier wave is shifted by one of four possible angles (0, 90, 180, or 270 degrees) to represent each symbol. This allows for the transmission of information twice as much as per symbol compared to simpler modulation schemes like BPSK (Binary Phase Shift Keying), which only use two possible phase angles.

According to Figure 4.2, the analysis is done for non-linear precoding techniques namely: Tomlinson- Harashima, Dirty Paper Coding, Vector Perturbation, and Proposed Optimized Particle Filter. According to figure 4.2, the simulation result shows that the bit error rate value of the Proposed Particle Filter is minimum compared to Tomlinson- Harashima, Dirty Paper Coding, and Vector Perturbation precoding techniques because the graph of the Proposed Optimized particle Filter found below all other precoding techniques graph. From this, it is concluded that having a minimum bit error rate value is essential for ensuring the quality and reliability of wireless communication systems. Therefore the Proposed Optimized Particle Filter can provide high-quality voice and video communication, reliable data transmission, and efficient control of systems.

According to Figure 4.3, the X-axis represents the signal-to-noise ratio in a decibel scale and Y- the axis represents the bit error rate. It is known that the bit error rate (BER) is a measure of the accuracy of the received signal. It represents the probability that a bit in the received signal is corrupted due to noise or other factors. A lower BER indicates a more accurate received signal, which is important for reliable communication. And also it is known that the signal-to-noise ratio (SNR) is a measure of the strength of the signal relative to the noise present in the system. It is defined as the ratio of the power of the signal to the power of the noise. A higher SNR indicates a stronger signal and less noise, which results in a better quality of the received signal.

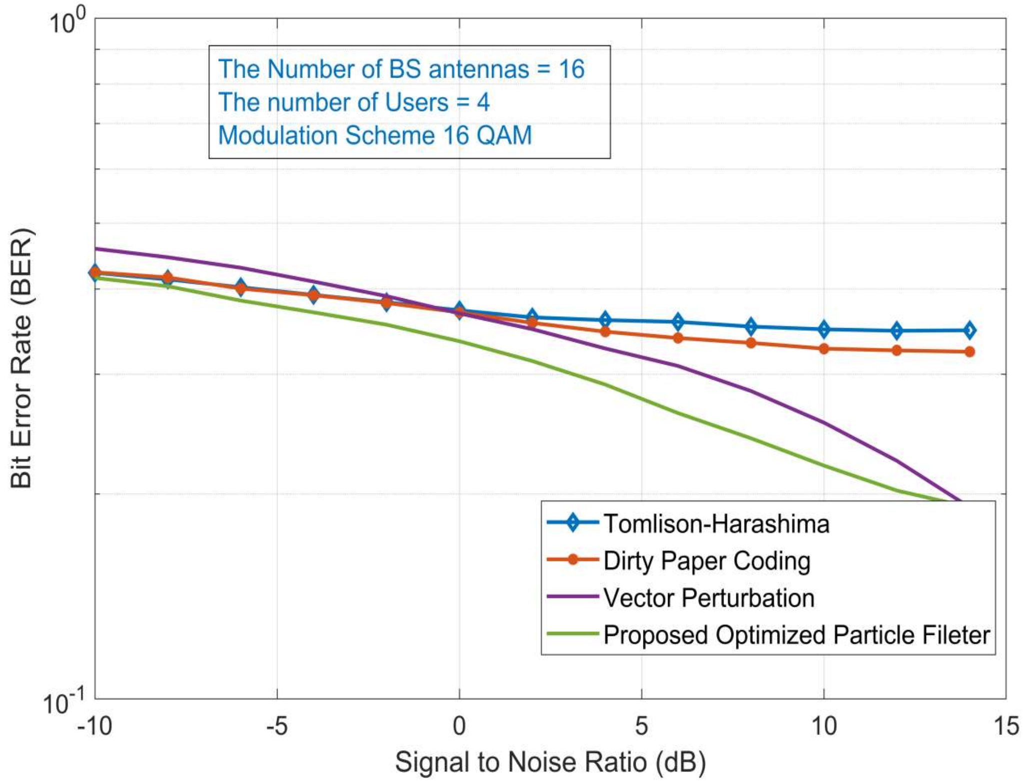


Figure 4. 3 Signal Noise Ratio versus Bit Error Rate Analysis of TH, DPC, VP, and Proposed OPF Precoding Techniques Using 16-QAM Modulation Scheme

Figure 4.3 is simulated using 16 numbers base station antennas, 4 numbers users, and a modulation scheme of 16 QAM. QAM stands for Quadrature Amplitude Modulation. It is a digital modulation scheme that combines both amplitude and phase modulation to transmit digital information over a radio frequency carrier signal. Like QPSK, QAM uses a constellation diagram to represent the possible combinations of amplitude and phase that can be used to represent digital symbols. However, unlike QPSK, which uses only four possible phase angles, QAM can use a larger number of phase angles, allowing for the transmission of more bits per symbol.

In QAM, the amplitude and phase of the carrier wave are simultaneously modulated to represent each symbol. The amplitude and phase of the carrier wave are controlled by two separate digital signals, which are combined to create a single complex signal that represents the modulated symbol. The complex signal is then transmitted over the channel.

The number of bits that can be transmitted per symbol in QAM depends on the size of the constellation diagram used. For example, a 16-QAM constellation diagram has 16 possible combinations of amplitude and phase, which can represent 4 bits per symbol. Similarly, a

64-QAM constellation diagram has 64 possible combinations of amplitude and phase, which can represent 6 bits per symbol. However, as the number of possible combinations increases, the signals become more susceptible to noise and interference, which can degrade the quality of the transmitted signal.

QAM is widely used in digital communication systems, including cable modems, digital television broadcasting, wireless networking, and cellular communications. It is also used in some forms of digital subscriber line (DSL) technology for high-speed internet access over telephone lines.

According to Figure 4.3, the analysis is done for non-linear precoding techniques namely: Tomlinson- Harashima, Dirty Paper Coding, Vector Perturbation, and Proposed Optimized Particle Filter. According to Figure 4.3, the simulation result shows that the bit error rate value of the Proposed Particle Filter is minimum compared to Tomlinson- Harashima, Dirty Paper Coding, and Vector Perturbation precoding techniques because the graph of the Proposed Optimized particle Filter found below all other precoding techniques graph. From this, it is concluded that having a minimum bit error rate value is essential for ensuring the quality and reliability of wireless communication systems. Therefore the Proposed Optimized Particle Filter can provide high-quality voice and video communication, reliable data transmission, and efficient control of systems.

According to Figure 4.4, the X-axis represents the signal-to-noise ratio in a decibel scale and Y- the axis represents the bit error rate. It is known that the bit error rate (BER) is a measure of the accuracy of the received signal. It represents the probability that a bit in the received signal is corrupted due to noise or other factors. A lower BER indicates a more accurate received signal, which is important for reliable communication. And also it is known that the signal-to-noise ratio (SNR) is a measure of the strength of the signal relative to the noise present in the system. It is defined as the ratio of the power of the signal to the power of the noise. A higher SNR indicates a stronger signal and less noise, which results in a better quality of the received signal.

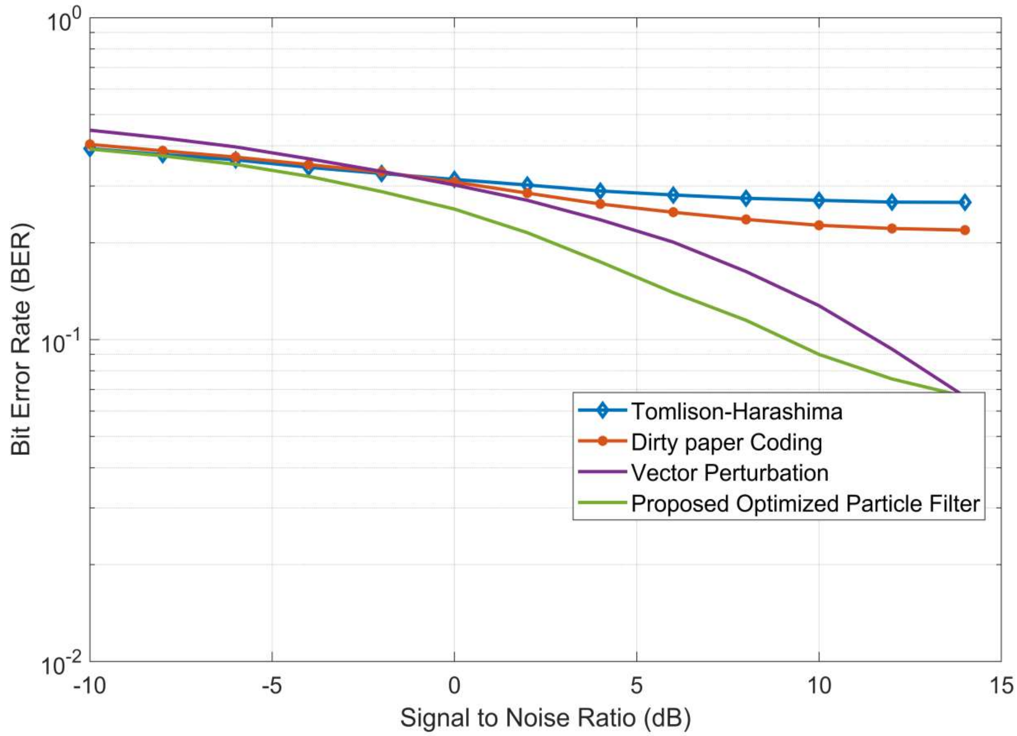


Figure 4. 4 Signal Noise Ratio versus Bit Error Rate Analysis of TH, DPC, VP, and Proposed OPF Precoding Techniques Using 64-QAM Modulation Scheme.

Figure 4.4 is simulated using 6 numbers base station antennas, 4 numbers users, and a modulation scheme of 64 QAM. As described above, QAM stands for Quadrature Amplitude Modulation. It is a digital modulation scheme that combines both amplitude and phase modulation to transmit digital information over a radio frequency carrier signal.

According to Figure 4.4, the analysis is done for non-linear precoding techniques namely: Tomlinson- Harashima, Dirty Paper Coding, Vector Perturbation, and the Proposed Optimized Particle Filter. According to figure 4.4, the simulation result shows that the bit error rate value of the Proposed Particle Filter is minimum compared to Tomlinson-Harashima, Dirty Paper Coding, and Vector Perturbation precoding techniques because the graph of the Proposed Optimized particle Filter found below all other precoding techniques graph. From this, it is concluded that having a minimum bit error rate value is essential for ensuring the quality and reliability of wireless communication systems. Therefore the Proposed Optimized Particle Filter can provide high-quality voice and video communication, reliable data transmission, and efficient control of systems.

## 4.3. Average Sum Spectral Efficiency Analysis

Spectral Efficiency (SE) and SNR (Signal-to-Noise Ratio) are two important metrics used to evaluate the performance of communication systems. SNR is a parameter used to measure the strength of a signal in comparison to noise in a communication channel. It is usually stated in decibels (dB) and is defined as the ratio of signal power to noise power. Higher signal strength in comparison to noise is indicated by a higher SNR, which may result in enhanced signal quality and fewer information errors being received. In general, a minimum SNR is required for reliable communication, and the required SNR depends on the modulation scheme, channel bandwidth, and other factors.

Spectral Efficiency, on the other hand, is a measure of how efficiently a communication system uses the available frequency spectrum to transmit data. It generally refers to the quantity of data that can be carried per unit of frequency bandwidth and is measured in bits per second per hertz (bps/Hz). To maximize the capacity of a communication system, higher spectral efficiency indicates that more data can be carried using the same amount of spectrum. The trade-off between SNR and spectral efficiency occurs often in real-world communication systems. For instance, 256-QAM can achieve greater spectral efficiency than QPSK, a lower-order modulation technique, but it may also require a higher SNR to obtain the same degree of error performance.

The spectral efficiency can also be improved by employing a wider bandwidth, although doing so may also result in more noise and interference, which lowers the SNR the user terminal input or uplink pilot signals are used by the base station to determine the CSI in large MIMO systems. The received CSI at the base station is not uncontrolled and is not error-free because of different environmental factors on the wireless channel. The number of antennas and the average sum spectral efficiency (SE) are both important parameters in the analysis of wireless communication systems. A wireless system's spatial diversity, which may improve the system's performance in terms of signal quality, reliability, and coverage, is directly correlated with the number of antennas in the system. A system's capacity can be increased by using several antennas for transmitting various data streams simultaneously using spatial multiplexing techniques. Adding more antennas also improves the system's resistance to fading, which is the phenomenon of signal attenuation caused by interference or other factors.

The average sum of spectral efficiency, on the other hand, is a measure of the system's overall spectral efficiency. It represents the average capacity per unit bandwidth of the system, taking into account all the users in the system. This metric is important because it directly affects the system's ability to support a large number of users and meet the growing demand for high-speed data services.

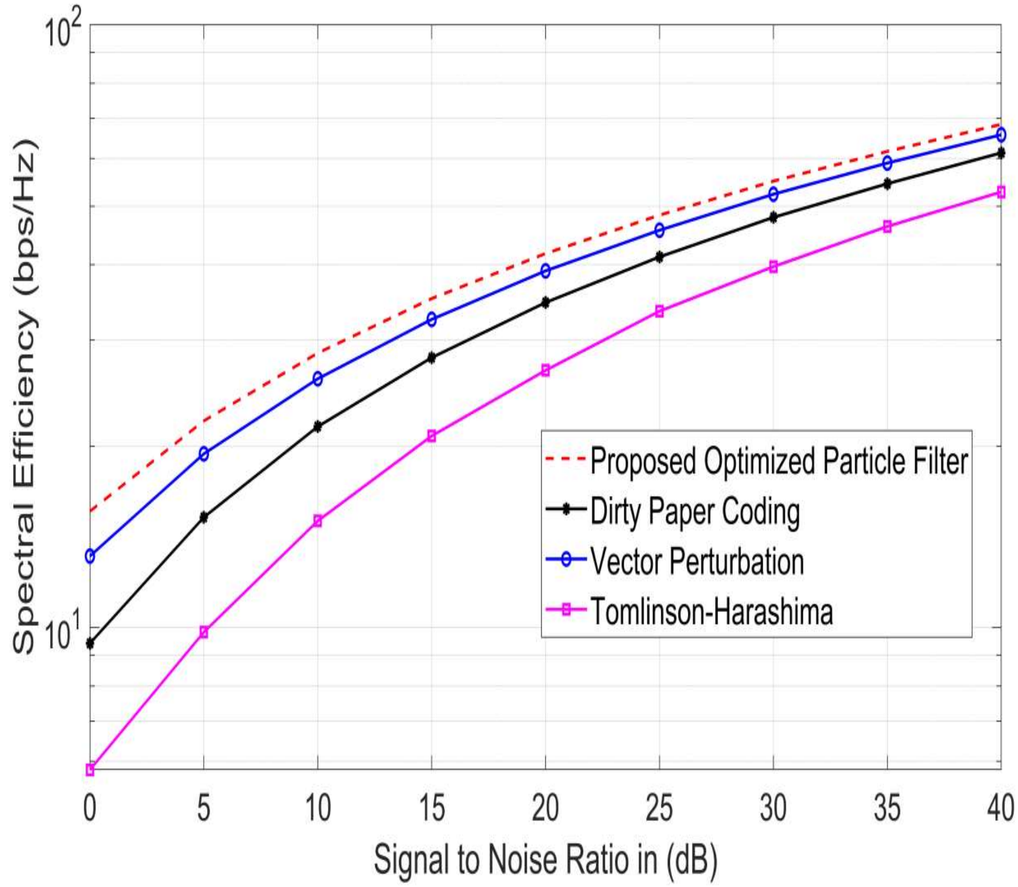


Figure 4. 5 Signal Noise Ratio versus Spectral Efficiency in bits per second per Hertz Analysis of TH, DPC, VP, and Proposed OPF Precoding Techniques

The number of antennas and the average sum spectral efficiency are both important parameters in the analysis of wireless communication systems. The number of antennas in a wireless system is directly related to the system's spatial diversity, which can improve the system's performance in terms of signal quality, reliability, and coverage. With multiple antennas, a system can use spatial multiplexing techniques to transmit multiple data streams simultaneously, increasing the system's capacity. Adding more antennas also improves the system's resistance to fading, which is the phenomenon of signal attenuation caused by interference or other factors.

The average sum of spectral efficiency, on the other hand, is a measure of the system's overall spectral efficiency. It represents the average capacity per unit bandwidth of the system, taking into account all the users in the system. This metric is important because it directly affects the system's ability to support a large number of users and meet the growing demand for high-speed data services. Figure 4.5 is simulated for signal-to-noise ratio versus spectral efficiency analysis.

From Figure 4.5, the simulation result which is represented with a red curve represents the proposed optimized particle filter. As it can be seen from the result the proposed optimized particle filter outperforms dirty paper coding, vector perturbation, and Tomlinson – Harashima. Because the graph of the proposed optimized particle filter is found above all.

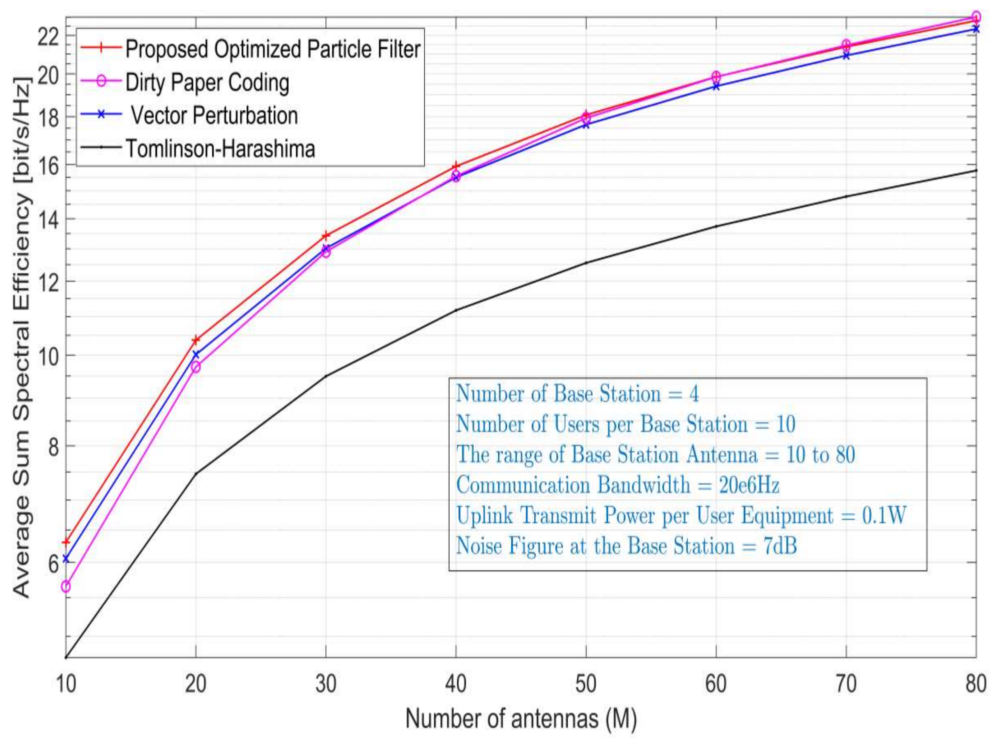


Figure 4. 6 Number of Antennas versus Average Sum Spectral Efficiency in Bits per Second per Hertz Analysis of TH, DPC, VP, and Proposed OPF Precoding Techniques

Figure 4.6 shows the number of antennas versus average sum spectral efficiency in bit per second per hertz of dirty paper coding, vector perturbation, Tomlinson – Harashima, and proposed optimized particle filter precoding techniques. The figure is simulated using 4 base stations, 10, users per base station, from 10 to 80 number of base station antenna, 20MHz communication bandwidth, and 7dB, the noise figure of the base station. According to the result in Figure 4.6 as the number of antennas increases the average sum spectral efficiency also increases. Figure 4.6 red graph shows the number of antennae versus the average sum spectral efficiency of the proposed optimized particle filter. As can be seen from the simulation result the red line found above all graphs, shows the proposed optimized particle filter outperforms the existing dirty paper coding, vector perturbation, and Tomlinson – Harashima non-linear precoding techniques. Dirty paper coding and perturbation non-linear precoding techniques have comparable performance to that of optimized particle filter non-linear precoding techniques.

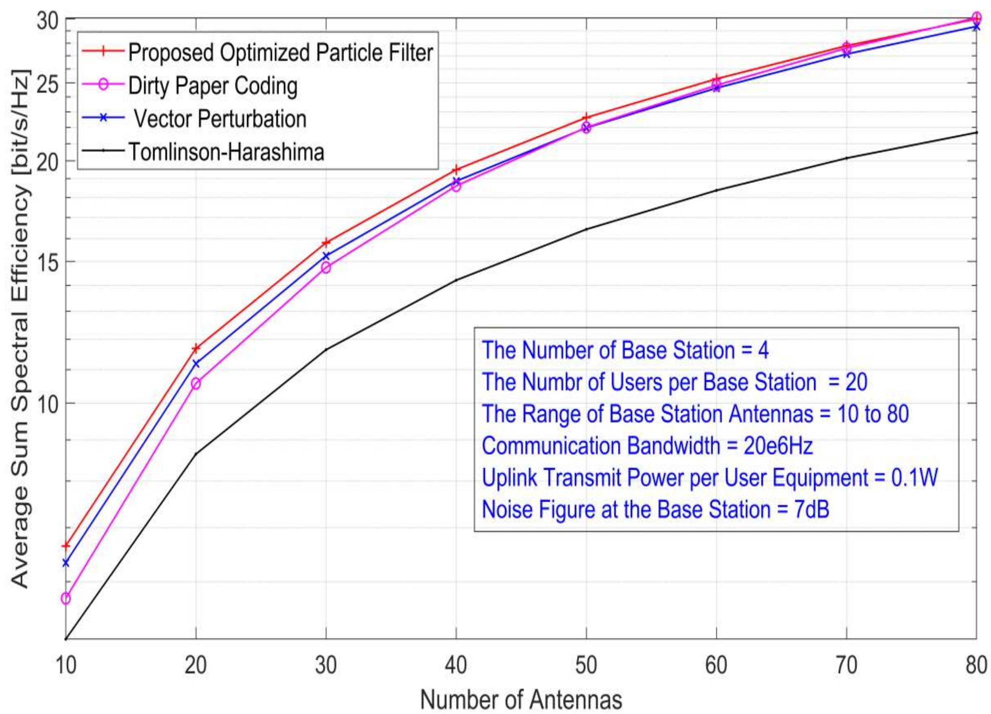


Figure 4. 7 Number of Antennas versus Average sum Spectral Efficiency in bit per second per Hertz Analysis of, TH, DPC, VP, and Proposed OPF precoding techniques.

Figure 4.7 shows the number of antennas versus average sum spectral efficiency (SE) in (b/s/Hz) bit per second per hertz of dirty paper coding, vector perturbation, Tomlinson – Harashima, and proposed optimized particle filter precoding techniques like figure 4.6. The figure is simulated using 4 base stations, 20 users per base station, 10 to 80 numbers base station antenna, 20MHz communication bandwidth, and a 7dB noise figure at the base station.

According to the result in Figure 4.7, the number of antennas and average sum spectral efficiency both increase. Form figure 4.7 red graph shows the number of antennae versus the average sum spectral efficiency of the proposed optimized particle filter. As can be seen from the simulation result the red line found above all graphs, shows the proposed optimized particle filter outperforms the existing dirty paper coding (DPC) precoding, vector perturbation (VP) precoding, and Tomlinson – Harashima (TH) precoding non-linear precoding techniques. Dirty paper coding (DPC) precoding and vector perturbation (TH) precoding non-linear precoding techniques have comparable performance to that of optimized particle filter non-linear precoding technique. Generally optimized particle filter non-linear precoding technique has better average sum spectral efficiency for multi-massive MIMO systems as can be concluded from simulation results of Figure 4.6 and Figure 4.7.

In general, increasing the number of antennas in the wireless system can improve its spectral efficiency, since it allows for more spatial multiplexing and better resistance to fading. However, the relationship between the number of antennas in the wireless channel and the spectral efficiency is not always straightforward and depends on various system parameters such as the channel conditions, the modulation scheme, and the interference levels. Therefore, a detailed analysis that takes into account both the number of antennas and the average sum spectral efficiency (SE) is necessary to optimize the performance of wireless systems.

## 4.4. Computational Complexity Analysis

Computational complexity analysis is important in wireless communication precoding techniques for several reasons: Performance trade-offs: Precoding techniques are used to improve the communication quality in wireless systems by mitigating interference and enhancing the signal-to-noise ratio. However, these techniques are often computationally intensive, and the complexity of the employed algorithms has an impact on performance. By analyzing the computational challenges for different precoding techniques, it is possible to identify the trade-offs between performance and complexity and choose the most appropriate technique for a given application.

Resource utilization: Wireless systems typically have limited resources, such as processing power and battery life. Precoding techniques that require high computational resources can quickly deplete these resources, leading to reduced system performance and shorter battery life. By analyzing the computational complexity of precoding techniques, it is possible to design algorithms that are efficient in terms of resource utilization, thereby improving system performance and extending battery life.

Real-time operation: Wireless systems often require real-time operation, where data must be processed and transmitted within strict time constraints. Computationally intensive precoding techniques may not be able to meet these real-time requirements, leading to delays and reduced system performance. By analyzing the computational complexity of precoding techniques, it is possible to design algorithms that can operate in real-time, thereby improving system performance.

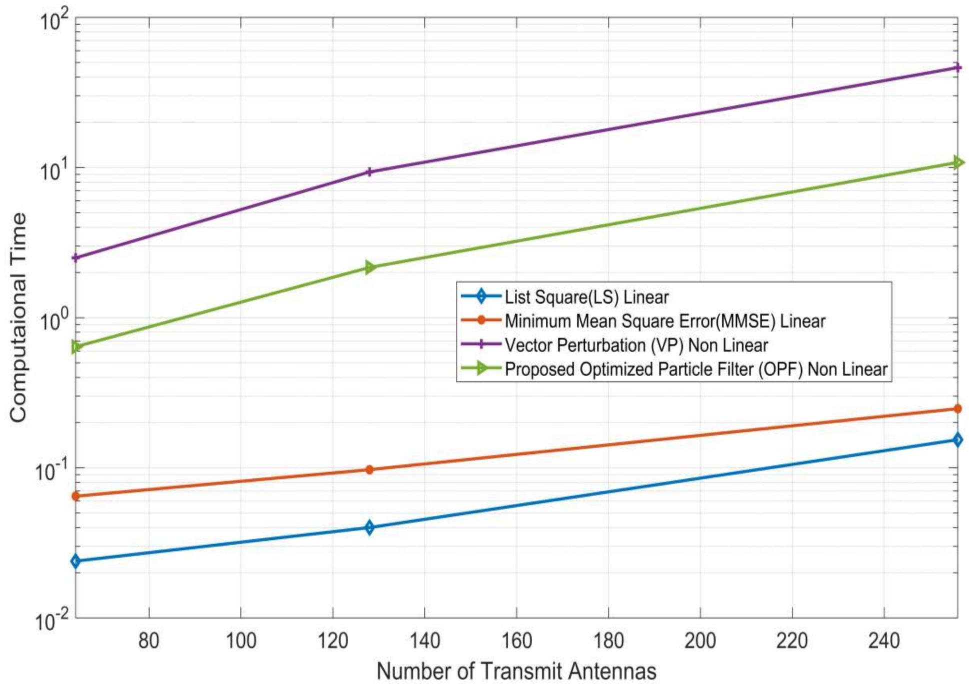


Figure 4. 8 Number of Transmit Antennas versus Computational Time Analysis of TH, DPC, VP, and Proposed OPF precoding techniques

Figure 4.8 is a simulation result that shows the number of transmit antennas versus computational time complexity. In Figure 4.8 two types of precoding techniques come into comparison namely: linear and non-linear precoding techniques. It is known that linear precoding techniques are less complex compared to non-linear precoding techniques. The techniques of linear and non-linear precoding that are represented in the analysis are chosen by observing better performance. List square and Minimum Mean Square Error are linear precoding techniques that have a better impact on existing system performance. Vector perturbation and optimized particle filter precoders are chosen filters to see their impact of it on the existing system.

The number of transmit antennas in a wireless communication system can have a significant impact on the computational time required to implement precoding techniques. In general, the computation time required for precoding increases as the number of transmit antennas increases as well. This is because precoding techniques involve matrix operations, such as matrix inversion, multiplication, and decomposition. As the size of the matrices used in these operations increases with the number of transmit antennas, the computational complexity increases as well. For example, in MIMO (multiple input multiple outputs) systems, the number of transmit antennas is typically denoted as M, and the computational time required for precoding techniques scales with $M^3$. This indicates that the computing time required for precoding will increase by a factor of 8 if the number of transmit antennas is doubled.

However, the exact relationship between the number of transmits antennas and computational time can depend on the specific precoding technique used, as some techniques may have lower computational complexity than others. Additionally, advances in computing hardware and algorithms can also help to mitigate the impact of increasing numbers of transmit antennas on computational time.

In general, computational complexity analysis is essential for designing efficient and effective precoding techniques for wireless communication systems. By understanding the trade-offs between performance and complexity, it is possible to choose the most appropriate technique for a given application, optimize resource utilization, and ensure real-time operation.

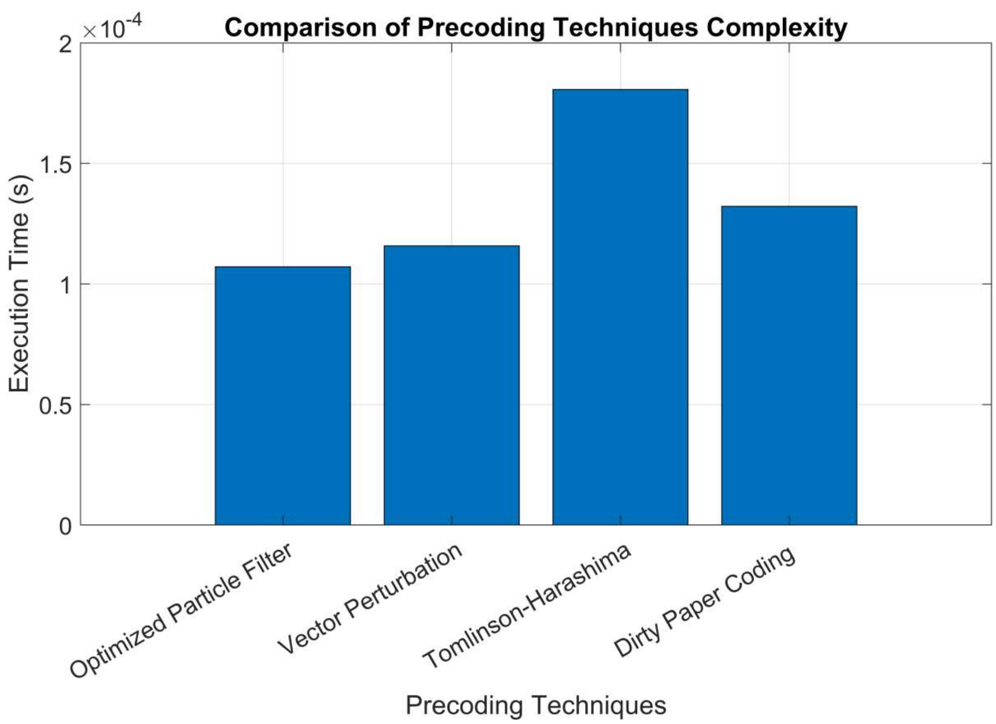


Figure 4. 9 Execution Time (s) of TH, DPC, VP, and Proposed OPF precoding techniques

Figure 4.10 shows the simulation result analysis of TH, DPC, and VP and proposed optimized particle filter precoding techniques. As can be seen from the result optimized particle filter has less execution time. From this result, it can be concluded that the proposed optimized particle filter precoding techniques outperform other.

# CHAPTER FIVE

# 5. CONCLUSION AND RECOMMENDATIONS

## 5.1. Conclusion

Precoding is a beamforming concept that permits multi-stream transmission in systems with multiple antennas. In massive MIMO systems, precoding is essential because it optimizes throughput while minimizing the effects of path loss and interference. In massive MIMO systems, the base station determines the CSI using uplink pilot signals or user terminal input. Due to various environmental conditions on the wireless channel, the received CSI at the base station is not uncontrolled and is not perfect. The calculated CSI still significantly affects the base station's downlink performance even if it is not always error-free. Estimated channel state information (CSI) and precoding approach used at the base station were used to decrease interference and increase spectral efficiency (SE). The effectiveness of downlink massive MIMO depends on the precoding method used and an accurate calculation of CSI.

Massive MIMO systems benefit greatly from the precoding process, but it also adds more computations to the system, which makes it more computationally demanding. As there are more antennas, the computation becomes more complicated. For massive MIMO systems, therefore more practicable to employ low complexity and efficient precoders. To address this problem, an optimized particle filter was presented in this thesis work. In the OPFP, the particle filter is used to estimate the channel state information (CSI) of the wireless channel, which is then used to optimize the precoder for data transmission.

Signal-to-noise ratio versus bit error rate analysis, Signal-to-noise ratio versus spectral efficiency analysis, the number of transmit antennas versus average sum spectral efficiency analysis, and other parameters were used to analyze the results. The output of the simulation results that the suggested optimized particle filter performs better in terms of average sum spectral efficiency (SE) and bit error rate (BER) than the current precoding approaches on different modulation techniques. Computational complexity analysis of TH, DPC, and VP and proposed optimized particle filter precoding techniques. From the analysis result optimized particle filter has less execution time than others non-linear precoding techniques.

## 5.2. Recommendation

According to the simulation result, the complexity analysis is done in this thesis. However, the complexity analysis of the simulation results shows that the proposed optimized particle filter has some complexity compared to the existing system.

Some points recommended for future works are:

1. It is better if the performance of the proposed optimized particle filter is checked under practical channels like Pedestrians and Vehicular Channel Models.
2. It is recommended that optimized particle filter complexity be further reduced.

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