Comparative Analysis of Pre-Coding Techniques for the Multiuser Massive MIMO System

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A Thesis Submitted to the Department of Electronics and Communication Engineering

School of Electrical Engineering and Computing

Office of Graduate Studies

Adama Science and Technology University

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Adama, Ethiopia

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APPROVAL PAGE OF M.SC. THESIS

We, the advisors of the thesis entitled "Comparative Analysis of Pre-coding Techniques for the Multiuser Massive MIMO System" developed by Tinsae Gebremedhin; 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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We, the undersigned, members of the Board of Examiners of the thesis by Tinsae Gebremedhin have read and evaluated the thesis entitled "Comparative Analysis of Pre-coding Techniques for the Massive Multiuser MIMO" and examined the candidate during the open defence. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Electronics and Communication Engineering (Communication Engineering).

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

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DECLARATION

I hereby declare that this Master Thesis entitled "Comparative Analysis of Pre-Coding Techniques for the Multiuser Massive MIMO System" is my original work. That is, it has not been submitted for the award of any academic degree, diploma, or certification in any other university. All sources of material used for this thesis have been duly acknowledged through citation.

Name of Student	Signature	Date

RECOMMENDATION

We, the advisors of this thesis, hereby certify that we have read the revised version of the thesis entitled "Comparative Analysis of Pre-coding Techniques for the Multiuser Massive MIMO System" prepared under our guidance by Tinsae Gebremedhin submitted in partial fulfillment of the requirements for the degree of Masters of Science in Electronics and Communication Engineering(Communication Engineering). Therefore, we recommend the submission of a revised version of the thesis to the department following the applicable procedures.

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Major Advisor	Signature	Date
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Co-advisor	Signature	Date

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LIST OF ACRONYMS AND ABBREVIATIONS

5G	Fifth Generations
ADCs	Analog-to-digital converters
B5G	Beyond Fifth Generation
BD	Block diagonalization
BER	Bit Error Rate
BS	Base Station
BUAR	Base Station-to-User Antenna Ratio
CSI	Channel State Information
DACs	Digital-to-analog converters
DL	Downlink
DPC	Dirty paper coding
EE	Energy Efficiency
IEEE	Institute of Electrical and Electronics Engineers
IUI	Inter-user interference
MATLAB	Matrix Laboratory
MSE	Mean Squared Error
MIMO	Multiple-Input Multiple-Out
MU-MIMO	Multi-User Multiple-Input Multiple-Out
M-MIMO	Massive- Multiple-Input Multiple-Out
MMSE	Minimum mean square error
MSE	Mean square error
MRT	Maximum Ratio Transmission
PSK	Phase shift key
QAM	Quadrature amplitude modulation
QoS	Quality of Service
QPSK	Quadrature phase shift key
RF	Radio Frequency
RZF	Regularized zero forcing
RX	Receiver

SE	Spectral Efficiency
SINR	Signal to Interference plus Noise Ratio
SNR	Signal-to-Noise ratio
SQUID	Squared-infinity Norm Douglas-Rachford Splitting
TX	Transmitter
UE	User Equipment
ZF	Zero forcing

ABSTRACT

The number of consumers and applications is continually expanding, which encourages the study and advancement of wireless technology. Wireless communications should ideally have a high data rate and high connection efficiency. Future wireless communication systems will have to address some fundamental needs, such as simultaneously servicing a large number of users, maintaining high throughput for each user, ensuring low energy consumption, and so on. In practice, inter-user interference occurs when multiple users access the wireless link, necessitating the adoption of complex transmission techniques such as interference cancellation to maintain a specified level of service. To overcome inter-user interference, and improve signal-to-noise ratio, a huge MIMO system with very large antenna arrays is proposed. Massive MIMO (multiple-input, multiple-output) is a promising technology that has introduced the concept of employing hundreds or thousands of antennas of the user simultaneously, Multi-stream transmission in systems with many antennas possible with the aided of pre-coding (signal preprocessing), Large number of antennas will help to concentrate radiated energy into a smaller area, improving the system's throughput and energy efficiency. This thesis aims to compare and combine linear and nonlinear (hybridized) pre-coding based on iterative algorithms to retain the advantages of both linear and nonlinear pre-coding. The results reveal that the proposed pre-coding technique can be approached optimal performance in terms of decreasing bit error rate and increasing Energy Efficiency than the existing pre-coding technique such as Maximum Ratio Transmission (MRT) and zero-forcing (ZF), Wiener Filter (WF) and nonlinear pre-coder as Squared-infinity norm Douglas-Rachford splitting(SQUID), Dirty-Paper Coding(DPC).

Keywords: MIMO; ZF; MRT; SQUID; Massive MU-MIMO; Energy Efficiency; Digital-to-analog converters (DACs), Iterative algorithms

CHAPTER ONE

1. INTRODUCTION

1.1 Background

Due to the global demand for wireless data traffic increasing all the time, future cellular networks will require much higher area data throughput. This goal can be met without the addition of more bandwidth or base stations if spectral efficiency (measured in bits/s/Hz/cell) is improved (Van Chien & Björnson, 2016). To improve the spectral efficiency, we need new technology called massive multiple-input multiple-output (MIMO). The massive multiple-input multiple-output (MIMO) system, also known as the large-scale antenna system, can increase spectral efficiency for a given total transmit power. Increased capacity is achieved by introducing additional spatial channels that are used combined with space-time coding., energy efficiency (EE), and reliability by configuring a massive array of antennas at existing base stations (BSs) and has been regarded as a potential technology for next-generation wireless communication networks(Lu et al., 2014).

Unfortunately, when a large number of antennas and radio frequency chains (RF) are used, the complexity, system costs, and circuit power consumption of massive MIMO systems increase (Albreem et al., 2021). The data converters at the BS are a major source of power consumption in massive MU-MIMO systems. A pair of digital to analog converters (DACs) generate the transmit baseband signal at each RF chain in the downlink. These DACs' power consumption grows exponentially with resolution (in bits) and linearly with bandwidth(Akalu, 2021).

MIMO is a physical layer technology that enables more data to be sent in the same amount of time and bandwidth. MIMO systems, as contrasted with Single Input Single Output systems, which use only one antenna at the transmitter and receiver, allow numerous data streams to be delivered in distinct spatial paths at the same time, boosting data speeds. When many streams are delivered across wireless channels at the same time, signal mixing occurs at receivers. As an outcome, additional signal processing is necessary, either at the receiver or at the transmitter, or both, to separate the data stream, which is known as MIMO processing(Version et al., 2017). MIMO processing involves several key techniques, including spatial multiplexing, beamforming, pre-coding, and channel estimation. Beamforming is used to steer the sent signal toward the receiver, while spatial multiplexing is used to transmit multiple independent data streams concurrently across the same frequency band. While channel estimation is used to determine the wireless channel characteristics and adjust the transmission accordingly, pre-coding is used to optimize the transmitted signal based on the channel circumstances.

MIMO technology is classified as follows depending on how many antennas are employed at both the transmitter and the receiver: point-to-point MIMO, multi-user MIMO, and massive MIMO. This thesis is about multi-user and Massive MIMO, which is arguably the ultimate expression of MIMO technology. MU- massive MIMO allows a single base station to serve a large number of terminals while using the same time-frequency resources. The MU-massive MIMO scenario is effectively obtained from the Point-to-Point MIMO setup by dividing the K-antenna terminal into multiple autonomous terminals.

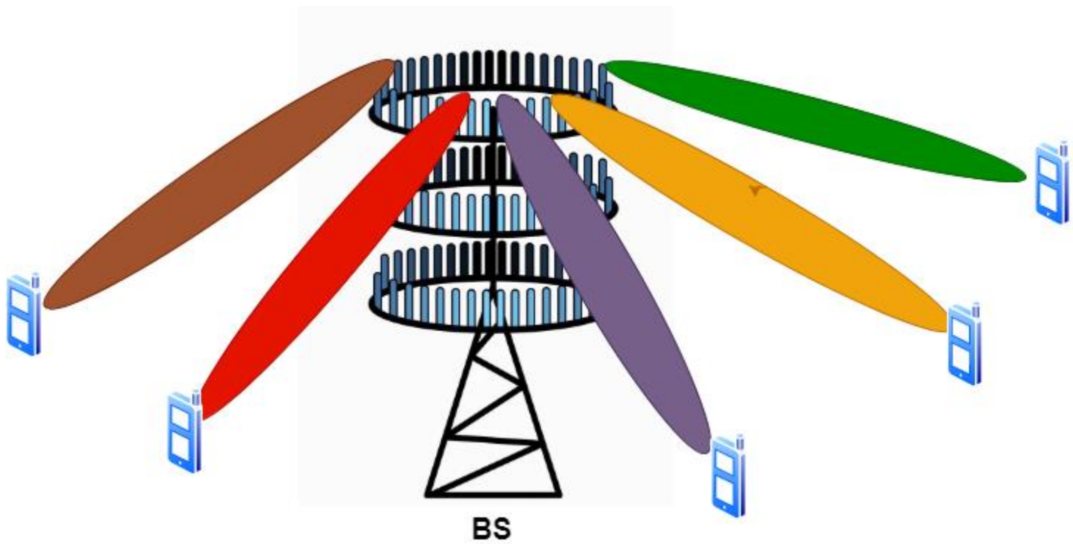

Figure 1.1: Multiuser massive MIMO (Ali et al., 2018)

1.1 Motivation of the Study

The sector of wireless connectivity has studied and developed huge MIMO wireless connectivity solutions in response to the worldwide bandwidth challenge. Massive MIMO, which combines transmitter and receiver antennas, is one of the key technologies that will support the development of future networks. To address the fundamental challenges of this technology and realize different implementations of the intelligent pre-coding system, it is crucial to figure out the large MIMO system in more detail. It offers exceptional spectrum and energy performance with comparatively simple processing. For large MU-MIMO systems, the challenge between pre-coding algorithm complexity and performance increases considerably, indicating that new, effective pre-coding methods need to be devised.

1.2 Statement of the problem

Wireless communication's major challenges include spectral efficiency, link reliability, coverage, and energy efficiency. This is caused by the limited available bandwidth, the fading nature of the propagation channel, and the wireless nodes' mobility and autonomy. The rapid increase in demand for high-speed, high-quality multimedia services with varying quality of service (QoS) requirements creates both opportunities and challenges for system designers. A key goal of next-generation wireless networks is to provide diverse QoS guarantees to mobile users and applications. But even so, the wireless channel is affected by time-dispersive effects, Doppler, and multi-path fading, reducing the wireless system's spectral efficiency. A simple method for preserving the data rates offered is to increase the allocated bandwidth. Due to the scarcity of radio spectrum resources, this technique is difficult. Inter-user interference can indeed be reduced while using pre-coding to maintain higher data rates for the given bandwidth by focusing the energy on the desired user. Massive MIMO technology is now attracting a wide range of academic and industrial research. That is why it motivates me to work hard in this area. This thesis work performed a comparison of linear and nonlinear pre-coding under a large number of antennas and users and combine existing linear and nonlinear (hybridized) pre-coding based on iterative algorithms' optimum pre-coding technique in terms of energy efficiency, signal-to-noise ratio, and bit error rate.

1.3 Objective

1.3.1 General Objective

The main objective is finding the best pre-coding technique used to achieve energy and spectral efficiency of the Massive MIMO system by minimizing the total power consumption and enhancing the capacity of the system respectively from various existing techniques.

1.3.2 Specific Objectives

The specific objectives of this work are highlighted as follows;

- ✓ To Analyze linear (ZF, MRT, WF) and non-linear (DPC, SQUID) pre-coding techniques for massive MU-MIMO systems.
- ✓ To evaluate the Energy Efficiency and Bit Error Rate of each pre-coding type for a massive MU-MIMO system.

- ✓ To compare Energy Efficiency and throughput of both linear and nonlinear precoding techniques of massive MU-MIMO system.
- ✓ To improve the performance parameters of MU-MIMO using a hybrid pre-coding technique.

1.4 Significance of the Study

The increasing demand for high-speed mobile data generates several urgent design difficulties as today's wireless base stations strive to satisfy an RF spectrum that is being saturated at a rapid rate. In many congested global locations, the ability of our network to continually expand transmitting and obtaining data speeds is threatened. Deploying base stations with multiple antennas that can communicate with a range of spatially dispersed user terminals over the same frequency resource while using multi-path propagation is a step in the right direction. A method known as multiple input multiple output (MIMO) makes use of plenty of antennas. By using spatial diversity to prevent fading and interference, enhancing the robustness and quality of the wireless communication system. The system can better manage the impacts of fading and interference by employing numerous antennas to provide several communication channels, leading to more dependable and higher-quality wireless communication.

1.5 Scope of the Study

This paper focused on the effective analysis of linear and nonlinear precoders for the 5G and B5G M-MIMO systems that use frequency-flat channels and Channel-State-Information at the transmitter, including zero forcing, maximum ratio transmission, dirty-paper coding (DPC), and squared-infinity norm Douglas-Rachford splitting (SQUID), respectively. The energy efficiency and performance of ZF, MRT, and SQUD, DPC pre-coding under different SNRs are reviewed in the last section. We'll look at the cancellation diagram for various modulation schemes when there are a lot of users (K) and base station antennas (M).

1.6 Thesis Contributions and Outline

In every work of the literature that has been cited so far in the literature review, pre-coding has been investigated at various levels. In this paper, we look at quantized pre-coding for huge MU-MIMO downlinks in frequency-flat channels. This work is not restricted to linear pre-coding. It covers both nonlinear precoders, in which the data vector and CSI are used to directly produce the DAC outputs, and linear-quantize precoders, in which a linear precoder is followed by a finite-resolution DAC. The following is a summary of our contributions.

- ✓ This work examines large MIMO pre-coding techniques and explains their performance-complexity profile, allowing the reader to distinguish between various pre-coding algorithms with a broader variety of viable solutions. It begins with a look at the literature on precoders for huge MIMO systems. Then it discusses the advantages and disadvantages of precoded huge MIMO systems. It then goes over the fundamental linear and nonlinear precoders used in huge MIMO systems.
- ✓ Compare the bit error rate for M-MIMO with a given target of SINR for the optimal strategy of nonlinear pre-coding to that achieved with sub-optimal and lower complexity linear transmission. Pre-coding (e.g., zero-forcing, Maximum Ratio Transmission, Dirty paper coding, Squared-infinity Norm Douglas-Rachford Splitting). We evaluate the energy efficiency of each pre-coding type in terms of throughput.

1.7 Organization of the Thesis

The rest of the thesis is organized as follows. In chapter 2 survey of the literature on the development of the Massive MIMO system, linear pre-coding, zero forcing, Wiener filter, maximum ratio transmission, Nonlinear pre-coding, dirty-paper coding (DPC), squared-infinity norm Douglas-Rachford splitting (SQUID). Additionally, it addresses the benefits of massive MIMO technology as well as any possible difficulties that may arise. The research approach taken for this thesis. A mathematical formulation for massive downlinks is included. MIMO consideration.in chapter 3. In chapter 4, includes various simulation results and discussions for various linear and nonlinear pre-coding techniques and proposes an optimal pre-coding technique from an M-MIMO perspective. Chapter 5, the final work is concluded by summarizing the key ideas and recommendations for future extension of the work.

CHAPTER TWO

2. LITERATURE REVIEW

Nowadays, both academics and industry are giving close attention to massive MU-MIMO technologies. Various research projects have looked into how well pre-coding methods perform in huge MIMO systems. This chapter presents the theoretical background and a review (survey) of the various works of literature that have been related to this research.

2.1 Massive MIMO Overview

The term "massive MIMO" (multiple inputs multiple outputs) refers to a communication method that supports multiple concurrent users by using a huge number of antenna components, often between dozens and hundreds, and occasionally up to thousands. By taking advantage of the wireless channel's spatial dimension, this technique is intended to boost the capacity and effectiveness of wireless communication networks. Huge MIMO has several advantages, including the ability to simultaneously use frequency and temporal resources while providing service to several consumers. This is accomplished through spatial multiplexing, in which the base station sends independent data streams to several customers on the same frequency band while employing various antenna beams. The capacity to arrange which users have access to the reception at any given time while accommodating multiple users simultaneously. According to the most common massive MIMO theory, user terminals only have one antenna whereas there are many more antennas at the base station (BS) than there are available users. This makes sure that a receiver antenna array can broadcast and receive data from several users simultaneously through the transmitter. Each array makes use of a large number of antennas to do this. Cell towers may use all of those antennas' many transmission modes and complex signal processing. The emergence of enormous MIMO has had a huge impact on the research and development sector throughout the last decade. As a result, many next-generation communication technologies, such as 5G below 6 GHz, have adopted massive MIMO as their primary technology(Albreem et al., 2019).

Massive MIMO has a lot more antennas than there are UEs in the cell, thus the beam is much narrower. This enables the base station to deliver RF energy to the UE more precisely and effectively. Without the requirement for several reception antennas, UE can be simplified by controlling the phase and gain of the antenna separately while leaving the channel information with the base station. Increased cell site capacity and throughput are produced by the installation of numerous base station antennas since it enhances the cell's signal-to-noise ratio. Demand for wireless speed, connectivity effectiveness, and customer density will all continue to rise. Massive MIMO technology is being developed for 5G and beyond 5G (B5G) wireless networking networks to simultaneously accommodate many devices with extremely high latency. Massive MIMO antenna arrays can focus their signal energy to reduce the propagation losses that come with high-frequency transmission in 5G and B5G networks.

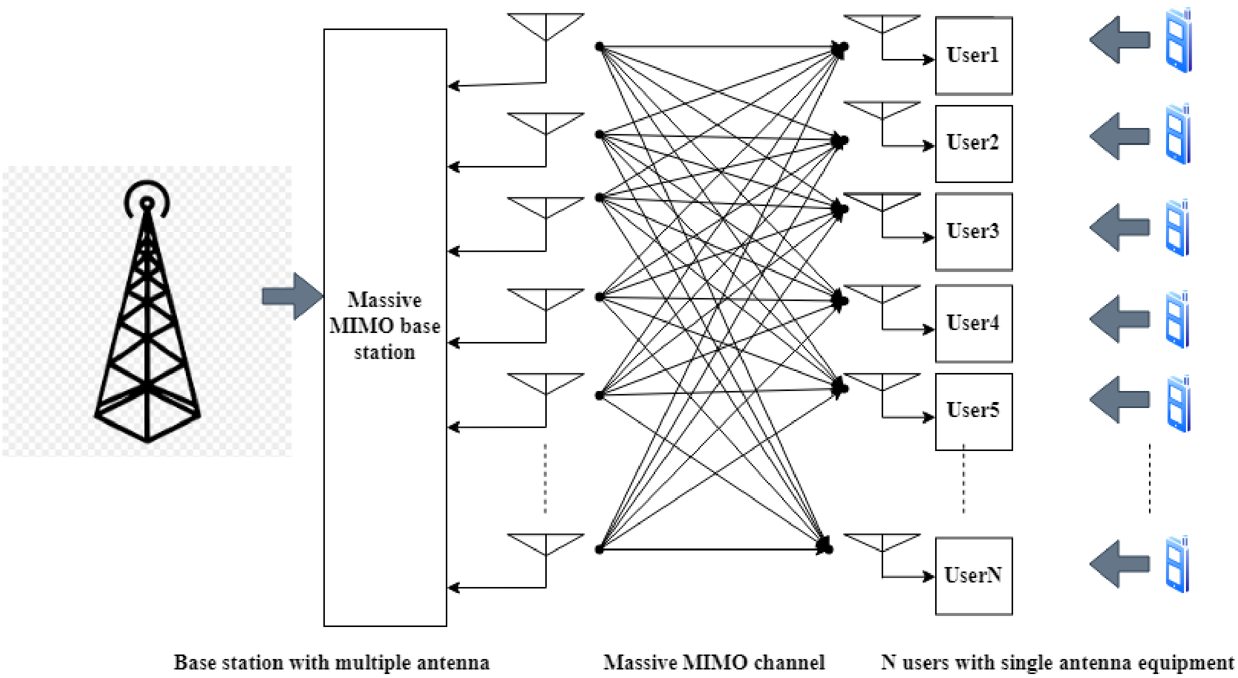

Figure 2.1: Multiuser massive MIMO architecture (Albreem et al., 2019)

2.2 Massive MIMO Working Principle in 5G Networks

Massive MIMO technology can improve radio connection quality, the capacity of the network, and throughput by utilizing a high number of antenna components within a single Antenna module of a base station. This is accomplished by combining spatial multiplexing and diversity techniques, which allow the system to simultaneously broadcast and receive many data streams to and from several users. And pre-coding can help to improve the efficiency of wireless communication networks by boosting data rates, enhancing wireless connection dependability, and lowering interference. It is possible to serve multiple users at the same time thanks to the additional capacity. Spatial multiplexing, transmitter and receiver diversity, and pre-coding lay the groundwork for increased signal reliability and data rate while reducing interference. Massive MIMO's fundamental operating principle in 5G and beyond 5G networks is as follows:

2.2.1 Multiple Antennas

An enormous number of antennas, generally hundreds or thousands, are installed on the base station in a Massive MIMO system. These antennas are employed to simultaneously send and receive signals for several users. This allows for an increase in data flow while also enhancing the communication link's dependability and lowering the likelihood of errors.

2.2.2 Spatial Multiplexing

Massive MIMO uses a large number of spatially distinct antenna arrays that may simultaneously broadcast and receive numerous data streams. In spatial multiplexing, as seen in Figure 2.2, the transmitter sends various independent data streams to the receiver through various antennas. Additionally, the receiver has several antennae that are utilized to isolate and receive the transmitted data streams. Multiple distinct data streams can be created from the overall data stream created specifically for a given consumer. These data streams are gathered at the receiver side by a variety of receiving antenna components, which then merge the various distinct data streams into a single data stream This enables larger data rates and more dependability since the signal quality can be improved by using several antennas to lessen interference, fading, and other distortion effects and boost the spectral efficiency as a result in increases the overall capacity and data rates(Elgam et al., 2023).

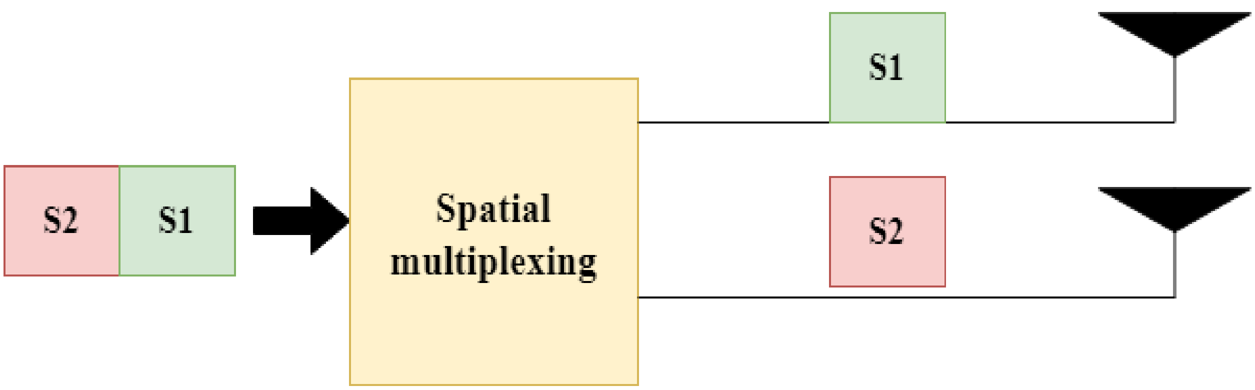

Figure 2.2 spatial multiplexing in MIMO (Renzo et al., 2016)

2.2.3 Channel Estimation

The channel estimate is the technique of calculating the wireless channel between numerous TX/RX antennas in MIMO systems. To optimize data transmission and reception in MIMO systems, accurate channel estimation is crucial. In MIMO systems, the matrix of channels is approximated to show how the signals broadcast from the many antennas at TX and the signals received at the numerous antennas at RX relate to one another. Numerous methods, such as pilot-based estimation, blind estimation, and hybrid estimation, can be used to estimate the channel matrix.

The method employed the most frequently in MIMO systems is a pilot-based estimate. In this method, known pilot symbols are inserted into the transmitted signal by the TX, allowing the RX to calculate the channel response(Gao et al., 2023). The RX interpolates the matrix of channels between the pilot symbols to estimate the matrix of channels at other points in time or frequency. It then uses the received pilot symbols to estimate the channel matrix.

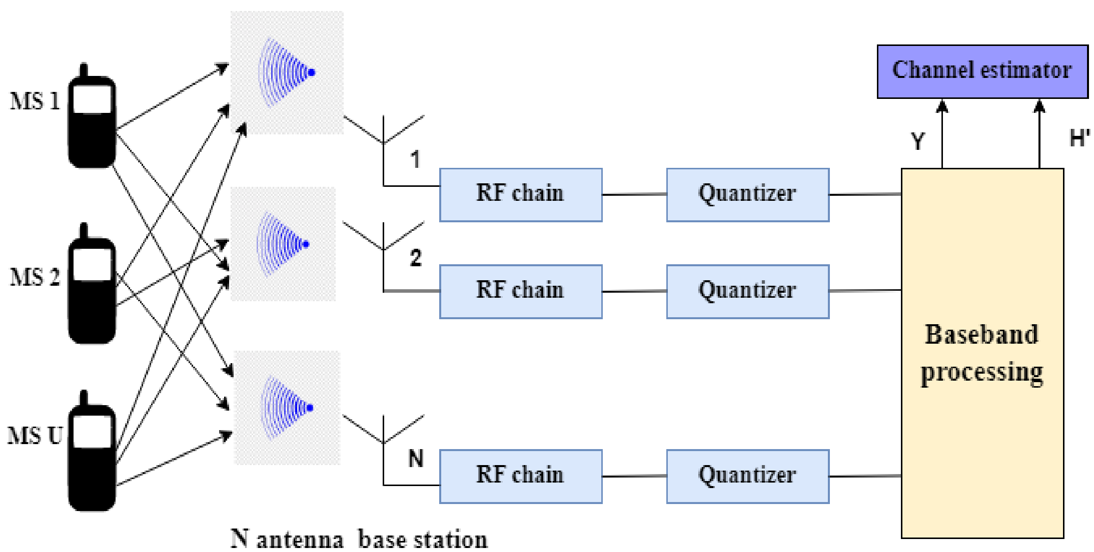

Figure 2.3: Massive MIMO Channel estimation *(MOQBEL et al., 2017)*

The base station in large MIMO systems estimates the CSI using uplink pilot signals sent by the user terminals or other information from the terminals. The wireless channel is affected by several external circumstances, therefore the received CSI at the base station is imperfect.(Fatema et al., 2017). While the base station may not always get perfect CSI due to different external factors that affect the wireless channel, the downlink performance of a base station in a massive MIMO system is strongly dependent on the accuracy of the estimated Channel State Information (CSI). The CSI is necessary for the base station to recognize and precode signals sent in the uplink and downlink directions, respectively, by users. In a huge MIMO system, the base station is aware of all user's pilot sequences and uses them to estimate the channels based on the pilot signals received. To recognize coherent signals sent by the base station, each user additionally requires some knowledge of the CSI. Through downlink training, one can learn this information. The user simply needs to be aware of the effective channel gain to detect the desired signals because the base station pre-codes the signals for the users utilizing linear pre-coding techniques. To get the CSI from the users and the effective channel gain required for the users to detect their intended signals, the base station, therefore, spends some time pre-coding the pilots in the downlink.

2.2.4 Beamforming

The system performs more effectively when many antennas are placed at the TX and RX. By specifically altering the amplitude and phase of the signal components, the signals are directed towards a particular direction or position in beamforming. As a result, there is less interference and noise generated during the transmission or reception of the signals. (Bouchenak et al., 2021). This is made feasible by utilizing Channel State Information, allowing for this performance boost. The base station can employ beamforming to focus the broadcast signals on particular areas, such as a particular user or group of users while reducing interference from other sources. This can greatly increase the system's capacity, effectiveness, and dependability, especially in densely populated metropolitan areas and other places where there is a large demand for wireless data.

2.2.5 Diversity in the Receiver

In MIMO communication systems, diversity is a crucial topic. MIMO is a technique that boosts the effectiveness and dependability of the communication system by using numerous antennas at the TX and RX. To reduce the impacts of fading, interference, and other distortions, diversity in MIMO refers to the employment of several antennas to generate a variety of separate communication channels between the TX and RX. To increase the resilience of the signal by boosting the radio link's dependability and overall signal quality, diversity makes use of the signal's inherent properties by utilizing numerous antennas to acquire different versions of the same signal. To further boost the accuracy and dependability of the received signal, receiver diversity techniques can be employed in conjunction with other signal processing methods like equalization and coding.

2.3 Massive MIMO Features

- ✓ Several hundred antennas per base station.
- ✓ Multiple receiving terminals are served by the base station.
- ✓ Antenna with a small size.
- ✓ Low levels of transmission power per antenna.

- ✓ High directive gains.
- ✓ Advanced interference management strategies.
- ✓ Depend on precise channel state information.

2.4 Massive MIMO Advantages

Massive MIMO (Multiple Input Multiple Output) technologies are complicated and difficult to deploy, but the advantages they may have may exceed the drawbacks. Massive MIMO deployment can at times feel like attempting to ride a bucking bronco, but the benefits and resources it offers make the effort worthwhile. A few benefits of the massive MIMO (MU-MIMO) system are listed below:

I, Interference reduction and avoidance: In a MIMO system, widening the spatial separation between users can reduce interference and boost efficiency. The spatial dimension can be used to focus signal energy on the intended user while reducing interference from other users. The parameter coupling involved makes it difficult to achieve all of these benefits at once, though. It might not be possible to achieve peak performance in every area simultaneously, and there might be some compromise between these advantages.

I, Energy efficiency: The ability of the system to transmit and receive data while utilizing the least amount of energy feasible is referred to as energy efficiency in huge MIMO systems. This is accomplished by maximizing a variety of system parameters, including the number of antennas, the modulation scheme, the transmit power, and the signal processing methods used.

III, Array gain: Array gain is a term used to describe the increase in Signal strength that results from the coherent mixing of signals at the RX. Through spatial processing at numerous antennas at the TX and/or the receiver, coherent combining can be achieved.

IV, High spectral efficiency and communication reliability: High spectral efficiency describes a system's capacity to transfer a lot of data over a little amount of frequency spectrum. This is accomplished by creating several spatial streams utilizing multiple antennas at the transmitter and receiver, which may then be utilized to send numerous data streams at once. MIMO systems can make the best use of available resources and boost the spectral efficiency of the communication link by utilizing cutting-edge signal processing techniques like beamforming and spatial multiplexing. On the other side, communication dependability in MIMO systems refers to the system's capacity to maintain a steady and continuous connection between the transmitter and receiver.

V, Capacity and link reliability: By enhancing diversity gain and preventing fading, massive MIMO increases connection robustness. The capacity grows without limit as the number of antennas increases when a multi-cell minimal average square error (MMSE) pre-coding combination and spatial channel correlation are used, even when pilot contamination is present.

VI, Spatial diversity gain: Communication reliability is improved by increasing spatial variation. Several antennas are used to broadcast copies of an information signal, reducing the possibility that at least one of the copies may experience a deep fade when the signal is received.

2.5. Massive MIMO (M-MIMO) Applications

The cellular world is moving towards big MIMO as 5G demands it. Spectral efficiency is essential for 5G because there is a finite amount of bandwidth available. To connect billions of mobile devices, 5G networks would also be necessary. That would require high precision and energy efficiency from MIMO. The ecosystem of our planet is becoming more intertwined as technology improves. Self-driving cars are coming, the Global Internet getting started, and networks for smart cities are already in place. All of these industries will soon benefit from 5G, which calls for the connection of billions of devices. Data beaming to and from specific devices would be necessary to do this via massive MIMO. Because of Massive MIMO's energy efficiency, these networks could not need another oil boom.

2.6. Challenges in Massive MIMO

Despite the numerous benefits of Massive MIMO, several concerns must be addressed. The major challenges in Massive MIMO are described below.

2.6.1 High power consumption

Massive MIMO consumes more power due to the presence of several dozen antennas and several RF chains corresponding to each antenna. Each component of the radio frequency chain consumes greater power as its number increases.

2.6.2 Pilot Contamination

When nearby cells share the same set of pilot signals, a phenomenon known as pilot signal contamination can happen, causing interference between the transmitted signals and the pilot signals. As a consequence, it could be difficult to estimate the channel accurately, which might cause problems during decoding and signal processing. Additionally, pilot contamination can reduce the system's capacity and spectrum efficiency, especially in densely populated urban areas where nearby cells might be using an identical set of pilot signals.

2.6.3 Hardware Efficiency

The term "hardware efficiency" in the context of MIMO refers to the system's capacity to achieve high performance and dependability while utilizing the fewest possible hardware resources, such as antennas, transceivers, and other signal processing elements.

2.6.4 Signal Detection

In MIMO systems, signal detection is the process to recognize transmitted signals at the receiver despite interference and background noise. Multiple antennas are utilized at the TX and RX in MIMO systems to increase the communication link's capacity and dependability. There are several methods for signal detection in MIMO systems, such as linear and nonlinear detection.

- Linear Detection: Matrix operations and linear algebra serve as the foundation for linear detection techniques. In linear detection, the broadcast signal is estimated by multiplying the received signal by a detection matrix.
- Nonlinear Detection: Nonlinear procedures like sphere decoding and decision feedback equalization (DFE) are the foundation of nonlinear detection systems. In nonlinear detection, the transmitted signal is estimated from the received signal by processing it through a nonlinear function.

2.6.5 Pre-coding

Multi-stream transmission in systems with many antennas is made possible by pre-coding, a beamforming idea. Pre-coding is a signal processing method that boosts the accuracy and dependability of data transmission in wireless communication systems. Reducing the impacts of interference and signal fading, entails modifying the transmit signal at the transmitter before it is delivered over the wireless channel. It is a method that employs transmit diversity by weighting the data stream; in further words, the transmitter delivers the coded data to the receiver to help it discover the channel.

The transmitted signal in wireless communication systems can be corrupted by several things, including multipath fading, interference from other signals, and noise. By pre-multiplying the data symbols by a complicated matrix that is created to take into consideration the properties of the wireless channel, pre-coding is employed to enhance the signal quality. Channel state information (CSI), which is collected by input from the receiver, is often used to determine this matrix.

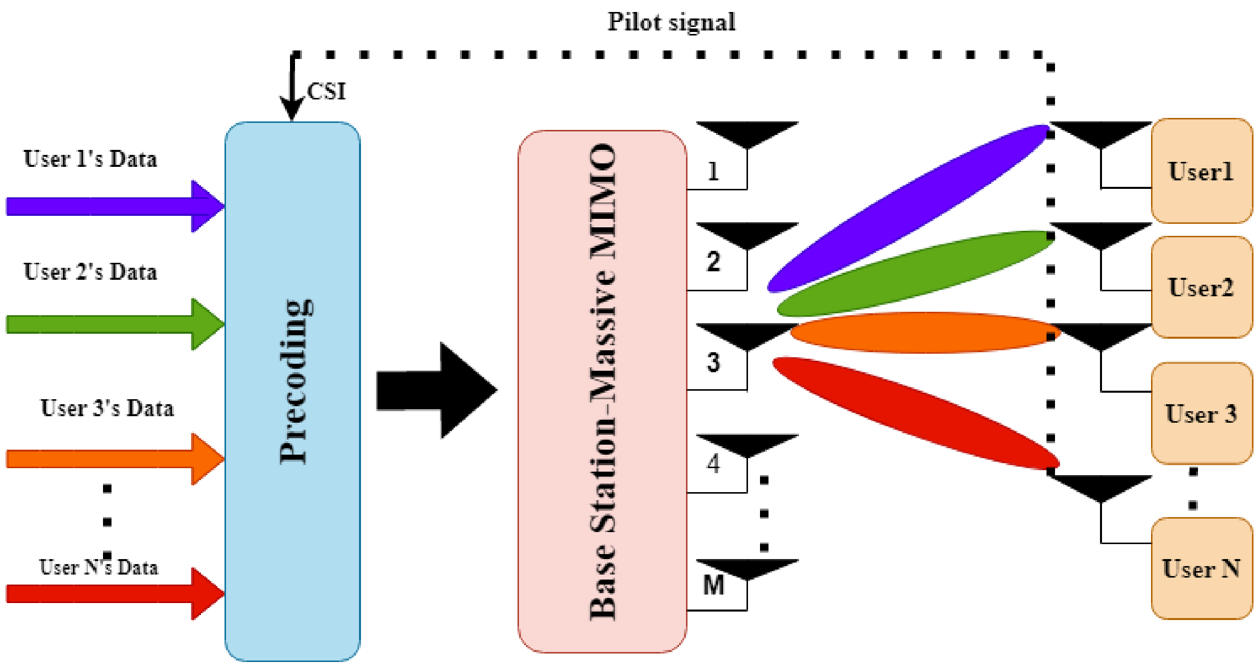

Figure 2.4: Large-scale MIMO system with pre-coding having M base station antennas and N users (Albreem et al., 2021*)*

Pre-coding is crucial in huge MIMO systems because it boosts throughput while minimizing the impact of route loss and interference. Using uplink pilot signals or input from the user equipment, the base station calculates channel state information (CSI) in large MIMO systems. The effectiveness of DL massive MIMO depends on the precision of the CSI estimation and the pre-coding method employed. Pre-coding in huge MIMO systems is depicted in Figure 2.2.

Constellation mapping is a popular pre-coding technique where the data symbols to be transmitted are mapped onto a collection of points in a complicated plane known as a constellation. The purpose of the pre-coding in this instance is to transmit the constellation points with the least amount of noise and interference-induced signal distortion.

Pre-coding, in other words, seeks to modify the transmitted signal in a way that enables the receiver to precisely decode the transmitted data symbols from the received signal, even in the presence of noise and interference. To maximize the SNR at the receiver, the pre-coding process might optimize the broadcast signal by utilizing a constellation mapping technique.

2.7. Frequency-flat wireless channel

The AWGN function can be used to simulate frequency-flat channels since it adds Gaussian noise to a signal while maintaining its power and channel response. Assuming a frequency-flat channel, the AWGN function is suitable for simulating communication networks that use such channels. Frequency-flat channels have several benefits for communication systems:

- Simplicity: Compared to frequency-selective channels, which can exhibit complex and time-varying responses, frequency-flat channels are frequently easier to model and analyze. As a result, designing and perfecting communication systems for frequency-flat channels may be simpler.
- Robustness: Compared to frequency-selective channels, frequency-flat channels are less likely to experience frequency-dependent distortion and interference. Higher communication system performance may arise from making frequency-flat channels more resistant to noise and interference.
- Low complexity equalization: The received signal can be equalized with a straightforward scalar multiplication because the channel response is constant across the whole bandwidth of the signal. Due to this, equivalence is simpler and requires less calculation.

2.8 Related work

Due to the limited available global bandwidth, research into wireless access methods like massive MIMO has gained more traction. In particular, enormous MU-MIMO (Multi-User MIMO) technology is paving the way for more investigation into massive MIMO systems and beyond networks by becoming accepted in both academic and commercial circles. For huge MIMO systems, the effectiveness of precoding schemes has been the subject of numerous studies. The list below includes a few of these investigations in brief:

In(Mezghani & Heath, 2022), two design criteria were analyzed, the active constellation extension (ACE) and the symbol error rate (SER). The generalized approximate message passing (GAMP) technique is used in a modified manner to resolve both formulations. Furthermore, based on the analysis of the GAMP algorithm's state evolution, theoretical performance estimates are determined. According to simulation and analytical data, the MSE-based technique performs similarly to the SER-based formulation in terms of uncoded SER. Good performance forecasts are given by the analytical results up to medium SNR. The suggested combined pulse shaping and pre-coding methodology, compared to conventional linear approaches, produce notable gains in spectrum efficiency and detection.

In (Khorsandmanesh et al., 2022) the pre-coding matrix was examined using a sphere decoding (SD) method, and a low-complexity heuristic approach to quantized pre-coding was proposed. This method is sufficiently computationally efficient for big MIMO systems. The numerical results show that our proposed pre-coding significantly outperforms quantization-unaware pre-coding and other preceding techniques in terms of the sum rate. Given the reduction in complexity, the suggested heuristic method's performance loss in comparison to quantization-aware pre-coding is minimal when applying a heuristics approach appropriate for real-time applications. Information on both ideal and realistic channel states is taken into account.

In(Shewanega, 2021) the downlink dispersion was the primary focus of this study. The performance of the upcoming 5G wireless system will be enhanced by pre-coding methods for massive MIMO systems, which operate under the assumption that both the base station and the user terminals are outfitted with an antenna array. The algorithms for obtaining capacity are nonlinear, however linear pre-coding techniques typically produce acceptable performance with a great deal less complexity. This work examined a comparison of various linear pre-coding methods for huge MIMO wireless systems. The effectiveness of the pre-coding scheme is assessed and contrasted with an iterative pre-coding scheme created to provide the highest rate gain possible by utilizing the increased degrees of freedom in space.

In (Pramono & Triyono, 2018), compare the effectiveness of various linear precoding techniques in downlink multiuser MIMO systems, research was done. In terms of achievable sum rate and bit error rate (BER), the study assessed the efficiency of linear precoders such as BD, ZF, and MRT. The performance was assessed with different transmitter-receiver antenna counts and signal-to-noise ratios (SNR).

(Jacobsson et al., 2017a) for huge MU-MIMO downlink systems using 1-bit digital-to-analog converters (DACs), a research study examined the performance of higher-order modulation techniques, such as 8-PSK or 16-QAM. Low-complexity nonlinear precoding techniques and channel estimation algorithms were developed at the user equipment to achieve low error rates. According to the study, nonlinear precoding techniques perform better than linear quantization techniques for reliably transmitting higher-order constellations. The effectiveness of MU-MIMO systems can be increased by using nonlinear precoding techniques to lessen the effects of quantization errors, which are more noticeable in systems that employ 1-bit DACs. The study also discovered that in MU-MIMO systems with higher-order modulation schemes, channel estimate accuracy is crucial to achieving low error rates. In (Choi et al., 2022) formulates a pre-coding optimization issue with antenna selection; nevertheless, because of the detailed EE characterization, obtaining the best joint pre-coding and antenna selection solution is difficult. To overcome this problem, the researcher divides it into two parts: pre-coding direction and power optimization. It also characterizes the first-order optimality condition for the pre-coding direction, which includes the effects of quantization distortion and antenna selection. To maximize EE for a given pre-coding direction, the results showed a gradient descent approach to find the best solution for pre-coding power.

In (Jacobsson et al., 2017b) Examine the issue of narrowband downlink pre-coding. Digital-to-analog converters at the base station with limited resolution and a massive MIMO system. Several non-linear precoders are described based on the ideal MMSE downlink pre-coding problem after exploring linear precoder performance such as zero-forcing and maximal-ratio transmission. An approximate closed-form expression of the rate feasible was obtained using Bussgang's theorem. In recent months, numerous research articles have centered on large MIMO systems. (Shi et al., 2021) gives a complete analysis of the linear pre-coding techniques for massive MIMO in different cell arrangements. A few practical applications and pre-coding algorithm design difficulties were also explored. However, it did not resolve the problems caused by the non-linear pre-coding. In a survey published by ((Shahjehan et al., 2022)), detailed explanations of the theoretical foundations of massive MIMO detection were presented, along with an overview of its twelve-year history. The authors conducted a detailed investigation into the creation of optimal, almost optimal, linear, approximated large MIMO detection algorithms. A few non-linear small-scale MIMO detectors and their use in large-scale MIMO systems are also mentioned. Due to its benefits over conventional point-to-point communications, as mentioned above, the large MIMO concept has received a lot of interest in recent research. (Rahman & Siddiqui, 2016) The BER performance of a massive MIMO system with a rising number of BS antennas, users, and SINR was evaluated. They compared ZF and MMSE pre-coding under Perfect and Imperfect CSIT in terms of BER and spectrum efficiency. The effectiveness of a large MIMO system employing different pre-coding techniques (MMSE, ZF, and MRT) is studied under Rayleigh fading channel circumstances. Three distinct types of data from the CSIT.

CHAPTER THREE

3. MATERIALS AND METHOD

In this thesis, pre-coding techniques for massive MIMO systems on the downlink were examined. Secondary sources of information used included academic publications, books on 5G technology, IEEE articles, and past research studies. Using their techniques, researchers have created effective broadcast pre-coding algorithms for huge MIMO downlink systems. The following techniques are created to attain the desired objectives based on the above literatures and the problem statement:

1) The system model and various mathematical formulations

- Mathematical model that analysis linear (ZF, MRT,) and non-linear (DPC, SQUID) pre-coding techniques for massive MU-MIMO system
- Combining (hybridized) both linear and nonlinear pre-coding technique based on iterative algorithm.
- A mathematical model for Bit Error Rate and signal-to-noise ratio of each pre-coding type for a massive MU-MIMO system.
- Prepare a mathematical model to calculate the Energy Efficiency and capacity of each pre-coding technique.

2) Understand pre-coding matrixes with their capacity.

3) Determine simulation input parameters.

4) Conduct the simulation with MATLAB R2021.

- Simulation for energy efficiency analysis of both linear and non-linear pre-coding.
- Simulation for Bit Error Rate analysis using various forms of modulation techniques for linear and non-linear pre-coding and analysis with constellation diagram through modulation.

5) Result Analysis & Interpretations

- Analyzing study or research outcomes to reach a conclusion

3.1 Materials

This thesis study utilized software tools such as MATLAB/R2021 and Concept Draw DIAGRAM. MATLAB is a programming tool that provides engineers and scientists with the ability to analyze and construct systems and technologies that have the potential to transform the world. With

MATLAB, users have access to a comprehensive suite of features and functions that enable them to design, simulate, and analyze complex systems and data

3.2 System Model

Since it is feasible to effectively create the MU-massive MIMO scenario by dividing the K-antenna terminal into numerous autonomous terminals, a research article focuses on the point-to-point MIMO system model. In other words, the K-antenna terminal is divided into numerous separate terminals such that the MU-massive MIMO configuration can be derived from the Point-to-Point MIMO arrangement.

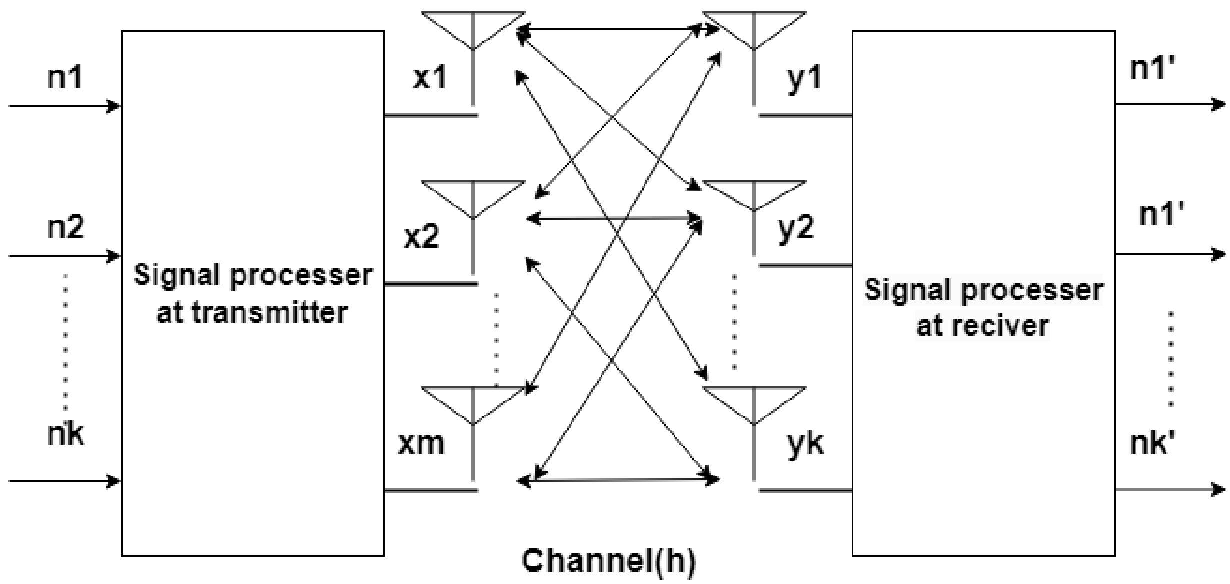

Figure 3.1: point to point MIMO system model (Abdu, 2017)

MIMO broadcast system in which the transmitting station has M antennas and sends data to N users, each of whom has a single reception antenna. Using the fundamental ideas of linear algebra and matrix multiplication, the discrete-time, narrowband, and time-varying channel models may be used to explain the MIMO broadcast system at a certain moment as follows:

$$\boldsymbol{y_k} = \sum_{j=1}^{m} \boldsymbol{h_{ij}} \boldsymbol{x} + \boldsymbol{\alpha_j}, \text{ i=1… m} \tag{3.1}$$

Where $\boldsymbol{h_{ij}}$ between the jth receiving antenna and the ith transmit antenna, is the channel response, $\mathbf{y_i}$ is the received signal at the jth antenna, $\boldsymbol{x_i}$ Is the symbol transmitted from the ith antenna, $\boldsymbol{\alpha_j}$ is the noise signal at the jth received antenna.

In matrix form equation (2.1) becomes,

$$\boldsymbol{Y} = \boldsymbol{Hx} + \boldsymbol{\alpha} \tag{3.2}$$

In matrix form

$$\begin{bmatrix} Y_1 \\ Y_2 \\ Y_k^{\vdots} \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12\ldots} & h_{1m} \\ h_{21} & h_{22\ddots} & h_{2m} \\ h_{k1} & h_k^{\vdots} & h_{km}^{\vdots} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_m^{\vdots} \end{bmatrix} + \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_j^{\vdots} \end{bmatrix} \tag{3.3}$$

Where $x \in \mathbb{C}^{M\times 1}$ is the channel input from the transmitter, $H \in \mathbb{C}^{K\times M}$, is the discrete-time channel matrix, $Y \in \mathbb{C}^{K\times 1}$ is the received signal, and $\alpha \in \mathbb{C}^{K\times 1}$ is an additive noise vector. The channel gain from the transmit antenna to the user is represented by the element of (i, j).

3.3 Linear Pre-coding

Linear pre-coding methods are simple to implement and have a reasonable capacity. To enhance the quality of transmitted signals, communication systems use the signal processing method known as linear pre-coding. Before the data is delivered through the communication channel, it must first undergo a linear transformation (pre-coding matrix). To increase the overall quality of the received signal, linear pre-coding aims to maximize the signal-to-noise ratio (SNR) at the receiver. Nonlinear pre-coding, on the other hand, can access more capacity with greater receiver complexity. Maximum ratio transmission (MRT), and zero-forcing (RZF) pre-coding, are examples of linear pre-coding techniques that are discussed in this paper.

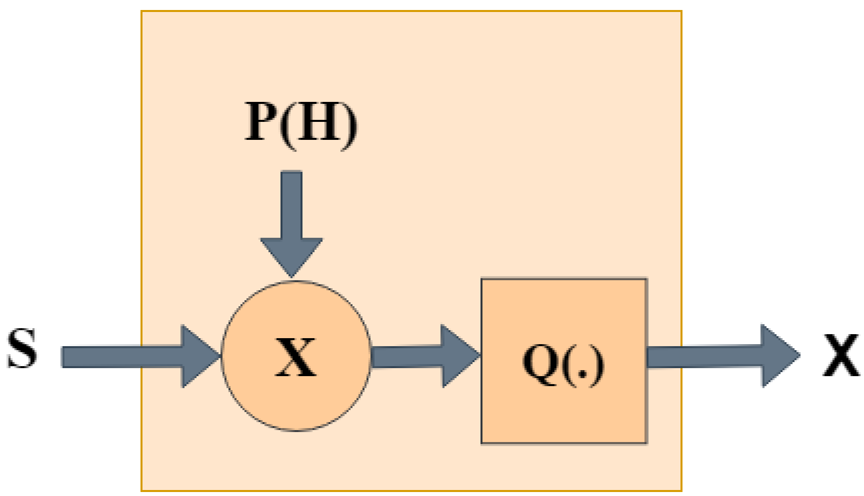

Figure 3.2: Linear-quantized precoders

H is used by the precoder to create the pre-coding matrix P. transmitting vector is the x = Q (Ps), which is Ps in quantized form. The quantizers are indicated here by Q (.)

3.3.1 Maximum Ratio Transmission (MRT) Pre-coding

MRT pre-coding is one of the oldest pre-coding techniques used to maximize the received SNR at the user's mobile terminal, and it is consistent for MIMO systems where the BS emits low signal power to the users. The MRT precoder maximizes the power directed to each UE while ignoring multi-user interference MUI(Varasteh et al., 2018).

Signal-to-noise ratio (SNR) defines as;

$$p = \beta^{MRT} B/\alpha^2 \tag{3.4}$$

Where α^2 is the noise power and the optimal MRT scaling factor defined as

$$\beta^{MRT} = \frac{B}{\mathrm{tr}(\mathrm{HH}^{\mathrm{H}}} \tag{3.5}$$

Where $\mathrm{H}^{\mathrm{H}}$is the conjugate transpose of the channel matrix H.

Pre-coding matrix of MRT is expressed as;

$$\mathrm{P}^{\mathrm{MRT}} = \mathrm{H}^{\mathrm{H}} / \mathrm{tr}(\mathrm{HH}^{\mathrm{H}}) \tag{3.6}$$

Substitute equation (3.2) into equation (3.1)

$$p = \frac{B}{\alpha^2 * \mathrm{tr}(\mathrm{HH}^{\mathrm{H}}} \tag{3.7}$$

Rearrange the expression for p to obtain;

$$\alpha^2 = \frac{B}{p * \mathrm{tr}(\mathrm{HH}^{\mathrm{H}}} \tag{3.8}$$

Substitute equation (3.7) into equation (3.5)

$$\mathrm{P}^{\mathrm{MRT}} = 1/\left(p * \mathrm{tr}(\mathrm{HH}^{\mathrm{H}})\right) * \left(\frac{B}{\alpha^2}\right) * \mathrm{H}^{\mathrm{H}}) \tag{3.9}$$

$$\mathrm{P}^{\mathrm{MRT}} = \frac{1}{\beta^{\mathrm{MRT}}\mathrm{B}} \mathrm{H}^{\mathrm{H}} \tag{3.10}$$

$$\beta^{\mathrm{MRT}} = \frac{1}{\mathrm{B}} \sqrt{\frac{1}{\mathrm{P}} \mathrm{tr}(\mathrm{HH}^{\mathrm{H}})} \tag{3.11}$$

$$X^{MRT} = Q(P^{MRT} S) \tag{3.12}$$

where $\mathrm{P}^{\mathrm{MRT}}$ is the MRT pre-coding matrix, $\beta^{\mathrm{MRT}}$is the MRT scaling factor, B is the total power budget, s is the symbol vector, and H^{H} is the conjugate transpose of the channel matrix H. The MRT algorithm produces a massive MIMO system's sum capacity when the number of antennae (M) is substantially greater than the number of users (K) and M increases indefinitely (M>>K and M >∞). When the interference between users (IUI) is negligible relative to the noise (noise-limited systems), the MRT method performs close to optimally. When the values of M and N are similar in the MRT algorithm, the system experiences a strong IUI. As a result, each user's throughput decreases, degrading the huge MIMO idea(Fatema et al., 2017). Each antenna in the BS may process signals locally, which is another incredible feature of the MRT algorithm(Lee, 2018).

3.3.2 Wiener Filter (WF) Pre-coding

In order to reduce the MSE between the sent signal and the signal received at the receiver, WF is a linear precoding technique. The system's performance in terms BER and SNR can be improved by using the WF precoding matrix, which is computed based on the channel matrix and noise variance.

$$\mathrm{P}^{WF} = \frac{1}{\beta^{WF}} H^{H}(HH^{H} + UN_0 I_U)^{-1} \tag{3.13}$$

$$\beta^{WF} = \sqrt{\sqrt{\frac{1}{P}}\operatorname{tr}((HH^{H} + UN_0 I_U)^{-1})HH^{H}(HH^{H} + UN_0 I_U)^{-1}} \tag{3.14}$$

$$X^{WF} = Q(P^{WF}S) \tag{3.15}$$

where P^{WF} is the WF pre-coding matrix, $\beta^{WF}$is the WF scaling factor **H** channel matrix, and s is a symbol vector. And H^{H} is the conjugate transpose of the channel matrix H.

3.3.3 Zero-Forcing (ZF) Pre-coding

One common technique for MIMO pre-coding is ZF pre-coding. It is commonly used even by those who are unfamiliar with noise statistics due to its low complexity. It is possible to remove inter-user interference for ZF MU by projecting each stream onto its orthogonal complement. The pseudo-inverse of the channel matrix is used by the BS as the pre-coding matrix to remove multiuser interference with ZF pre-coding.(Jacobsson et al., 2017b). By setting the noise variance N_0 to zero, the ZF pre-coding matrix is produced (Joham et al., 2005).

$$\mathrm{P}^{ZF} = \frac{1}{\beta^{ZF}} H^{\dagger} \tag{3.16}$$

$$\text{Where } H^{\dagger} = H^{H}(HH^{H})^{-1} \tag{3.17}$$

$$\beta^{ZF} = \sqrt{\sqrt{\frac{1}{P}}\operatorname{tr}((HH^{H})^{-1})} \tag{3.18}$$

$$X^{ZF} = Q(P^{ZF}S) \tag{3.19}$$

Where P^{ZF} is the ZF pre-coding matrix, $\beta^{ZF}$is the ZF scaling factor, $H^{\dagger}$is the pseudo-inverse of the channel matrix **H**, s is a symbol vector. And H^{H} is the conjugate transpose of the channel matrix H.

3.3.4 Regularized Zero-Forcing (RZF) Pre-coding

RZF is a linear precoding method is used in wireless communication systems that combine the advantages of zero-forcing (ZF) precoding with a regularization term to enhance system performance. The equation for RZF precoding involves a precoding matrix that maximizes the received signal-to-interference-plus-noise ratio (SINR) while satisfying power constraints, which is then multiplied by the transmitted data to generate the vector of transmitted signals. The precoding vector is obtained by multiplying the precoding matrix with the transmitted signal vector and is used to modulate the signal before transmission. The regularization parameter controls the trade-off between the performance of the system and the complexity of the precoding matrix and can be optimized based on the specific requirements of the communication system(Beamforming et al., 2019).

$$\mathrm{P}^{RZF} = \frac{1}{\beta^{RZF}} H^{\dagger} \quad (3.20)$$

$$\text{Where } H^{\dagger} = H^{H}(HH^{H} + \lambda I)^{-1} \quad (3.21)$$

$$X^{RZF} = Q(P^{RZF} S) \quad (3.22)$$

Where P^{RZF} is the RZF pre-coding matrix, β^{RZF} is the RZF scaling factor, H is the channel matrix system, $H^{\dagger}$ is the pseudo-inverse of the channel matrix and H^{H} is the conjugate transpose of the channel matrix H. λ And I regularization parameter and identity matrix respectively.

3.4 Nonlinear Pre-coding

In the cases in which the linear pre-coding techniques are insufficient to achieve the specified performance requirements, nonlinear pre-coding techniques are often applied. Nonlinear pre-coding techniques, for instance, can be employed to boost the system's performance in conditions with significant interference or non-Gaussian noise. Techniques for nonlinear pre-coding can be computationally challenging and may need a lot of processing power. They can, however, significantly outperform linear pre-coding approaches in some circumstances, such as those with high interference.

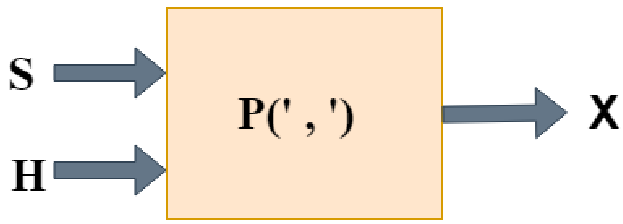

Figure 3.3 Non-Linear-quantized precede

The precoder uses **H** to directly compute the quantized transmit vector$X \in X^B$ as a nonlinear function of **s** and **H**, i.e., **x** = *P*(**s***;* **H**).

3.4.1 Squared infinity-norm relaxation with Douglas-Rachford splitting (SQUID)

SQUID pre-coding is a relatively recent method of creating pre-coding matrices for wireless communication systems, and various research has assessed its performance. SQUID pre-coding has generally been found to offer appreciable performance gains over linear pre-coding techniques and other nonlinear pre-coding approaches in several contexts.

One of the benefits of SQUID pre-coding is the ability to handle non-convex and non-smooth objective functions, which are prevalent in many wireless communication systems. Due to this, it can preserve complex signal and interference structures that linear pre-coding methods are unable to capture(Jacobsson et al., 2017b). Additionally, SQUID pre-coding can be distributed and parallelized, both of which can increase its scalability and effectiveness.

Precoded vector;

$$\mathbf{x} = P\,(\mathbf{s};\,\mathrm{H}). \tag{3.23}$$

$$X^{SQUID} = \frac{1}{\sqrt{(2*B)*x((1{:}B,1)+1i*x(B+1{:}2*B,1))}} \tag{3.24}$$

$$\beta^{SQUID} = real(Hx' * s)/(norm(Hx,2)^{2+U*N_0} \tag{3.25}$$

Where [U, B] = size channel matrix H,N_0 noise power spectral density (scalar), $\beta^{\mathrm{SQUID}}$is the SQUID scaling factor $X^{SQUID}$is SQUID Precoded vector.

3.4.2 Dirty paper coding (DPC)

In order to eliminate known interference without reducing power, dirty paper coding is used. Only the transmitter is aware of this interference, but in order to reach the weighted sum capacity, all channels must be fully informed of their states. Additionally, the DPC algorithm can deliver outstanding performance without requiring additional power on the transmission side or CSI sharing with the reception side.(Kassa, 2011).

The precoded vector X is expressed by

$$X^{DPC} = P^{DPC} * S \tag{3.26}$$

$$P^{DPC} = inv(H' * H) * H' \tag{3.27}$$

P^{DPC}; S the pre-coding matrix of DPC. DPC aims to select the pre-coding matrix P in a way that reduces the interference brought on by the channel. The influence of the channel matrix H on the received signal y is specifically what we want to cancel out, and it may be written as follows:

$$Y = Hx + \alpha \tag{3.28}$$

3.5 Proposed Method

In multi-antenna wireless communication systems, a technique known as combined quantized linear and nonlinear pre-coding is employed to simplify the pre-coding algorithm while retaining the advantages of both linear and nonlinear pre-coding. By combining the squared infinity-norm relaxation with Douglas-Rachford splitting (SQUID) precoding and Regularized Zero-Forcing (RZF) Pre-coding techniques, we can benefit from the advantages of both techniques and improve the overall performance of a wireless communication system. SQUID precoding is designed to minimize the transmit power while satisfying a certain data rate requirement. It achieves this by optimizing the precoding matrix to maximize the signal-to-interference-plus-noise ratio (SINR) subject to a transmit power constraint. This results in a precoding matrix that minimizes the transmit power while maintaining a certain level of performance. On the other hand, RZF precoding is designed to reduce multi-user interference and improve the bit error rate (BER) performance. It achieves this by using a matrix that equalizes the channel response across all users and reduces the interference between them.

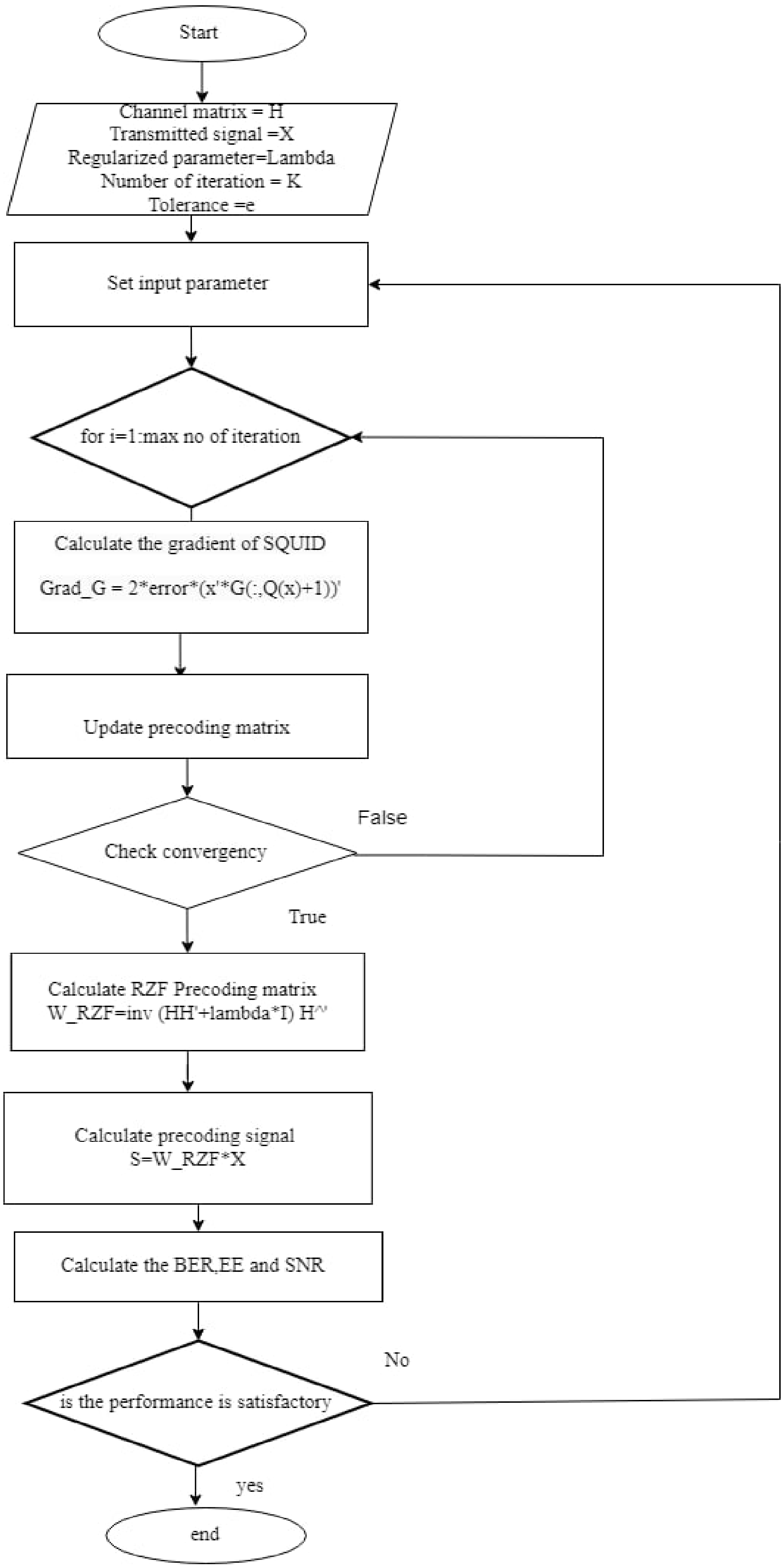

Figure 3.4: Flow chart of proposed work

In a system with combined pre-coding, the transmitted signal is initially linearly precoded using matrix multiplication. After that, the generated signal is quantized with a finite amount of bits, and the quantized signal is precoded using nonlinear methods such as constellation shaping or phase rotation. A combination of the precoded signals is then sent utilizing numerous antennas.

Where H represents the channel matrix, Γ the gradient descent step size, and grad_F and grad_G represent the gradients of the objective function concerning F and G, respectively.

The proposed pre-coding method is based on iterative algorithms,

Initialize

Linear pre-coding matrix (F)

Nonlinear pre-coding matrix (G)

Repeat until convergence:

Perform nonlinear pre-coding:

y = G (: Q(x) +1) *x

Perform linear pre-coding:

x= F*s

Quantize signal:

Q(x) = q (x)

Calculate error:

Error = y - H*G (: Q(x) +1) *x

Update F using gradient descent:

F = F - Γ*grad_F

Update G using gradient descent:

G (: Q(x) +1) = G (:,() +1) - Γ*grad_G

Return $\hat{x}$

The gradients can be calculated as follows:

Grad F = 2*H'*error*x'

Grad G = 2*error*(x'*G (: Q(x) +1))'

3.6 Performance Metrics of Pre-Coding Algorithm

Depending on the particular application and system constraints, a variety of indicators can be used to assess the performance of linear and nonlinear pre-coding techniques. The following are some typical performance indicators for both linear and nonlinear pre-coding algorithms: Metrics like SNR, MSE, BER, and EE can be used to evaluate how effectively pre-coding methods perform in massive MIMO downlink systems.

3.6.1 Bit Error Rate (BER)

Bit Error Rate (BER) is a metric used to determine a digital communication system's performance. It is described as the proportion of bits in error to all bits transmitted within a specific time frame.

$$\text{BER}=\frac{\text{No.of bits in error}}{\text{Total No. of transmitted bits}} \tag{3.29}$$

A crucial factor in evaluating the effectiveness of signal pre-coding methods is BER.

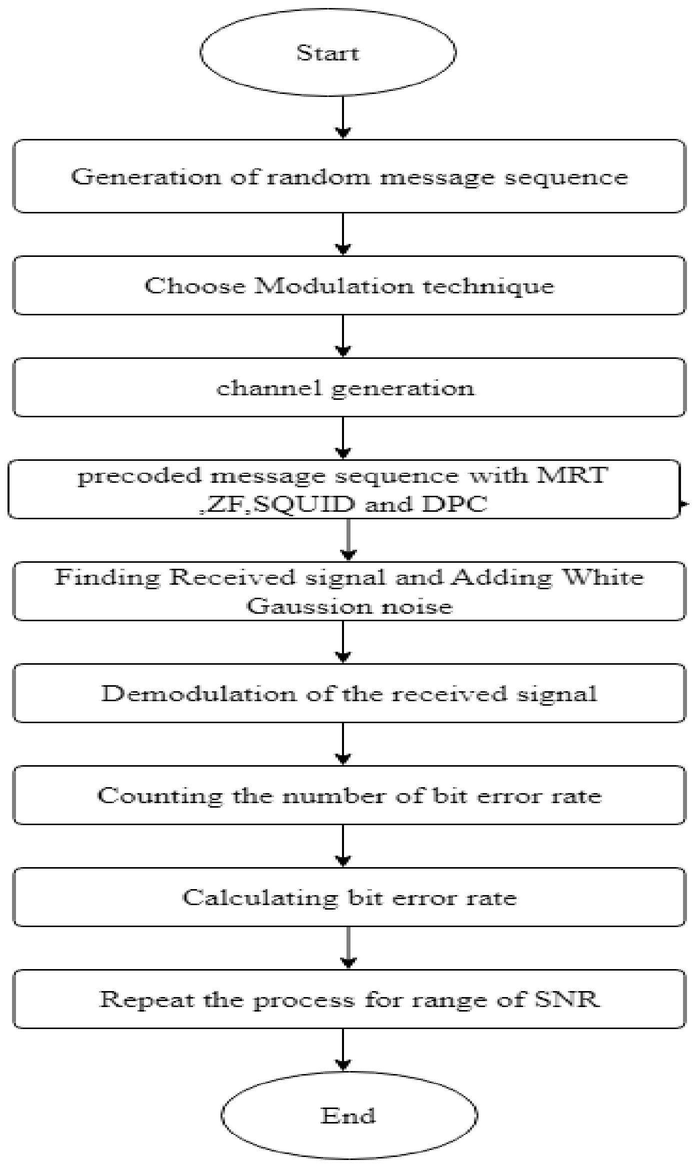

Figure 3.5: Flow chart to find the BER performance of system

3.6.2 Signal-to-Noise Ratio (SNR)

The ratio of signal power to noise power is known as the signal-to-noise ratio (SNR) in digital communication systems. The strength of the desired signal to background noise (the unwanted signal) is measured by the SNR.

$$SNR = \frac{p_S}{p_W} \tag{3.30}$$

As an alternative, the signal-to-noise ratio () utilized in this thesis work can be determined in terms of symbol energy and power spectral density of noise () as follows:

$$\text{SNR}=\frac{E_S}{No} \tag{3.31}$$

In addition, the energy of the symbol is given by:

$$E_S = \frac{1}{Ns}(sum(abs(x)^2)) \tag{3.32}$$

Where N_S indicates the total number of symbols and x the transmitted signal.

3.6.3 Energy Efficiency (EE)

This particular system under consideration will determine the mathematical formula that combines energy efficiency and the total number of antennas in a communication system. A communication system's energy efficiency is typically stated as the ratio of its capacity to power consumption. Which is written as follows:

$$EE = \frac{Capacity}{Power\ consumption} \tag{3.33}$$

A communication system's capacity is often constrained by its available bandwidth (B) and the signal-to-noise ratio (SNR) of the received signal, which is denoted as follows:

$$C = B * \log[1 + SINR] \tag{3.34}$$

A communication system's power usage is often a function of the transmit power (Pt) and the number of antennas (N), as shown in the following formula:

$$P_{cons} = P_{transmit} * N \tag{3.35}$$

As a result, the energy efficiency of a communication system can be stated as:

$$EE = \frac{B * \log[1 + SINR]}{P_{transmit} * N} \tag{2.36}$$

This equation demonstrates that the number of antennas employed in a communication system has an inverse relationship with the system's energy efficiency. This is due to the fact that adding antennas often necessitates boosting transmit power, which raises the system's overall power consumption. As a result, while having many antennas can increase a communication system's data rate and dependability, it can also decrease the system's energy efficiency.

CHAPTER FOUR

4. RESULTS AND DISCUSSION

In this section, the results of a research study are presented, which aimed to evaluate the performance of downlink precoding in a narrowband massive multi-user multiple-input multiple-output (MU-MIMO) system using various performance metrics, including bit error rate (BER), energy efficiency (EE), and signal-to-noise ratio (SNR). The study sought to achieve a specific objective, which was to investigate the effectiveness of downlink precoding in improving the performance of a narrowband massive MU-MIMO system.

Table 4.1: Simulation parameters

No.	Simulation parameter	Type and Value	Remark
1	Number of DAC levels (Jacobsson et al., 2017b)	2 <= L <= 32	Variable
2	Number of UEs	U= 2, 8, 16, 32, 64….	Variable
3	Number of BS antennas	B = 8, 32, 64,128,256….	Variable
4	Modulation schemes	BPSK, QPSK, 8PSK, 16QAM, 64QAM	Variable
5	SNR Range	-10dB:3dB:15dB	Variable
6	Channel	Frequency-selective channel	
7	Transmitted power (Wang, n.d.)	0.1W	fixed
8	Bandwidth (Wang, n.d.)	$20M$HZ	fixed

4.1 Performance comparison of the proposed pre-coding and other pre-coding techniques

Bit error ratio (BER) and Signal-to-Noise Ratio (SNR) are two crucial metrics that are frequently taken into account while assessing the performance of a newly suggested precoder for a communication system. These metrics are used to compare the Effectiveness of the proposed precoder to another precoder that already exists and has a similar architecture. Better transmission quality is indicated by a lower BER, whereas a higher SNR denotes a stronger signal compared to noise. These indicators can be analyzed and compared to establish the usefulness of the new precoder as well as how well the two precoders performed.

4.1.1 Performance comparisons of the proposed precoder with other precoders based on Bit Error Rate

We begin by contrasting the bit error rate (BER) without coding of the developed precoder's performances. To simulate the performance, we'll suppose that the UEs employ nearest-neighbor symbol decoding. And that the baseband signal modulation schemes are BPSK, QPSK, 8PSK, 16QAM, and 64QAM, respectively. The antenna size is 8x32 (BUAR = 4), 64x128 (BUAR=2), and 128x256 87(BUAR=2), 256×1024 (BUAR=4) where the first number is the number of MS users' antennas and the second number denotes the number of base station antennas.

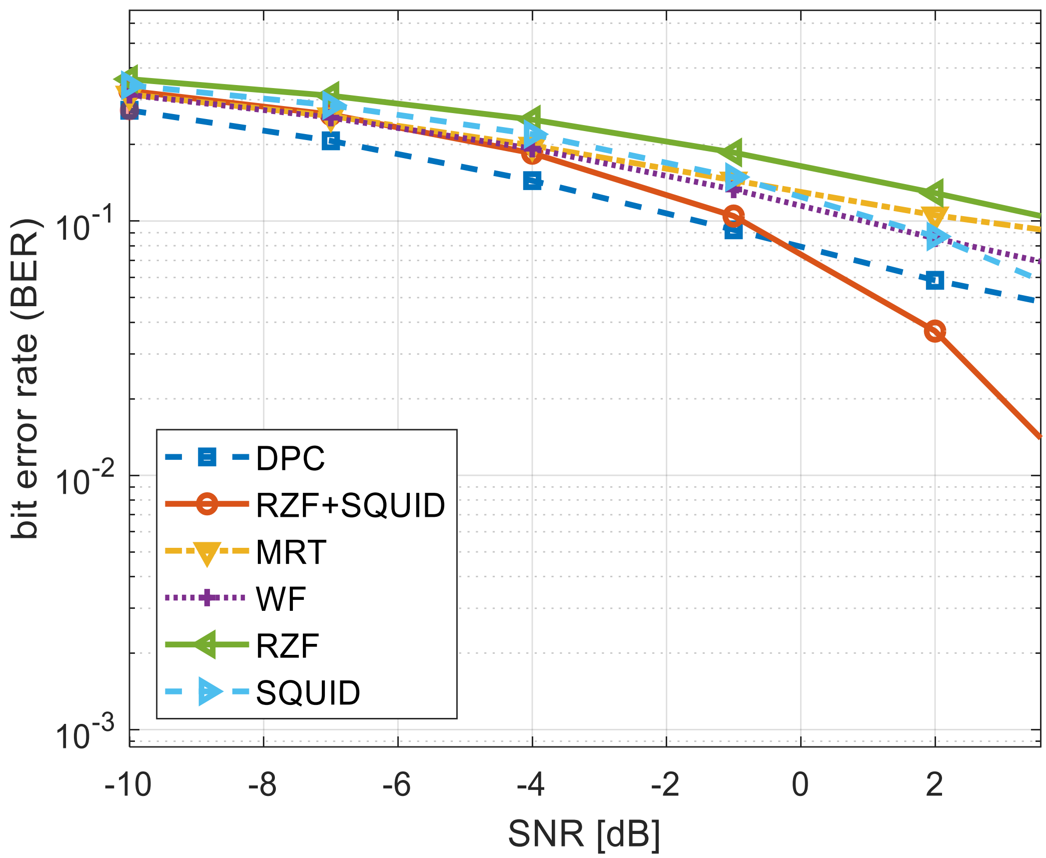

Figure 4.1: BER performance of proposed pre-coding technique and other types of pre-coding at 8×32 M-MIMO system, BPSK

Figure 4.1 evaluates the BER of the suggested algorithm in comparison to alternative methods that are currently in use for an 8x32 (BUAR = 4) antenna arrangement utilizing BPSK modulation and the proposed algorithm outperformed SQUID, ZF, MRT, WF and DPC. The proposed algorithm achieved a BER = 1.1163×10^{-3} at signal-to-noise ratio (SNR) = 5dB, whereas the SQUID algorithm achieved a BER = 3.674×10^{-2} at the same SNR = 5dB, and the DPC algorithm achieved a BER = 3.674×10^{-2} and the WF precoding achieved a BER= 4.276×10^{-2} at the same SNR. The Pre-coding based on MRT, and RZF methods perform BER = 8.162×10^{-2} and BER = 4.663×10^{-2} respectively. The precoder based on RZF performs moderately well. The precoder based on the proposed method has good performance.

Table 4.2: Tabular data of BER versus SNR proposed pre-coding technique and other types of pre-coding at 64×128M-MIMO system, BPSK

SNR (dB)	BER					
	RZF+SQUID	SQUID	DPC	RZF	WF	MRT
-10	2.92×10^{-1}	3.333×10^{-1}	2.733×10^{-1}	3.333×10^{-1}	3.144×10^{-1}	2.504×10^{-1}
-7	2.195×10^{-1}	2.745×10^{-1}	2.195×10^{-1}	2.745×10^{-1}	2.543×10^{-1}	2.574×10^{-1}
-4	1.371×10^{-1}	2.053×10^{-1}	1.431×10^{-1}	2.053×10^{-1}	1.878×10^{-1}	2.053×10^{-1}
-1	6.138×10^{-2}	1.36×10^{-1}	9.219×10^{-2}	1.36×10^{-1}	1.248×10^{-2}	1.443×10^{-2}
2	1.456×10^{-2}	7.718×10^{-1}	5.858×10^{-2}	8.272×10^{-2}	7.718×10^{-2}	1.055×10^{-2}
5	1.1163×10^{-3}	3.674×10^{-2}	3.687×10^{-2}	4.663×10^{-2}	4.276×10^{-2}	4.698×10^{-2}

Table 4.2 examines how the recommended pre-coding method performs in relation to various current methods for the following parameters: 64 users, 128 base station antennas, over BPSK at SNR = -10dB to 5dB. The effectiveness of the suggested precoder outperforms all existing methods, as we can see from the table. By taking into account a certain value of SNR, the table below depicts the tabular version of Figure 4.1.

According to the results shown in Table 4.2, the suggested pre-coding technique performs better than all other pre-coding techniques overall. In comparison to the previous pre-coding approaches, the suggested pre-coding strategy achieves lower Bit Error Rate (BER) at all SNR levels. As a result, it can be concluded that the suggested pre-coding methodology can offer transmission quality and signal strength that are noticeably superior to those of the other techniques now in use.

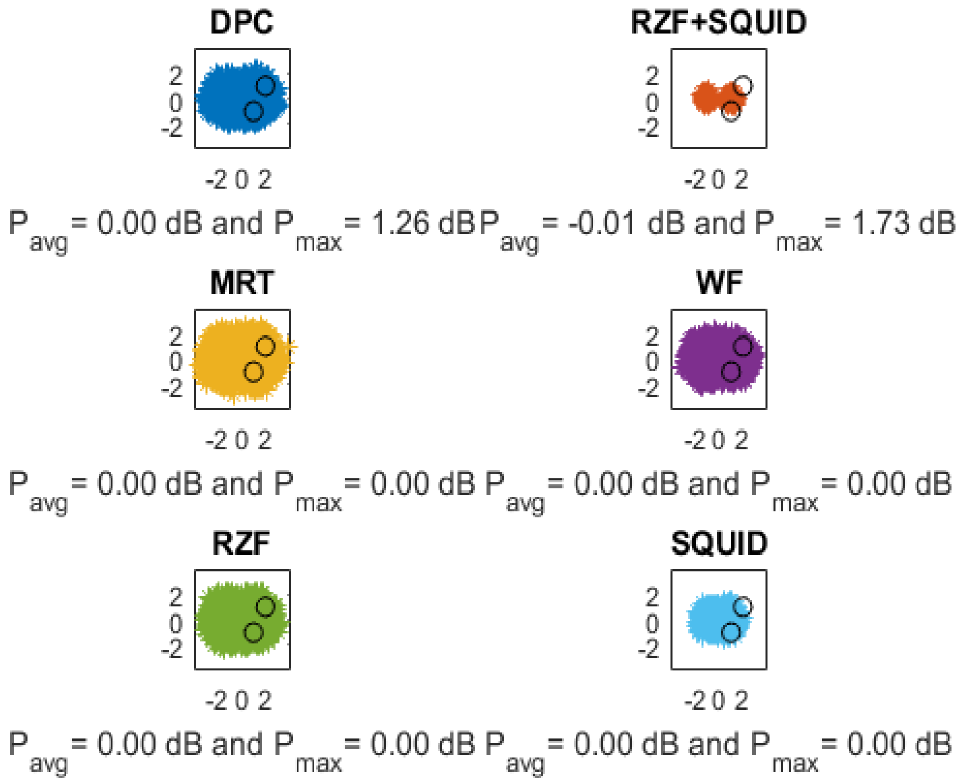

Figure 4.2: Cancellation diagram of proposed 1pre-coding technique and other types of pre-coding at 2×8 m-MIMO system, BPSK

In Figure 4.2 cancellation diagram of the proposed pre-coding technique and other types of pre-coding techniques for the quantity of users = 2, the quantity of base station antennas = 8, over BPSK modulation at SNR = -10db to 2 db. The suggested pre-coding method is much close to the ideal constellation diagram. As compared to that of the currently used pre-coding technique. Average power and maximum power shows that the robustness of the system over noise and interference Average power of 1.73db and maximum power of -0.07 dB, which shows better resistance against noise and interference.

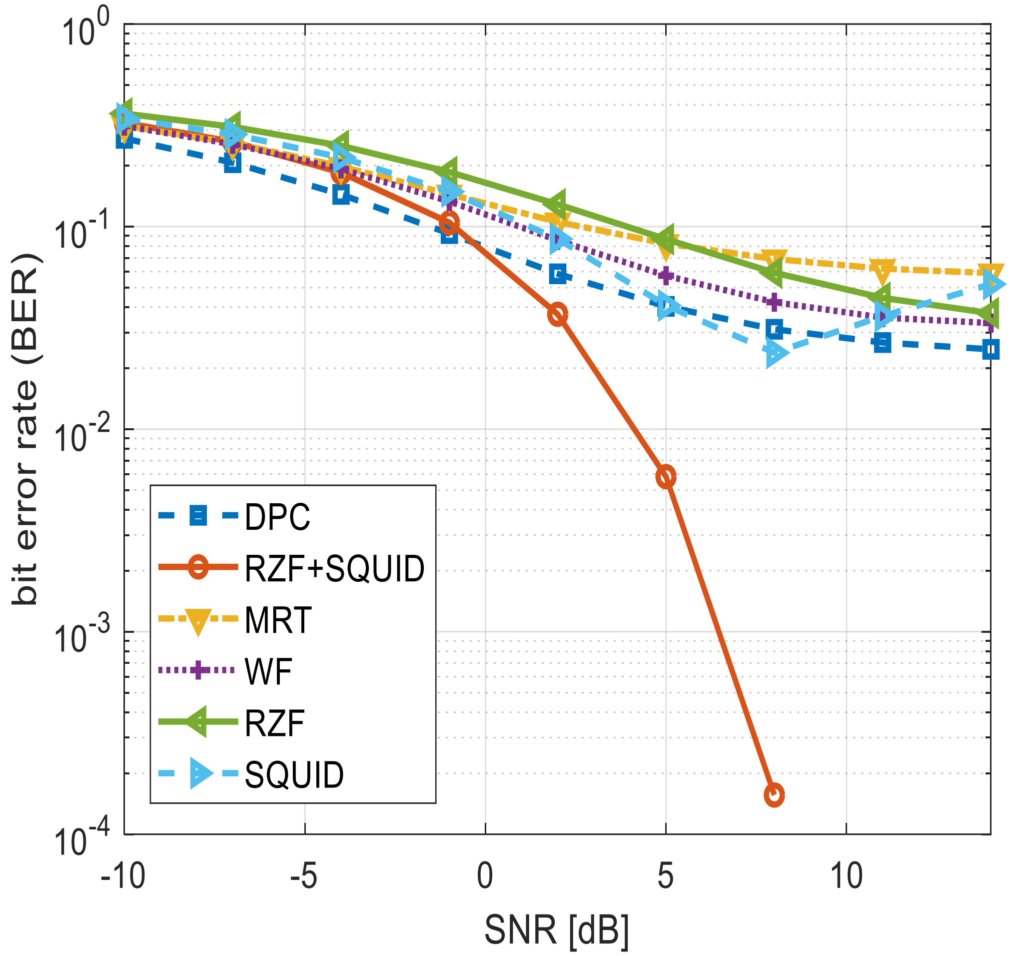

Figure 4.3: BER performance of proposed pre-coding technique and other types of pre-coding at 64×128 M-MIMO system, BPSK

Figure 4.3 compares the BER of the proposed algorithm to that of other approaches that are currently in use for a 64x128 (BUAR = 2) antenna arrangement utilizing QPSK modulation and the proposed algorithm outperformed SQUID, ZF, MRT, WF and DPC. The proposed algorithm achieved a BER = 4.062×10^{-4} at signal-to-noise ratio (SNR) = 2dB, whereas the SQUID algorithm achieved a BER = 7.406×10^{-3} at the same SNR = 2dB, and the DPC algorithm achieved a BER = 1.281×10^{-2} and the WF precoding achieved a BER=1.644×10^{-2} at the same SNR. The Pre-coding based on RZF, and MRT methods perform BER = 2.7×10^{-2} and BER = 0.5×10^{-2} respectively. The precoder based on SQUID performs moderately well. The precoder based on the proposed method has good performance.

Table 4.3: Tabular data of BER versus SNR proposed pre-coding technique and other types of pre-

coding at 64×128 M-MIMO system, BPSK

SNR (dB)	BER					
	RZF+SQUID	SQUID	DPC	RZF	WF	MRT
-10	1. 1.9×10^{-1}	2.502×10^{-1}	1.993×10^{-1}	2.503×10^{-1}	2.502×10^{-1}	2.504×10^{-1}
-7	1.15×10^{-1}	1.15×10^{-1}	1.15×10^{-1}	1.79×10^{-1}	1.733×10^{-1}	1.75×10^{-1}
-4	4.68×10^{-2}	6.375×10^{-2}	6.375×10^{-2}	1.035×10^{-1}	9.8×10^{-2}	1.116×10^{-1}
-1	9.406×10^{-2}	7.406×10^{-2}	2.941×10^{-2}	4.891×10^{-2}	4.566×10^{-2}	6.497×10^{-2}
2	4.062×10^{-4}	7.406×10^{-3}	1.281×10^{-2}	1.738×10^{-2}	1.644×10^{-2}	1.728×10^{-2}

Table 4.3 compares the effectiveness of the suggested pre-coding technique with various existing methods for the following parameters: 64 users, 128 base station antennas, over BPSK at SNR = -10dB to 2dBThe proposed precoder performs better than all previous techniques combined, as we can see from the table. By taking into account a certain value of SNR, the table below depicts the tabular version of Figure 4.3.

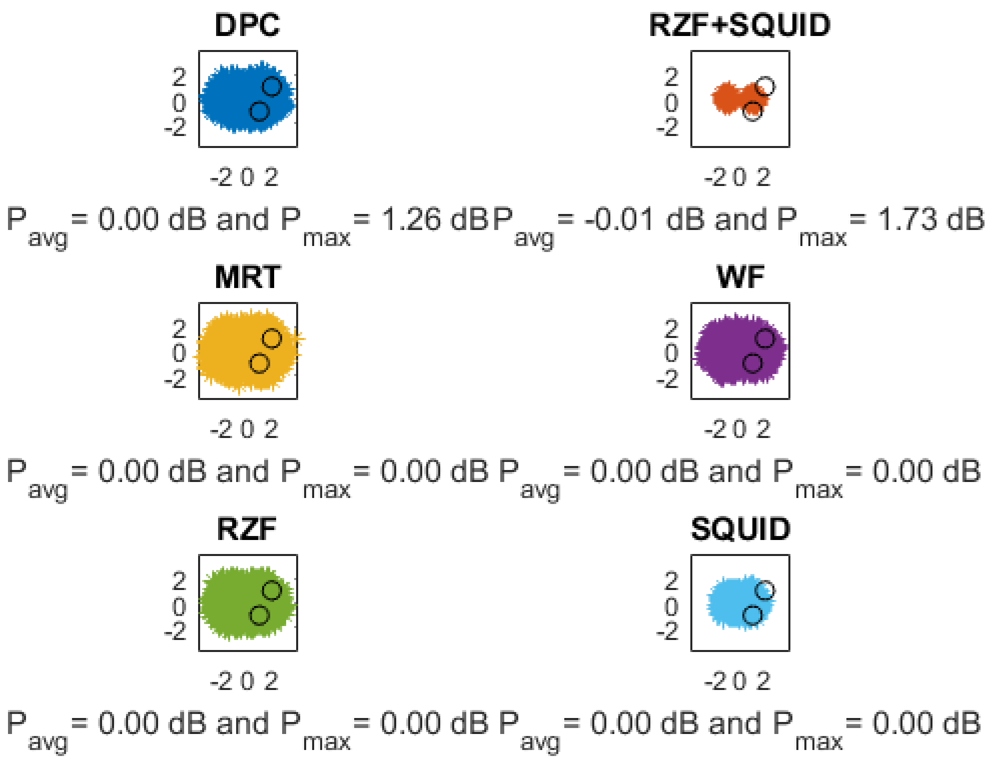

Figure 4.4: Cancellation diagram of proposed pre-coding technique and other types of pre-coding at 64×128 M-MIMO system, BPSK

In Figure 4.4 cancellation diagram of the proposed pre-coding technique and other types of pre-coding techniques for the number of users = 64, number of base station antennas = 128, over BPSK modulation at SNR = -10db to 5db.In the above figure of the existing precoder the color symbols highly deviate from the circle than the proposed precoder which shows large quantity of error occurs. The proposed pre-coding technique is much close to the ideal constellation diagram as compared to that of the currently used pre-coding technique and average power of 1.73db and maximum power of -0.01 dB, shows better resistance against noise and interference.

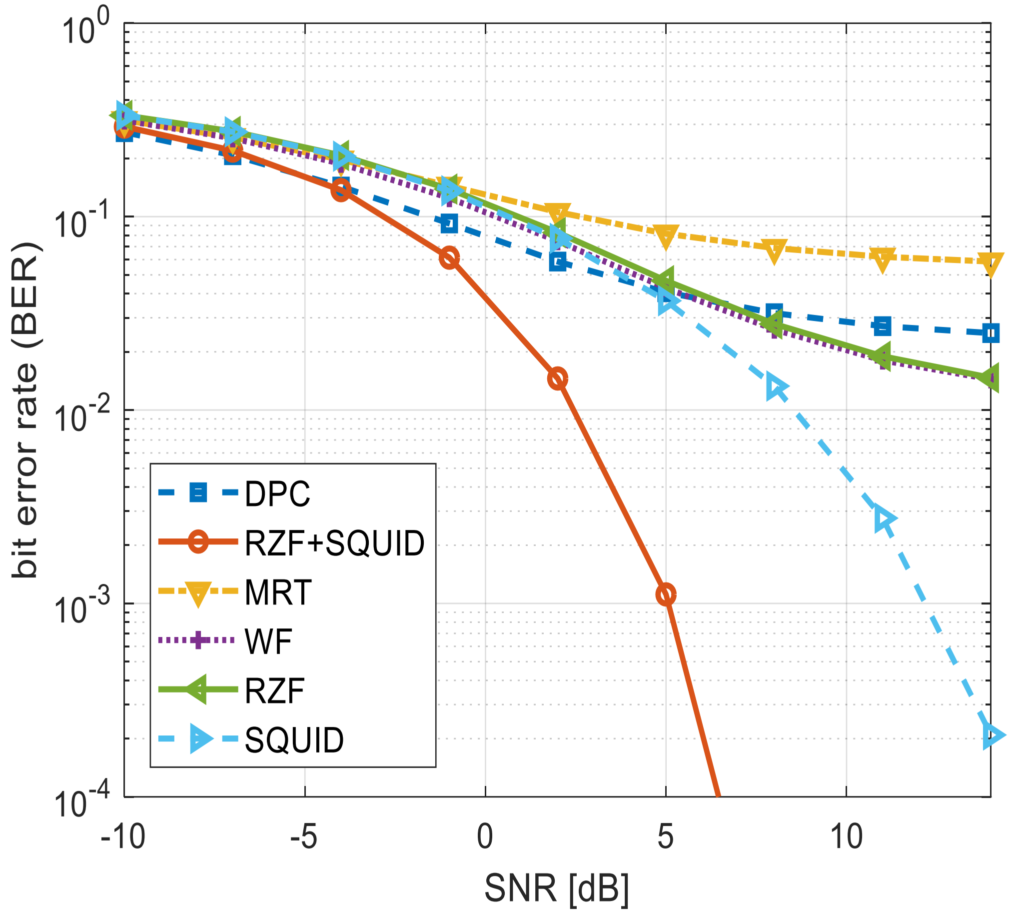

Figure 4.5: BER performance of proposed pre-coding technique and other types of pre-coding at 256×1024 M-MIMO system, QPSK

Figure 4.5 compares the BER of the proposed algorithm to that of other approaches that are currently in use for a 256x1024 (BUAR = 4) antenna arrangement utilizing QPSK modulation and the proposed algorithm has comparable BER performance with SQUID types of pre-coding whereas outperformed, ZF, MRT, and DPC types pre-coding method. The proposed algorithm achieved a BER = 1.1163×10^{-3} at the signal-to-noise ratio (SNR) = 5dB, whereas the SQUID and DPC algorithm achieved a BER = 3.674×10^{-2} and the DPC algorithm achieved a BER = 5.55×10^{-2} at the same SNR = 5dB respectively. The Pre-coding based on MRT, and ZF methods perform the BER = 8.99×10^{-2} and 5.55×10^{-2} respectively. The precoder based on DPC performs moderately well. The precoder based on the proposed method has good performance.

Table 4.4: Tabular data of BER versus SNR proposed pre-coding technique and other types of pre-coding at 256×1024 M-MIMO system, QPSK

SNR (dB)	BER					
	RZF+SQUID	SQUID	DPC	RZF	WF	MRT
-10	2.92×10^{-1}	3.333×10^{-1}	2.733×10^{-1}	3.333×10^{-1}	3.144×10^{-1}	2.504×10^{-1}
-7	2.195×10^{-1}	2.745×10^{-1}	2.195×10^{-1}	2.745×10^{-1}	2.543×10^{-1}	2.574×10^{-1}
-4	1.371×10^{-1}	2.053×10^{-1}	1.431×10^{-1}	2.053×10^{-1}	1.878×10^{-1}	2.053×10^{-1}
-1	6.138×10^{-2}	1.36×10^{-1}	9.219×10^{-2}	1.36×10^{-1}	1.248×10^{-2}	1.443×10^{-2}
2	1.456×10^{-2}	7.718×10^{-1}	5.858×10^{-2}	8.272×10^{-2}	7.718×10^{-2}	1.055×10^{-2}
5	1.1163×10^{-3}	3.674×10^{-2}	3.683×10^{-2}	4.663×10^{-2}	4.276×10^{-2}	8.162×10^{-2}

Table 4.4 compares the effectiveness of the suggested pre-coding technique with various existing methods for the following parameters: 2 users, 8 base station antennas, over 8QAM at SNR = -10dB to 10 db. The performance of the proposed precoder is superior to that of the other approaches, as we can see from Table 4.4. By taking into account a certain value of SNR, the table above depicts the tabular version of Figure 4.5.

According to the results shown in Table 4.4, the suggested pre-coding technique performs better than all other pre-coding techniques overall. In comparison to the previous pre-coding approaches, the suggested pre-coding strategy achieves lower Bit Error Rate (BER) at all SNR levels. As a result, it can be concluded that the suggested pre-coding methodology can offer transmission quality and signal strength that are noticeably superior to those of the other techniques now in use.

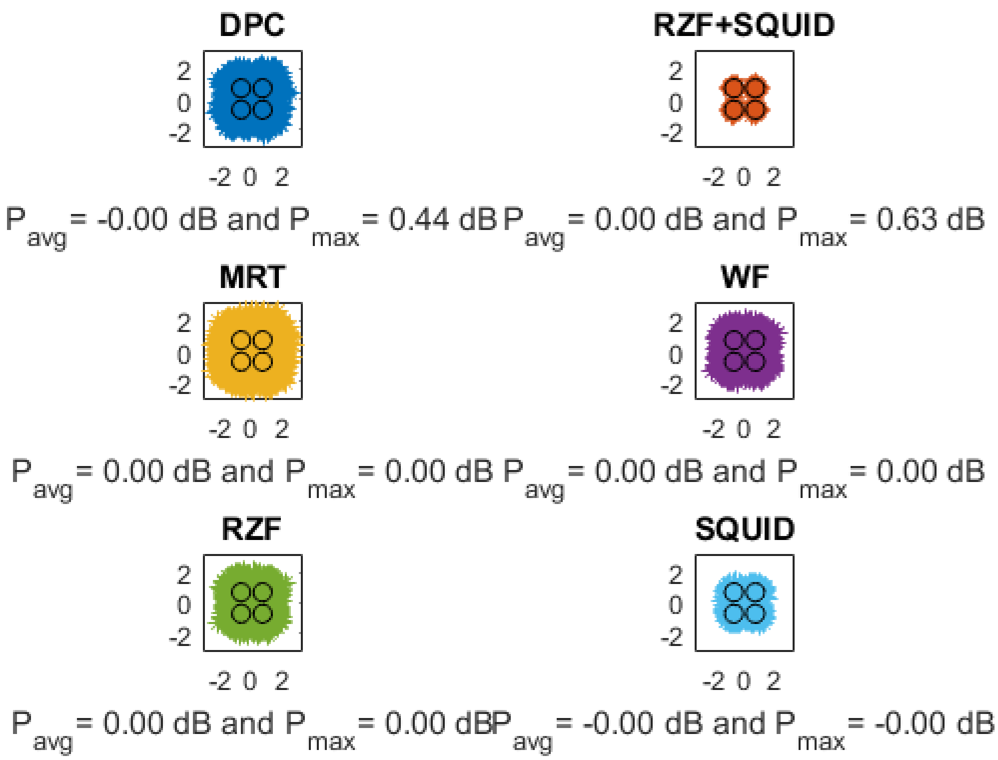

Figure 4.6: Cancellation diagram of proposed 1pre-coding technique and other types of pre-coding at 256×1024 M-MIMO system, 8PSK

Figure 4.6 shows a cancellation diagram that contrasts the effectiveness of the suggested pre-coding methodology with alternative pre-coding techniques for a system with 16 users and 128 base station antennas utilizing 8PSK modulation. The ideal constellation diagram is shown in the diagram for comparison as well as the findings for various SNR levels ranging from -10dB to 8db.

The cancellation diagram demonstrates that, in terms of its near to the ideal constellation diagram, the suggested pre-coding strategy performs noticeably better than the pre-coding method currently in use. This suggests that for a system with 16 users and 128 base station antennas utilizing 8PSK modulation, the suggested pre-coding technique can offer better transmission quality and signal strength than the present pre-coding technique.

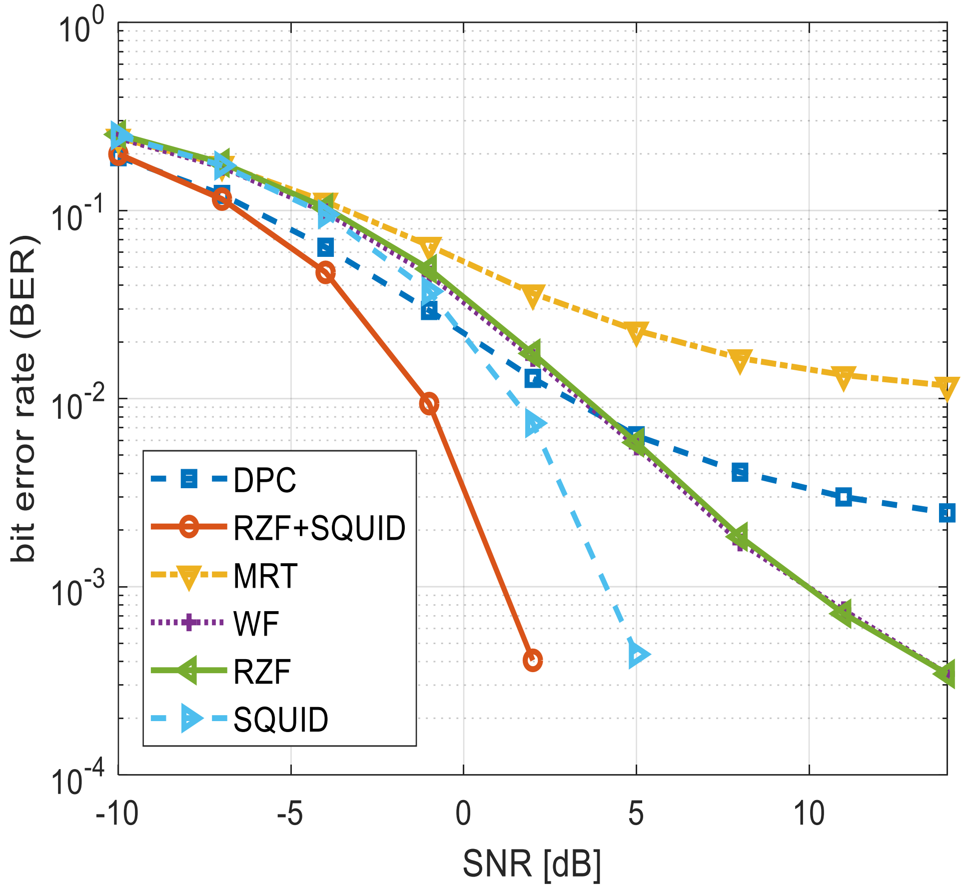

Figure 4.7: BER performance of proposed 1pre-coding technique and other types of pre-coding at 16×128 M-MIMO system, QPSK

Figure 4.7 compares the BER of the proposed algorithm to that of other approaches that are currently in use for a 16x128 (BUAR = 4) antenna arrangement utilizing QPSK modulation and the proposed algorithm has comparable BER performance with SQUID types of pre-coding whereas outperformed, ZF, MRT and DPC types pre-coding methods. The proposed algorithm achieved a BER = 4.062×10^{-4} at signal-to-noise ratio (SNR) = 8dB, whereas the SQUID algorithm achieved a BER = 7.406×10^{-3} at the same SNR = 8dB, and the DPC algorithm achieved a BER = 1.281×10^{-2} at the same SNR. The Pre-coding based on MRT, and RZF methods perform the BER = 3.628×10^{-2} and 1.738×10^{-2} respectively. In this case, the proposed pre-coding and SQUID types of pre-coding have a lower bit error rate but it is limited in the range of SNR of -10 dB to 8 dB respectively.

Table 4.5: BER performance of proposed pre-coding technique and other types of pre-coding at 16×128 M-MIMO system, QPSK

SNR	BER					
(dB)	RZF+SQUID	SQUID	DPC	RZF	WF	MRT
-10	1. 1.9×10^{-1}	2.502×10^{-1}	1.993×10^{-1}	2.503×10^{-1}	2.502×10^{-1}	2.504×10^{-1}
-7	1.15×10^{-1}	1.15×10^{-1}	1.15×10^{-1}	1.79×10^{-1}	1.733×10^{-1}	1.75×10^{-1}
-4	4.68×10^{-2}	6.375×10^{-2}	6.375×10^{-2}	1.035×10^{-1}	9.8×10^{-2}	1.116×10^{-1}
-1	9.406×10^{-2}	7.406×10^{-2}	2.941×10^{-2}	4.891×10^{-2}	4.566×10^{-2}	6.497×10^{-2}
2	4.062×10^{-4}	7.406×10^{-3}	1.281×10^{-2}	1.738×10^{-2}	1.644×10^{-2}	3.628×10^{-2}

Table 4.5 compares the effectiveness of the suggested pre-coding method pre-coding technique with various existing methods for the following parameters: 16 users, 128 base station antennas, over QPSK at SNR = -10dB to 8 db. The performance of the proposed precoder is superior to that of the other approaches, as we can see from Table 4.5. By taking into account a certain value of SNR, the table above depicts the tabular version of Figure 4.7.

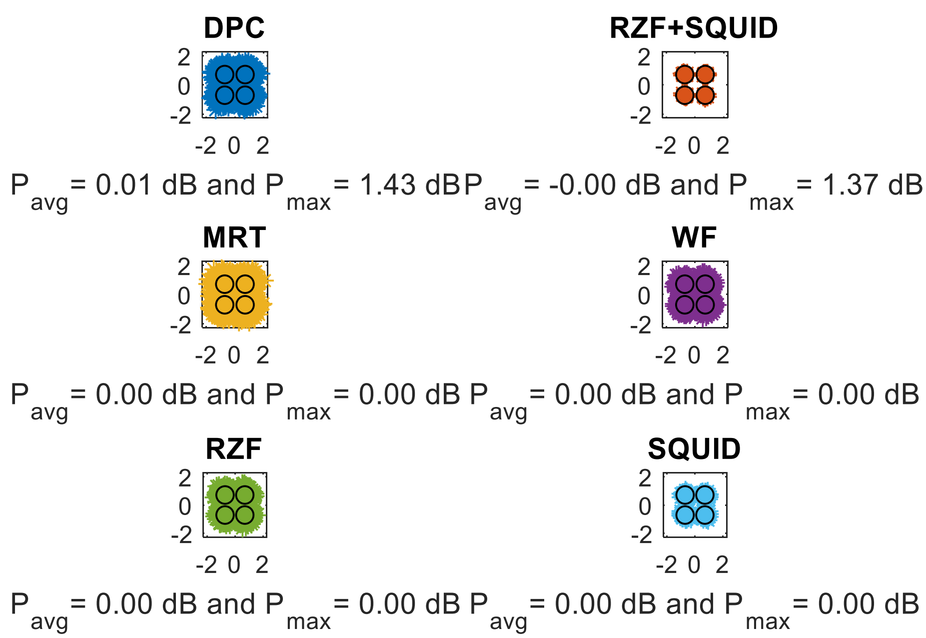

Figure 4.8: Cancellation diagram of proposed 1pre-coding technique and other types of pre-

coding at 16×128 M-MIMO system, 8PSK

In Figure 4.6 cancellation diagram of the proposed pre-coding technique and other types of pre-coding techniques for the number of users = 16, number of base station antennas = 128, over 8PSK modulation at SNR = -10db to 10 db. The proposed pre-coding technique is much close to the ideal constellation diagram as compared to that of the currently used pre-coding technique

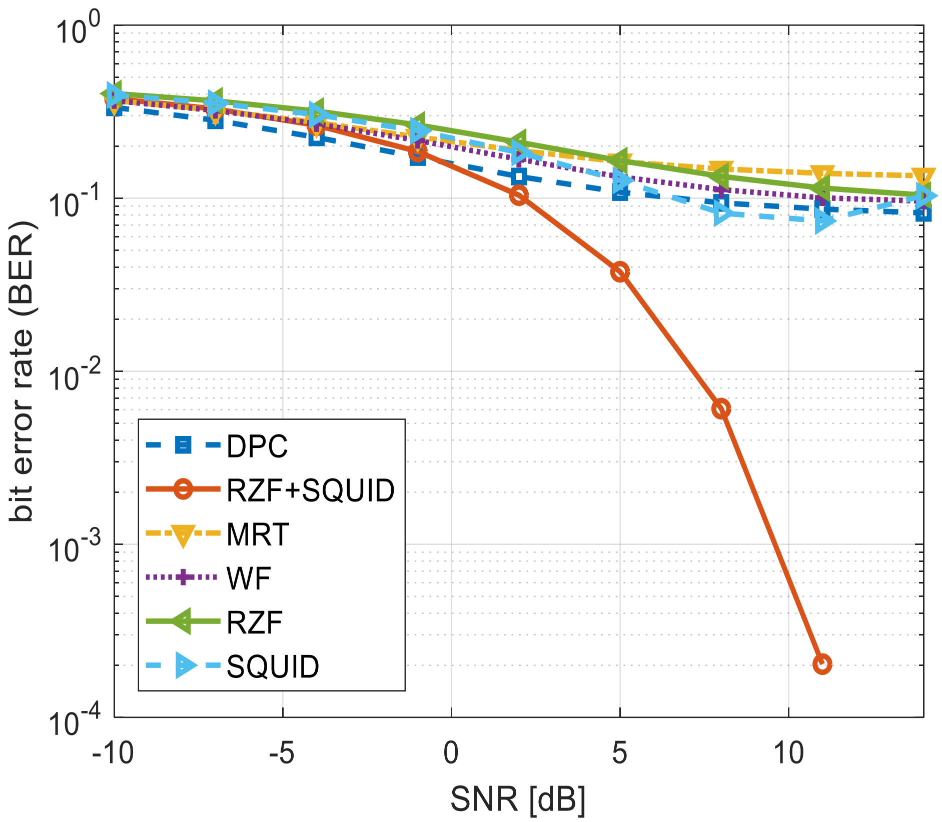

Figure 4.9: BER performance of proposed 1pre-coding technique and other types of pre-coding at 128×256 M-MIMO system, QPSK

Figure 4.9 compares the BER of the proposed algorithm to that of other approaches that are currently in use for a 128x256 (BUAR = 2) antenna arrangement utilizing QPSK modulation and the proposed algorithm has outperformed when compared to ZF, MRT, SQUID, and DPC types pre-coding method. The proposed algorithm achieved a BER = 6.078×10^{-3} at signal-to-noise ratio (SNR) = 8dB, whereas the SQUID algorithm achieved a BER = 3.758×10^{-2} at the same SNR = 10dB, and the DPC algorithm achieved a BER = 8.2×10^{-2} at the same SNR. The Pre-coding based on MRT, and RZF methods perform the BER = 1.478×10^{-1} and 1.475×10^{-1} respectively. As a result, shown for a large number of users and base station antennas the bit error rate of all existing precoders increased as the signal-to-noise ratio increased.

Table 4.6: Tabular data of BER versus SNR proposed pre-coding technique and other types of pre-coding at 128×256 M-MIMO system, QPSK 1

SNR (dB)	BER					
	RZF+SQUID	SQUID	DPC	RZF	WF	MRT
-10	1. 3.762×10^{-1}	3.942×10^{-1}	1.993×10^{-1}	4.023×10^{-1}	3.942×10^{-1}	3.942×10^{-1}
-7	3.212×10^{-1}	3.541×10^{-1}	1.15×10^{-1}	3.652×10^{-1}	3.541×10^{-1}	3.212×10^{-1}
-4	3.042×10^{-1}	3.042×10^{-1}	6.375×10^{-2}	3.187×10^{-1}	2.692×10^{-1}	2.692×10^{-1}
-1	1.862×10^{-2}	7.406×10^{-2}	2.453×10^{-1}	2.653×10^{-1}	2.156×10^{-1}	2.453×10^{-2}
2	1.048×10^{-1}	7.406×10^{-3}	1.836×10^{-1}	2.106×10^{-1}	1.836×10^{-1}	1.886×10^{-1}
5	3.758×10^{-2}	3.758×10^{-2}	1.268×10^{-1}	1.65×10^{-1}	1.328×10^{-1}	1.65×10^{-1}
8	6.078×10^{-3}	3.758×10^{-2}	8.2×10^{-2}	1.475×10^{-1}	1.121×10^{-1}	1.478×10^{-1}

In Table 4.6, the performance of the proposed pre-coding technique is contrasted with a number of other pre-coding techniques for a communication system with 128 users, 256 base station antennas, and QPSK modulation. At several SNR levels between -10dB and 8dB, the effectiveness of the pre-coding approaches is assessed.

According to the results shown in Table 4.6, the suggested pre-coding technique performs better than all other pre-coding techniques overall. In comparison to the previous pre-coding approaches, the suggested pre-coding strategy achieves lower Bit Error Rate (BER) at all SNR levels. As a result, it can be concluded that the suggested pre-coding methodology can offer transmission quality and signal strength that are noticeably superior to those of the other techniques now in use.

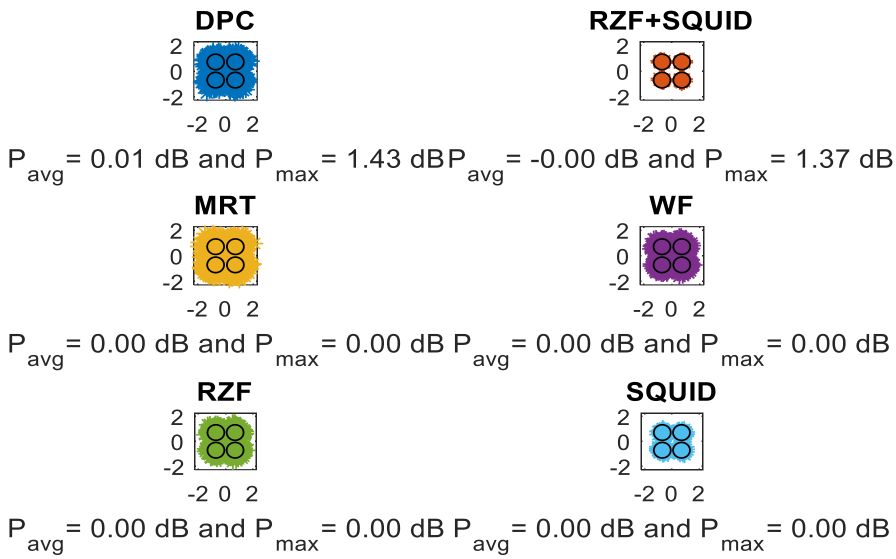

Figure 4.10: Cancellation diagram of proposed 1pre-coding technique and other types of pre-coding at 128×256 M-MIMO system, QPSK

A cancellation diagram, shown in Figure 4.10, compares the performance of the proposed pre-coding technique to those of other pre-coding techniques. The results are represented in the diagram for a system with128 users, 256 base station antennas, QPSK modulation, and a range of SNR values from -10 dB to 8 db. For comparison, the ideal constellation diagram, which depicts the best transmission performance, is also displayed.

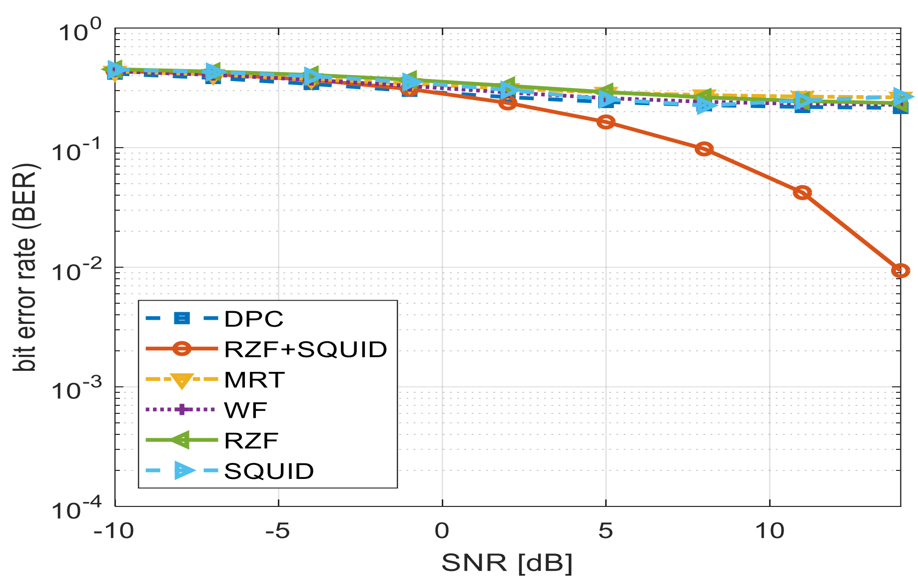

Figure 4.11: BER performance of the proposed1pre-coding technique and other types of pre-

coding at 64×128 M-MIMO system, 16QAM

The suggested approach outperformed the SQUID algorithm, which had a BER of 2.636×10^{-1}, and the DPC algorithm, which had a BER of 2.25×10^{-1} when the signal-to-noise ratio (SNR) was set to 8dB. At the same SNR level, the WF pre-coding approach produced a BER of 2.419×10^{-1} .The BER of the pre-coding techniques based on RZF and MRT, respectively, was 2.636×10^{-1} and 2.635×10^{-1}.

It is important to note that as the SNR grew, the BER of all the pre-coding algorithms in use also increased, indicating that the transmission quality declined as the signal-to-noise ratio decreased. However, the suggested pre-coding algorithm was able to keep BER low even at greater SNR levels, proving its better performance over the pre-coding techniques currently in use. The choice of the best pre-coding strategy for a particular communication system can be aided by these results, which offer valuable insight on the effectiveness of various pre-coding techniques in various scenarios.

Table 4.7: Tabular data of BER versus SNR proposed pre-coding technique with various existing methods for the following parameters: 128 users, 256 base station antennas, over 64QAM

SNR (dB)	BER					
	RZF+SQUID	SQUID	DPC	RZF	WF	MRT
-10	4.498×10^{-1}	4.498×10^{-1}	4.162×10^{-1}	4.497×10^{-1}	3.942×10^{-1}	3.972×10^{-1}
-7	4.064×10^{-1}	4.292×10^{-1}	4.292×10^{-1}	4.292×10^{-1}	3.541×10^{-1}	3.97×10^{-1}
-4	3.692×10^{-1}	3.966×10^{-1}	3.414×10^{-1}	3.966×10^{-1}	3.692×10^{-1}	3.966×10^{-1}
-1	3.094×10^{-1}	3.539×10^{-1}	3.094×10^{-1}	3.704×10^{-1}	3.283×10^{-1}	3.539×10^{-2}
2	2.368×10^{-1}	3.033×10^{-1}	2.89×10^{-1}	3.292×10^{-1}	3.033×10^{-1}	3.118×10^{-1}
5	1.641×10^{-1}	2.916×10^{-1}	2.545×10^{-1}	2.916×10^{-1}	2.599×10^{-1}	2.763×10^{-1}
8	9.769×10^{-2}	2.636×10^{-1}	2.25×10^{-1}	2.636×10^{-1}	2.419×10^{-1}	2.635×10^{-1}

In Table 4.7, the performance of the proposed pre-coding technique is contrasted with a number of other pre-coding techniques for a communication system with 128 users, 256 base station antennas, and QPSK modulation. At several SNR levels between -10dB and 8dB, the effectiveness of the pre-coding approaches is assessed.

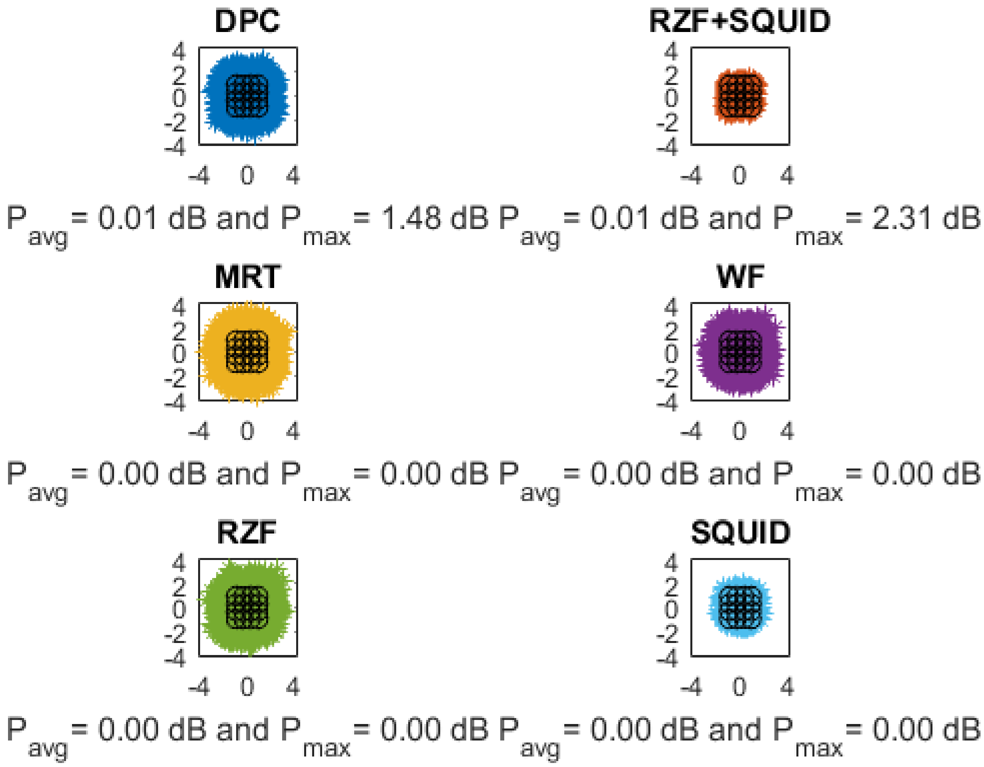

Figure 4.12: Cancellation diagram of proposed 1pre-coding technique and other types of pre-coding at 64×128 M-MIMO system16QAM

In Figure 4.12 cancellation diagram of the proposed pre-coding technique and other types of pre-coding techniques for the number of users = 64, number of base station antennas = 128, over 16QAM modulation at SNR = -10db to 8 db. The proposed pre-coding technique is much close to the ideal constellation diagram as compared to that of the currently used pre-coding technique.

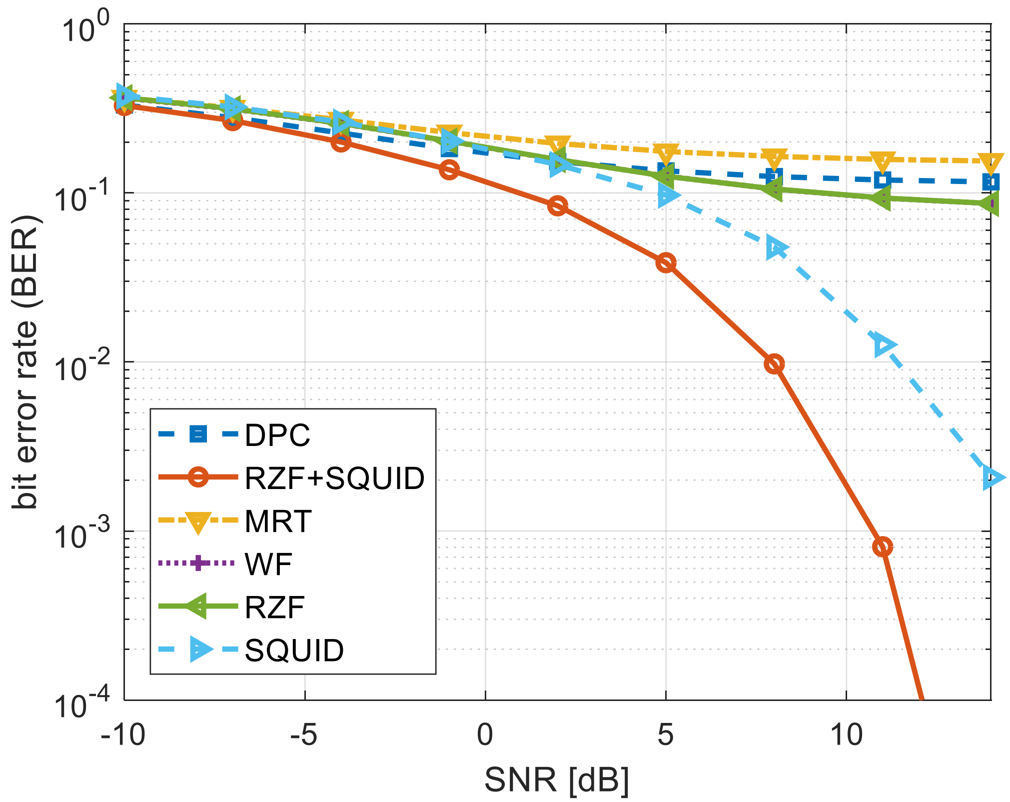

Figure 4.13: BER performance of the proposed2pre-coding technique and other types of pre-coding at 64×1024M-MIMO system, 64 QAM

Figure 4.13 compares the BER of the proposed algorithm to that of other approaches that are currently in use for a 64x1024 (BUAR = 2) antenna arrangement utilizing 64QAM modulation and the proposed algorithm has low BER compared to ZF, MRT, SQUID, and DPC types pre-coding methods. The proposed algorithm achieved a BER = 9.742×10^{-3} at a signal-to-noise ratio (SNR) = 8dB, whereas the SQUID algorithm achieved a BER = 4.784×10^{-2} at the same SNR = 8dB.The DPC algorithm achieved a BER = 1.249×10^{-1} and the WF precoding achieved a BER= 1.056×10^{-1} at the same SNR. The Pre-coding based on RZF, and MRT methods perform the BER = 1.64×10^{-1} and 1.055×10^{-1} respectively. As a result, shown for a large number of users and base station antennas the bit error rate of all existing precoders increased as signal-to-noise ratio increased.

It is important to note that all of the pre-coding techniques used at the time saw a rise in BER as the SNR grew, which shows that the transmission quality suffered from a weaker signal compared to the noise level. The suggested pre-coding algorithm, however, was able to keep BER low even at greater SNR levels, showing that it outperforms the current pre-coding techniques. These findings are helpful in determining which pre-coding strategy is best for a certain communication system since they give insight on how various pre-coding methods perform in various situations.

Table 4.8: Tabular data of BER versus SNR proposed pre-coding technique and other types of pre-coding at 128×256 M-MIMO system, 64QAM

SNR	BER					
(dB)	RZF+SQUID	SQUID	DPC	RZF	WF	MRT
-10	3.641×10^{-1}	3.746×10^{-1}	3.288×10^{-1}	3.746×10^{-1}	3.288×10^{-1}	3.42×10^{-1}
-7	2.678×10^{-1}	3.224×10^{-1}	3.145×10^{-1}	3.111×10^{-1}	3.133×10^{-1}	3.224×10^{-1}
-4	2.001×10^{-1}	2.625×10^{-1}	2.262×10^{-1}	2.507×10^{-1}	2.577×10^{-1}	2.706×10^{-1}
-1	1.371×10^{-1}	2.023×10^{-1}	1.829×10^{-1}	2.023×10^{-1}	2.1201×10^{-1}	2.275×10^{-1}
2	8.392×10^{-2}	1.469×10^{-1}	1.574×10^{-1}	1.574×10^{-1}	1.583×10^{-1}	1.961×10^{-1}
5	3.865×10^{-2}	9.701×10^{-2}	1.35×10^{-1}	1.254×10^{-1}	1.354×10^{-1}	1.758×10^{-1}
8	9.742×10^{-3}	4.784×10^{-2}	1.249×10^{-1}	1.64×10^{-1}	1.056×10^{-1}	1.055×10^{-1}

In Table 4.8, the performance of the proposed pre-coding technique is contrasted with a number of other pre-coding techniques for a communication system with 128 users, 256 base station antennas, and 64QAM modulation. At several SNR levels between -10dB and 8dB, the effectiveness of the pre-coding approaches is assessed.

According to the results shown in Table 4.7, the suggested pre-coding technique performs better than all other pre-coding techniques overall. In comparison to the previous pre-coding approaches, the suggested pre-coding strategy achieves lower Bit Error Rate (BER) at all SNR levels. As a result, it can be concluded that the suggested pre-coding methodology can offer transmission quality and signal strength that are noticeably superior to those of the other techniques now in use.

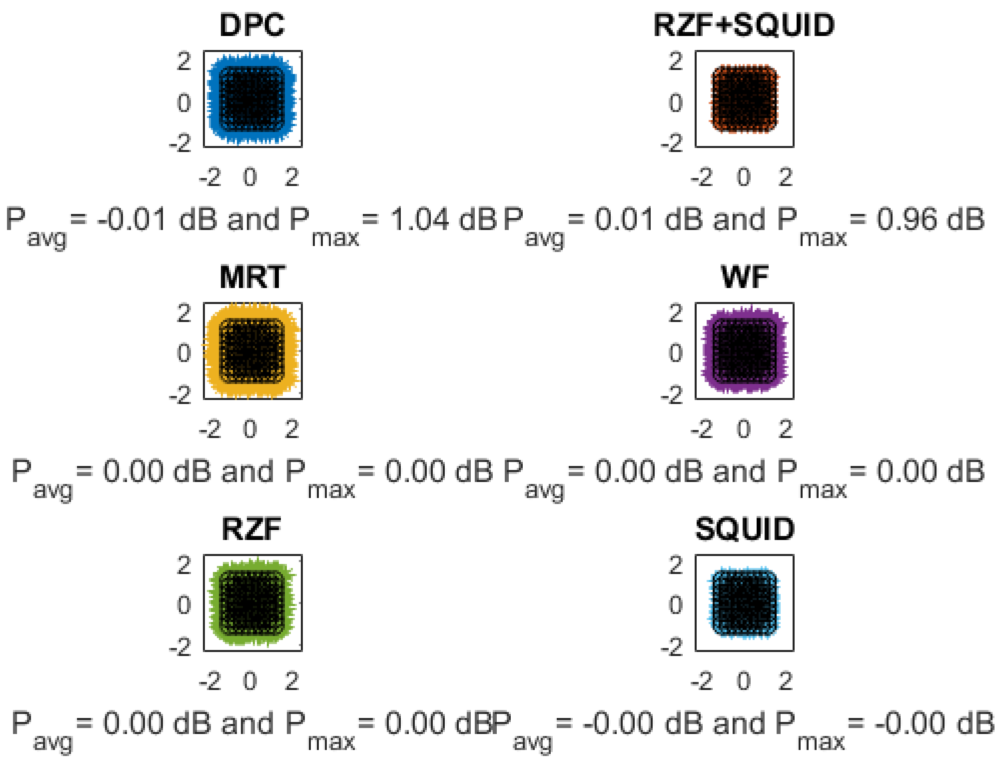

Figure 4.14: Cancellation diagram of proposed 2pre-coding technique and other types of pre-coding at 64×1024 M-MIMO system 64QAM

A cancellation diagram, shown in Figure 4.14, compares the effectiveness of the suggested pre-coding method to those of other pre-coding techniques. The results are represented in the diagram for a system with 64 users, 1024 base station antennas, 64QAM modulation, and a range of SNR values from -10 dB to 8 db. For comparison, the ideal constellation diagram, which depicts the best transmission performance, is also displayed.

In terms of its near to the ideal constellation diagram, the cancellation diagram shows that the proposed pre-coding methodology performs significantly better than the pre-coding method now in use. This shows that when compared to the current pre-coding technique, the suggested pre-coding technique can offer much better transmission quality and signal strength. The findings of this analysis can be used to evaluate the effectiveness of the suggested pre-coding methodology and to assist decide which pre-coding method is best for a particular communication system.

4.1.3 Performance comparisons of the proposed precoder with other precoders based on Energy efficiency

Comparing a proposed precoder's performance based on energy efficiency normally entails calculating the number of bits transferred per unit of energy spent and comparing it to the energy efficiency numbers for other precoding methods already in use. The comparison can be done for a variety of conditions, including different number of user, number of base station antenna and modulation techniques.

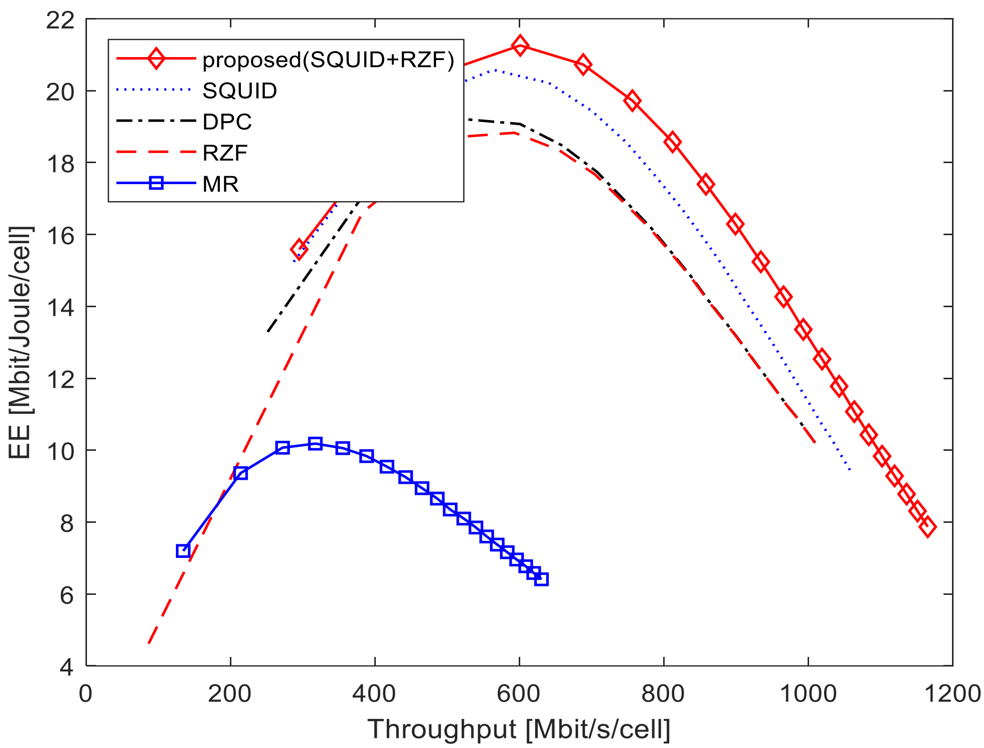

Figure 4.15: Energy efficiency versus throughput over frequency selective channel for Proposed (SQUID+RZF), SQUID, DPC and RZF for 2×16

The graph 4.15 typically shows a curve that illustrates the trade-off between throughput and energy efficiency. Energy efficiency typically decreases as throughput increases. This is due to the fact that transferring more bits per unit of time often consumes more energy.

Energy efficiency versus throughput a communication system's performance can be examined to find the best balance between throughput and energy efficiency using a graph of precoding approach. The graph could be useful in choosing the most appropriate transmission method to achieve the ideal balance between energy efficiency and throughput, depending on the requirements of the communication system.

4.2 Summary of performance comparison

According to prior result all-performance simulation findings, the suggested precoder (RZF+SQUID) has surpassed precoding methods that have been in use. It has done better in terms of BER and EE performance than RZF, MRT, WF, DPC, and SQUID.

The suggested precoder accomplished the best BER= 4.062×10^{-4} at the SNR=2dB, whereas SQUID BER= 7.406×10^{-3}, BER= 1.281×10^{-2}, for QPSK, 2x8 antenna configuration. At this condition the percentage the suggested precoder accomplished precoder from SQUID precoder is given by $\frac{(7.406\times10^{-3}-4.062\times10^{-4})}{7.406\times10^{-3}}\times100=94.51\%$. The suggested precoder accomplished the best BER= 1.1163×10^{-3} at the SNR=5dB, whereas RZF BER= 8.162×10^{-2}, for BPSK, 64×128, antenna configuration. At this condition the percentage performance improvement of the proposed precoder from RZF precoder is given by $\frac{(8.162\times10^{-2}-1.1163\times10^{-3})}{8.162\times10^{-2}}\times100=98.63\%$. The suggested precoder accomplished the best BER= 6.078×10^{-3} at the SNR=8dB, whereas SQUID BER= 3.758×10^{-2}, for QPSK, 128×256, antenna configuration. At this condition the percentage performance improvement of the proposed precoder from RZF precoder is given by $\frac{(3.758\times10^{-2}-6.078\times10^{-3})}{3.758\times10^{-2}}\times100=83.82\%$. The suggested precoder accomplished the best the optimal BER= 9.769×10^{-2} t the SNR=8dB, whereas RZF BER= 2.756×10^{-1}, for 16QAM, 64×128, antenna configuration. At this condition the percentage performance improvement of the proposed precoder from RZF precoder is given by $\frac{2.756\times10^{-1}-9.769\times10^{-2})}{2.756\times10^{-1}}\times100=64.55\%$. The suggested precoder accomplished the best BER= 9.769×10^{-2} t the SNR=8dB, whereas RZF BER= 2.756×10^{-1}, for 64QAM, 128×256, antenna configuration. At this condition the percentage performance improvement of the proposed precoder from RZF precoder is given by $\frac{2.756\times10^{-1}-9.769\times10^{-2})}{2.756\times10^{-1}}\times100=64.55\%$.

CHAPTER 5

5. CONCLUSION AND FUTURE WORK

Conclusions concerning the thesis findings are reviewed in this chapter, along with suggestions for future research projects based on the concepts covered here or potential substitutes that might reinforce the issues raised in this thesis.

5.1 Conclusion

In this study, the comparison of linear and nonlinear precoders for 5G and B5G (M-MIMO) systems was explored. The suggested hybrid pre-coding performs at its best under conditions of an array of antennas at the BS, M and active users, and modulation method the combined precoding have better outcome. The output of the simulation reveals the improvement of signal-to-noise ratio and energy efficiency (measured in bits/J) on the suggested hybrid pre-coding approach by retaining the advantages of both linear and nonlinear pre-coding. According to the study's results, the proposed precoder was more effective in mitigating the impact of noise and interference in the wireless channel when compared to existing precoders for narrowband massive MU-MIMO systems. Specifically, the combined precoder produced better outcomes. in terms of BER, EE, and SNR metrics. The simulation results demonstrated that the proposed precoder was able to achieve lower BER, higher EE, and better SNR as compared to existing precoders. These findings are significant as they suggest that the proposed precoder can be a promising solution for improving the effectiveness of narrowband large MU-MIMO systems in wireless communication networks.

In general, the simulation findings give scientists, engineers, and other professionals working on the design and improvement of narrowband massive MU-MIMO systems useful information. The outcomes can be used to improve these systems' effectiveness efficiency, which may have a significant impact on the reliability and standard of wireless communication networks.

5.2 Recommendations and Future Work

The following is a list of suggestions for possible future growth of the works of this thesis research:

- Although linear and nonlinear pre-coding can be accomplished in this study, signal recovery in the uplink will need to be solved by utilizing CSI in further work.
- Large-scale pre-coding The MIMO structures developed in this work only take pre-coding into account, a single cell in a single broadband network. Further research for a device (i.e.

expanding it to larger networks) with more than two cells is possible, and the quality of spectrum utilization should be improved.

- The majority of the huge MIMO research efforts to date have been on linear pre-coding methods. There are attempts to find low-complexity variations of non-linear precoders such as the SQUID and DPC, as has been shown throughout this thesis. Finding non-linear precoders that are equally sophisticated to linear precoders yet more effective and high performing holds enormous promise.
- Instead of using the best data estimation, the best algorithm can be chosen by utilizing machine learning is recommended to be done in the future. Even though the learning phase could significantly increase computational complexity, it is possible to acquire the ideal pre-coding method.

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