Adaptive Precoders for Down Link Massive MIMO System

Zelalem Abebe Gashaw

A Thesis Submitted to

The Department of Electronic and communication Engineering

School of Electrical Engineering and Computing

Presented in Partial Fulfilment of the Requirement for the Master of Science Degree in Electronic and Communication Engineering (Communication Engineering)

Office of Graduate Studies

Adama Science and Technology University

February, 2021

Adama, Ethiopia

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APPROVAL OF BOARD OF EXAMINERS

We, the undersigned, members of the Board of Examiners of the final open defence by Zelalem Abebe Gashaw have read and evaluated his thesis entitled “Adaptive Precoders for Down Link Massive MIMO System” and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfilment of the requirement of the Degree of Masters in communication Engineering.

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DECLARATION

I hereby declare that this MSc thesis is my original work and has not been presented for a degree in any other university, and all sources of material used for this thesis have been duly acknowledged.

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This MSc thesis has been submitted for examination with my approval as a thesis advisor.

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ABSTRACT

The number of users and applications is increasing rapidly which is also facilitating the research and development in wireless technology. Ideally, wireless communications can simultaneously have a fast data rate and connection efficiency. Future generation wireless communication will have to deal with some core requirements of simultaneously serving large number users, upholding high throughput for each user, assuring less energy consumption, etc. In practice, the inter-user interference arises when more users access the wireless link which requires complicated transmission techniques such as interference cancellation, to maintain a given desired quality of service. A massive MIMO with very large antenna arrays is proposed to overcome inter-user interference problem. Massive MIMO is one of these promising technologies which have introduced the concept of using hundreds or thousands of antennas at the base station and serving tens or hundreds of users simultaneously. A massive number of antennas will help to concentrate the radiated energy into smaller region hence will improve the throughput and energy efficiency of the system. In this thesis, the performance of a massive MIMO system has been investigated by utilizing adaptive pre-coding techniques like linear and nonlinear ZF and DPC. The results finally show that massive MIMO becomes more energy and spectral efficient in applying adaptive precoding technique than ordinary beamforming techniques which have been used by LTE.

Keywords*– MIMO, Massive MIMO, Pre-coding, ZF,DPC linear and nonlinear.*

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LIST OF ACRONYMS

5G ....Fifth Generaion
BD..Block Diagonalization
BER ....Beat Error Rate
BSs...Base Stations
CSIT .... Channel State Information at Transmiter
DPC ....Dirty Paper Coding
EE ....Energy Efficiency
FDD ....Frequency Division Duplex
IEEE ....Institute of Electrical and Electronics Engineers
LTE.. Long Term Evolution
MAC.. Multiple Access Channel, Multiple Access channel
MF .... Match Filter
MIMO... Multiple Input Multiple Output
MMSE ....Minimum Mean Square Error
MR ....Maximum Ratio
MRT .... Maximum Ratio Transmission
MU-MIMO .... Multiuser-Multiple Input Multiple Output
QAM.. Quadrature Amplitude Modulation
QoS ....Quality of Service
RZF..Regularized Zero Forcing
SDMA... Space-Division Multiple Access
SE .... Spectral Efficiency
SINR...Signal To Interferance Ratio
SNR ....Signal to Noise Ratio
TDD.. Time Division Duplex
TH.. Tomlinson-Harashima
ZF .... Zero Forcing

CHAPTER 1

INTRODUCTION

1.1. Background

High speed wireless services are in great need with the rapid development of smart terminals, such as iPhone and iPad, which brings huge challenge to the next generation wireless communication networks. Nowadays, the frequency spectrum has been used excessively, and it is uneconomical to better the spectrum efficiency (SE) by deploying more new small cell sites [1,2]. The massive multiple-input multiple-output (MIMO) system, or named large-scale antenna system, can improve SE, energy efficiency (EE) and reliability can be enhanced by MIMO system, or the large-scale antenna system, by configuring a massive array of antennas at existing base stations (BSs), which has been regarded as a potential technology for wireless communication networks of the next generation[3,4].The huge potential of massive MIMO has stimulated great interest of both academics and industry.

The physical layer would be the efficiency constraint of the wireless network, because, essentially, the amount of information that can be transmitted between two locations is restricted by the supply of bandwidth, electromagnetic transmission rules, and information theory concepts. There are three simple methods of enhancing the performance of a wireless network [5].

- Denser distribution of control points
- More bandwidth is used
- Increasing the spectral efficacy, i.e., the number of bits that can be transmitted per second in each bandwidth unit

While a growing density of access points is expected to be used by evolving wireless networks and standards to use new spectral bands, the need to maximize the spectrum efficiency of a given band will never vanish.

The use of multiple antennas, also known as MIMO technology, is a viable solution in order to vastly improve spectral efficiency. MIMO technology is, technically, broken into one of three categories: Point-to-Point MIMO, Multiuser MIMO, and Mega MIMO. This thesis work is about Massive MIMO, which would actually be MIMO technology's eventual manifestation.

A massive MIMO is a type of wireless communication device that uses a large number of antennas on an antenna array, on a scale of a few hundred or thousand [6]. For a single base station, the concept of massive MIMO is to support a multiplicity of terminals utilizing the same time-frequency services. The large MIMO scenario is essentially obtained from the Point-to-Point MIMO setup by separating the K-antenna terminal into many autonomous terminals.

The central principle of massive MIMO is to accomplish all the advantages of traditional MIMO, but on an immense scale. Massive MIMO is based on spatial multiplexing, which in turn depends on appropriate channel information or CSIT for the base station. This CSIT is achieved by sending pilots to BS from the terminals, on the basis of which BS estimates the reaction of the channel to each terminal. Both terminals occupy the full-time frequency resources simultaneously, either in uplink or in downlink transmissions. The base station must retrieve, on uplink, the individual signals emitted by the terminals. On the downlink, the base station has to ensure that any terminal only receives the signal intended for it. The multiplexing and de-multiplexing signal processing of the base station is made possible by using a huge number of antennas and by its possession of CSI. One of the ways to optimize transmission with this CSIT is pre-coding. This transmitter channel state information (CSIT) can be used to boost the efficiency of the large MIMO device using different methods of pre-coding. Using CSIT, the precoders tailor the transmission to the channel to increase the system's efficiency.

By concentrating the resources on the target user, pre-coding often tends to minimize inter-user interference. Some well-known pre-coding techniques are Minimum Mean Square Error (MMSE) precoding, Zero Forcing (ZF) precoding, Maximum Ratio Transmission (MRT) precoding, Regularized Zero Forcing (RZF) precoding, Tomlinson-Harashima (TH) precoding, etc. The efficiency of MMSE, ZF and MRT pre-coding is evaluated in a large MIMO scheme in this thesis work, considering ideal and imperfect CSIT conditions.

1.2. Statement of the Problem

- Spectral efficiency, connection stability, range and energy efficiency are the main challenges in wireless communication. This is due to the restricted bandwidth available, the fading existence of the transmission channel and the wireless nodes' versatility and autonomy.
- The exponential increase in demand for high-speed and high-quality multimedia services with numerous QoS specifications also presents device designers with opportunities and challenges.
- The random channel vectors between the users and the base station become almost orthogonal as the number of antennas increases [7].
- Most of the electrical base station power is expended on the downlink by power amplifiers and similar circuits and cooling systems [8].

1.3. Objectives of the Study

1.3.1. General Objective

The efficiency of a large MIMO device over the downlink is analysed adaptively using various pre-coding strategies and by applying modulation techniques.

1.3.2. Specific Objectives

The specific objectives of this proposed thesis are listed as follow:

- To count number of users in each virtual sector
- To calculate area of each virtual sector
- To calculate density of each virtual sector
- To compare complexity
- To calculate capacity using the selected pre-coders.
- To hybridize the best selected pre-coder in order to enhance the total rate
- To evaluate linear and non-linear pre coding to get adaptive performance of their best capacity.

1.4. Significance of the Study

A variety of pressing design problems are generated by the insatiable demand for high-speed mobile data as today's wireless base stations struggle to accommodate an exponentially saturated RF spectrum. Our ability to consistently increase sending and receiving data rates is under attack in many crowded metropolitan areas. One way forward is to deploy base stations with large numbers of antennas that communicate concurrently via the same frequency resource with several spatially divided user terminals and utilize multipath propagation. This technology is also referred to as massive multiple-input, multiple-output (MIMO), and is often defined as beamforming to address this threat with a large number of antennas.

1.5. The Motivation of the Study

In the wireless communication industry, the global bandwidth shortage has inspired the research and discovery of wireless connectivity technologies known as massive MIMO. Massive MIMO is one of the main enabling technologies for next-generation networks, putting transmitter and receiver antennas together to provide high spectral and energy performance through relatively easy processing. For the efficient rollout of 5G and beyond networks to realize different implementations of the intelligent sensing system, having a deeper understanding of the vast MIMO system to solve the fundamental problems of this technology is crucial.

1.6. Scope of the Study

This research study includes the design and simulation of Adaptive Precoders for Down Link massive MIMO by using linear and nonlinear pre-coding through MATLAB software to get better performance of capacity in Single BS

1.7. Limitation of the Study

Users can also be far away in a huge MIMO situation. Therefore, there is a different average connection SNR for each constituent link in the simulated MIMO link. This disparity is mostly attributed to the numerous long-term channel impairments that are faced by different links, such as path loss and shadow fading, and the number of K users is not greater than the number of M antennas.

1.8. Thesis Contributions and Outline

The Massive-MIMO method is described using a linear and nonlinear system of pre-coding. The expression of the system throughput and a user's attainable rate over Rayleigh fading channels are derived. The M-MIMO achieves improved efficiency with a separate linear and nonlinear pre-coding method. In this work, if the transmitter channel state information (CSIT) is not complete, statistical properties are used to obtain the lost information and there is noise in the channel. Since the pilot signals spread across the uplink channel (known at both ends of the connection and from which the base station estimates the channels).

So, the base station conducts a de-spreading procedure by correlating the received signals with each of the pilot sequences in order to get CSIT at downlink. The noise is also dispersed during the de-spreading process. In most literature, however, [30-33], Three forms of hypothetical inference (Ones Assumption, Mean Assumption and Random Assumption) are known to presume the missing information from the CSIT and evaluate the output of precoders, and there is no noise in the channel. Linear and nonlinear downlink pre-coding (ZF and DPC) is regarded as the number of base station antennas is usually much greater in massive MIMO than the number of terminals. In our case, we use only a single base station. In comparison, under high and low SINR conditions, zero-forcing and dirty paper coding themselves appear to be optimal.

Although adaptive alternatives are much easier to perform: nonlinear processing, which increases mathematical complexity and is ideal when the number of base stations and terminals is almost equal.

1.9. Thesis Outline

This thesis is organized into five chapters.

Chapter 1: Presents introduction of the research work, statement of the problems, objectives of the study, significance the study, motivation of the study, limitation of the study and scope of the study.

Chapter 2: Includes a literature review on the introduction of Massive MIMO system, precoding, Dirty paper coding, zero forcing and also it introduces the massive MIMO technology and discusses its potential advantages and the possible challenges that must to be dealt with.

Chapter 3: Describes the methodology followed in this research thesis.

Chapter 4: Presents the proposed results and discussions.

Chapter 5: Discusses the conclusions and recommendations.

CHAPTER 2

THEORETICAL BACKGROUND AND LITERATURE REVIEW

2.1. Chapter Overview

Massive MIMO (massive multiple-input multiple-output) is a type of wireless communications technology in which a very large number of antenna elements are fitted with base stations to maximize spectral and energy performance.

There will still be an increase in demand for wireless throughput, connectivity efficiency, and consumer density. For 5G wireless networking networks, massive MIMO technology is being built so multiple devices will be supported with extremely high latency simultaneously. To address the propagation losses inherent in high-frequency transmission in 5G networks, processing methods such as beamforming can focus the signal energy from massive MIMO antenna arrays.

2.2. Channel Reciprocity

In both frequency division duplex (FDD) and time division duplex (TDD) transmission modes, massive MIMO can run. In 5G, in TDD mode, where the channel estimation is based on channel reciprocity, Massive MIMO performs best. The approximate channel in the uplink in TDD systems is identical to its downlink counterpart, unlike FDD systems, where the uplink and downlink communications exist on different frequency bands. Thus, it can be used in the downlink for pre-coding. In functional TDD schemes, however, the RF transmission and receipt chains at the base station vary from the consumer terminals. This violates reciprocity and needs reciprocity calibration to fix this problem. Since its launch over a decade ago, it has developed from a radical 'academic' idea to one of the hottest research topics in the field of wireless communications, as well as a core work item in 5 G standardization.

The key concept is to equip base stations with clusters of several antennas in the same time-frequency network that are used concurrently to serve several terminals. For the antenna arrays, there are desirable form factors: in the 2 GHz band, a half-wavelength-spaced rectangular array of 200 dual-polarized sections is about 1.5 x 0.75 meters long. Massive MIMO works in TDD mode, and downlink beamforming uses the uplink-downlink reciprocity of radio transmission. In fact, the base station array uses channel estimates obtained from uplink pilots emitted by the terminals with regard to the number of base station antennas to learn the channel in both directions, which includes totally scalable Massive MIMO. Massive MIMO base stations run autonomously, without sharing payload data or channel status information with other cells. T. The following description is given by the authors L. Marzetta [5].

The useful and scalable variant of Multiuser MIMO is Massive MIMO. Massive MIMO and traditional Multiuser MIMO have three basic variations. First, G. knows only from the base station. Second, while this does not have to be the case, M is usually somewhat greater than K Third, both on the uplink and on the downlink, basic linear signal processing is used. These features make Massive MIMO versatile with regard to the number of antennas for the base station, M. (Note: M is the number of antennas, K is the number of users, and G denotes the channel matrix).

‘’Massive MIMO is a multi-user MIMO device with M and K per BS antennas. The system is characterized by M>> K and uses linear uplink and downlink processing to work in TDD mode.’’

2.3. Time or Frequency

One consideration in 5G networks involves the use of Time Division Duplexing (TDD) or Frequency Division Duplexing (FDD). Both of these approaches provide paths for uplink and downlink traffic.

FDD networks use dedicated spectrum for uplinks and downlinks, and the amount of spectrum for each is generally equal. That doesn’t always fit well with usage patterns; typically, there is more data heading downstream than upstream. When equal amounts of spectrum are dedicated to each direction, it can result in inefficient use of that spectrum.

TDD networks, on the other hand, can use the entirety of the spectrum for uplink or downlink. However, they can only transmit or receive at a point in time – basically, the uplink and the downlink take turns – whereas FDD networks can perform simultaneous transmission and reception. But we're talking milliseconds here, so any difference is something that is transparent to the user.

The use of the same channel for uplink and downlink with TDD allows better channel estimation for beamforming, making it better suited for Massive MIMO systems, in addition to the flexibility it can offer in terms of deployments and efficient spectrum utilization.

Massive MIMO is one element of what is being called 5G New Radio, which describes the radio technology behind all those appealing new features of 5G. As the current hot issue, Fifth Generation (5G) New Radio (NR) technology is expected to meet the explosive growth of current mobile data traffic, due to the advantages of higher transmission rate, lower latency, and lower energy consumption compared with existing communication technologies [9]. The key technologies of 5G include massive multi-input and multiple-output (MIMO), mmWave, ultra-densification, and so on [10].

Massive MIMO can fully exploit spatial degrees of freedom by configuring tens or even hundreds of antennas at the base station to improve the spectral efficiency, the multiuser multiplexing, and intercell interference [11], which is regarded as one of the key technologies of 5G NR. Theoretically, when assuming an infinite number of antennas at the base station (BS), the effect of small-scale fading and thermal noise can be eliminated only remains pilot contamination from other cells, which makes the simplest sort of pre-coding on the forward link and processing on the reverse link possible [12].

2.3.1. Massive -MIMO Advantages

Massive MIMO technologies are incredibly complicated, and it would be more complicated to introduce them than to ride a bronco in the rodeo. Nevertheless, the resources that big MIMO has to give are worth being knocked off the horse a few times. Here are the benefits of the massive MIMO (MU-MIMO) system.

- Performance of high spectrum leading to wide multiplexing gain as well as antenna array gain.
- High energy efficiency due to radiated energy concentration on MS/UE.

- High reliability attributed to significant gains in diversity.
- Due to orthogonal MS channels and extremely narrower lasers, poor inter-user interference and increased physical protection.
- Easy scheduling method.
- Robustness of individual part loss due to the vast number of components of the antenna array.
- Using low power and inexpensive materials, Massive MIMO can be made.
- It allows for a significant reduction in air interface latency.

2.3.2. Spectral Efficiency

As more and more of the electromagnetic spectrum is being used for different communication protocols, this is becoming a very interesting topic. A broad band of frequencies for 5G has been set aside by states, but such spectrums are not infinite. In order to target beams on individual users, Massive MIMO will exploit its antenna array. This helps 10 times higher spectral efficiencies than those of MIMO systems used with 4G to be obtained.

2.3.3. Energy Efficiency

Texas cannot generate oil indefinitely, so it's time for electronic devices to start worrying about energy conservation as well. In combination, large - scale mimo antennas can be used to improve the gain of the broadcast signals. This means that when processing data, they radiate less power, allowing for a more energy efficient device.

2.3.4. User Tracking

It helps individual users to be reliably monitored by the same thing that makes massive MIMO energy efficient. Their beam widths reduce as the antenna beams are concentrated on achieving high gain. Thus, with a narrow signal beam, the tower has to detect each person. This monitoring would provide consumers a link that is faster and more accurate than the wide area signals that have been used so far.

2.3.5. Massive MIMO Disadvantages

The drawbacks of the Massive MIMO System (M-MIMO) are as follows

- Pilot contamination with limited coherent interval and bandwidth due to limited orthogonal pilot subcarriers.
- High difficulty of signal processing due to huge numbers of antennas being used and UEs multiplexing (or Mobile subscribers).
- Sensitive to beam orientation, since an exceedingly smaller beam is used that is sensitive to MS rotation or antenna array swaying.
- The concept of channel reciprocity is used in Massive MIMO's TDD mode.

2.4. Massive MIMO (M-MIMO) Applications

Since 5G needs it, the cellular universe is really beginning to dig into massive MIMO. For 5G, there is a small amount of bandwidth available, so spectral effectiveness is very important. It would also need 5G networks to connect to billions of smartphones. They would require huge precision and energy savings from MIMO for that to happen.

A new portion of the high frequency spectrum for 5G technology was recently opened up by the US government. That will be very beneficial in the future, but frequencies below 6 GHz will have a smoother transition from 4G/LTE for the short-term transition period. It just so happens that at frequencies below 6 GHz, massive MIMO runs best. This band is still noisy, so massive MIMO is a perfect candidate because of the extra spectral effectiveness.

Our planet is getting more linked as technology progresses. The Internet of Things is beginning, self-driving vehicles are on the horizon, and smart cities have networks already in operation. 5G is poised to step into all these arenas, and billions of smartphones will need to be connected. To do that, huge MIMO would be needed in order to be able to beam data to and from individual devices. The energy efficiency of Massive MIMO would also suggest that these networks won't need another oil boom to fuel them.

Massive MIMO is a rodeo-like technology that's just as thrilling. It would allow mobile networks to connect vast numbers of users easily and effectively, almost using massive numbers of antennas. In order to enforce 5G, those attributes often happen to be what is needed. With billions of devices going online and a small frequency range, to help us move into the future, 5G would require massive MIMO. Here are the Massive MIMO (M-MIMO) applications:

- 4G LTE
- LTE Advanced
- Advanced WLAN versions e.g., 802.11ac, 802.11ad

MIMO stands for multiple inputs multiple output. This ensures that, via the transmitter, a receiver antenna array will receive data from and send data to several users at the same time. Each array uses multiple antennas in order to do this. Cell towers can take advantage of multiple transmission modes of all those antennas and complicated signal processing to transmit more data with greater efficiency.

Massive MIMO is the same notion, except multiple antennas instead. Around 4 transmitters can be used by MIMO networks, where massive MIMOs would use more than 100 antennas. The greater description is that an excessive number of antennas would be used by massive MIMO to outnumber consumers of transmitters. All of these antennas

2.5. Related Works

Different researchers placed the outcome of their work in massive mimo in various techniques, such as the author in [24]. The capability of MRT and ZF Pre-coding was derived and the spectral performance of downlink pilot transmission was assessed. [25] The BER efficiency of the massive MIMO device with a growing number of BS antennas has been investigated.[26] evaluated ZF and MRT pre-coding efficiency and compared them to a massive MIMO device under the fading channel of Rayleigh. With the rise in the number of BS antennas, they compared the feasible rate and transmission power. [27] Shows a performance analysis of a large multi-user MIMO downlink system using ZF, MMSE and MRT pre-coding under Rayleigh and Rician fading channel and with perfect CSIT.

Thomas L. Marzetta, et.al, the source, intensively studied the optimality of the linear matched type-combining filter and believed the receiver had an infinite number of antennas [28]. A basic linear beamforming (coordinated beamforming in the paper) has been shown to asymptotically approach the sum potential obtained by dirty paper coding (DPC), a recent hybrid pre-coding scheme where the analog precoder is selected from the antenna array response vectors while the optical precoder is selected from the antenna array response It is picked from a predefined codebook [27], suggested to achieve adequate efficiency, but suffers from a high degree of search difficulty.

More recently, depending on the source, another scheme called spatially sparse pre-coding is suggested in this study work motivation [17]. This paper compares linear and non-linear pre-coding elements such as ZF (zero forcing) from linear on the basis of this, and we also take DPC (dirty paper coding) from non-linear and change it to achieve the best ability to calculate its density by grouping the customer.

CHAPTER 3

METHODOLOGY

Linked secondary data sources, such as various books in LTE, in this research work, standardization records for 3GPP, past study trials by scholars, numerous Institute documents Articles by electrical and electronics engineers (IEEE), advances of 5G wireless infrastructure in general and the fundamentals of massive MIMO in particular. Based on the inputs retrieved from review of related literatures and the statement of the problem in mind, the methodology of this study is designed as follows.

3.1. System Design

The following procedures are methods that are used to conduct the suggested research:

- Data collection
  - Pre coding data will be collected from different site
- Literature review
  - Review of recent related works
- Data Analysis
  - Analyzing their energy efficiency separately
  - Calculating efficiency of DPC and ZF
- Simulation of the model and designed system using MATLAB Simulations
  - Outline simulation work flow
  - Perform target network capacity prediction simulations
  - Simulate target network to evaluate the capacity
- Result Analysis & Interpretations

  Perform the adaptivity of linear and nonlinear capacity in the given flow chart.

3.2. Downlink Data Transmission

Transmit pre-coding (beam forming) is a flexible technique for transmitting signals to one or more users from an array of M antennas. The aim of wireless communications is to maximize the signal power of the intended user and to decrease the interference of unwanted users. By sending the same data signal from both antennas, but with varying amplitudes and phases, high signal power is obtained, so that the signal components are applied to the consumer coherently. Low interfering is done by allowing the signal elements to be applied destructively to unwanted consumers. Mathematically, this correlates to the nature of beamforming vectors (which define Amplitudes and stages) to have large internal products with the described vectors the expected platforms and limited internal goods for consumer channels that are not intended. because pre-coding transmission focuses on signal energy at some locations, less energy is needed Arrives at other sites.

This facilitates multiple access (SDMA) for so-called space-division, where K spatially segregated users are served simultaneously. One beamforming vector which can be matched to its channel is assigned to each user. Unfortunately, the finite number of transmission antennas allows only a small amount of spatial orientation, which means that there are energy leaks between users that act as interference.

Although a beamforming vector that maximizes the signal power of the intended consumer is reasonably straightforward to build, it is difficult to find a fine balance between optimizing the signal power and minimizing the leakage of interference. There are essentially two methods of precoding: linear forms, e.g., ZF, MMSE, MF and non-linear precoding, e.g., DPC, THP, VP, et cetera.

Downlink data transmission requires a linear pre-coding process that integrates the symbols carrying the message with the projections of the downlink channels to establish the real signals emitted by the series. A weighted symbol is transmitted through the mth antenna [34],

$$x_m = \sqrt{\eta_m} q_m \tag{3.1}$$

$$x = D_y^{\frac{1}{2}} \tag{3.2}$$

Where η_m is a power control coefficient that satisfies $0 \leq \eta_m \leq 1$. The symbols $\{q_m\}$ have zero mean and unit variance, and they are uncorrelated?

$$\mathrm{E}\{qq^H\} = I_M \tag{3.3}$$

The signal received vector at the K user terminals can be expressed as:

$$y = \sqrt{\rho_d} H^T x + n \tag{3.4}$$

3.3. Achievable Rate

In Massive MIMO, the efficient channel connected with each of the terminals is a scalar point-to-point channel after sufficient signal processing. It takes a (complex-valued) scalar input symbol x and produces a (complex-valued) output signal y each time this channel is used. The action of the channel is characterized by the conditional probability distribution of *y* given *x*.

The efficiency of the scheme can be described by many methods. The realistic rate is one of the tools for quantifying the efficiency of the device. The attainable rate is followed by the Shannon theory. The overall rate that the transmitter will broadcast over the channel is implied by this principle.

The transmitter maps the message on a sequence of fxng symbols to communicate a message over a point-to-point scalar channel, and the receiver recovers the message from the sequence of fyng samples. The rate is called the effective number of bits transmitted per transmitted symbol, denoted by R, which is measured in bits per channel utilization (bpcu). Recall that BT samples will identify a waveform embedded in a time-frequency space of bandwidth B Hz and time-duration T seconds. It is then analogous to the propagation of BT symbols fxng to relay a waveform of bandwidth B Hz and time-duration T seconds. Therefore, the rate R is usually termed spectral efficiency and measured in bits per second per Hertz b/s/Hz).

According to the robust Shannon, the hypothesis alone suggests the optimality of a rough parity in typical Multiuser MIMO between transmitter antenna number (M) and receiver antenna number (Z) of net spectral efficiency; further growth of M generates only logarithmically higher throughputs while incurring linearly higher training time [35]. Massive MIMO provides a clean break from standard Multiuser MIMO. Steps are designed such that it operates further from the Shannon limit, but paradoxically retains much better performance than any typical Multiuser MIMO system.

It will use those capability bounds as the primary efficiency criterion in this work, inspired by the channel coding theorem. Using state-of-the-art channel coding technologies, these ability bounds will usually be approached closely in practice. Some key results on capacity and capacity bounds for point-to point scalar channels that will be needed for the performance analysis in pre-coding are discussed below.

3.4. Pre-coding

Pre-coding is a generalization of beamforming to support multi-stream transmission in multi-antenna wireless communications. In conventional single-stream beamforming, the same signal is emitted from each of the transmit antennas with appropriate weighting such that the signal power is maximized at the receiver output. When the receiver has multiple antennas, single-stream beamforming cannot simultaneously maximize the signal level at all of the receive antennas. In order to maximize the throughput in multiple receive antenna systems, multi-stream transmission is generally required.

In point-to-point systems, pre-coding means that multiple data streams are emitted from the transmit antennas with independent and appropriate weightings such that the link throughput is maximized at the receiver output. In multi-user MIMO, the data streams are intended for different users and some measure of the total throughput is maximized. In point-to-point systems, some of the benefits of pre-coding can be realized without requiring channel state information at the transmitter, while such information is essential to handle the inter-user interference in multi-user systems. Pre-coding in the downlink of cellular networks, known as network MIMO or coordinated multipoint, is a generalized form of multi-user MIMO that can be analysed by the same mathematical techniques.

Transmit pre-coding (beam forming) is a versatile technique for signal transmission from an array of M antennas to one or multiple users. In wireless communications, the goal is to increase the signal power at the intended user and reduce interference to non-intended users. A high signal power is achieved by transmitting the same data signal from all antennas, but with different amplitudes and phases, such that the signal components add coherently at the user. Low interference is accomplished by making the signal components add destructively at non-intended users.

This corresponds mathematically to designing beamforming vectors Since transmit pre-coding focuses the signal energy at certain places, less energy arrives to other places. This allows for so-called space-division multiple access (SDMA), where K spatially separated users are served simultaneously. One beamforming vector is assigned to each user and can be matched to its channel. Unfortunately, the finite number of transmit antennas only provides a limited amount of spatial directivity, which means that there are energy leakages between the users which act as interference.

While it is fairly easy to design a beamforming vector that maximizes the signal power at the intended user, it is difficult to strike a perfect balance between maximizing the signal power and minimizing the interference leakage. There are basically two techniques of precoding: linear pre-coding ZF (zero forcing) and non-linear pre-coding DPC (dirty paper coding).

Massive multiple input multiple output (MIMO), well viewed as one of the important techniques for fifth generation (5G) wireless communication, has attracted a great deal of research interest in current years [13-15]. The main idea of massive MIMO is to deploy a large-scale number of antennas and employ some simple pre-coding processing or detection technologies at the base station (BS), which significantly reduces user interference, and hence, spectral efficiency (SE), energy efficiency (EE), transmission reliability, and quality of service (QoS) can be significantly improved [16-19].

However, with the greatly increasing number of BS antennas, maybe up to dozens or even hundreds, the design of massive MIMO system brings up the new challenges. Therefore, various potential techniques for massive MIMO system must be well specified before its roll-out [20-23]. Pre-coding also helps to reduce the inter-user interference by focusing the energy on the desired user. Some well-known pre-coding techniques are, Minimum Mean Square Error (MMSE) precoding, Zero Forcing (ZF) precoding, Maximum Ratio Transmission (MRT) precoding, Regularized Zero Forcing (RZF) precoding, Tomlinson-Harashima (TH) precoding, etc. There are different types of research investigated the performance of the pre-coding techniques in Massive MIMO system.

3.5. Linear Pre-coding

Linear pre-coding is a pre-coding method based on the transmitter to compensate for the communication channel's multipath-interfering effect. The BS transmits linear pre-coded information data with the signal vector x using linear pre-coding techniques in the downlink, which is expected for the K usage by [44].

Linear pre-coding is a low-complexity, albeit su-optimal, alternative to DPC. When linear pre-coding is used, the transmit signal vector × is a linear function of the symbols $s_k(\in C^{Nx1})$, k+1,…K;

$$\times \quad \sum_{k=1}^{K} U_k s_k, \tag{3.5}$$

Where $U_k(\in C^{Nx1})$ is the pre-coding matrix for user k. this expression illustrates linear precoding's complexity advantage; If DPC is used, dirty-paper quantities are generated by the transmitting signal, which are complex non-linear operations, while linear pre-coding only includes regular linear operations. A block diagram of linear pre-coding at the BS is shown below.

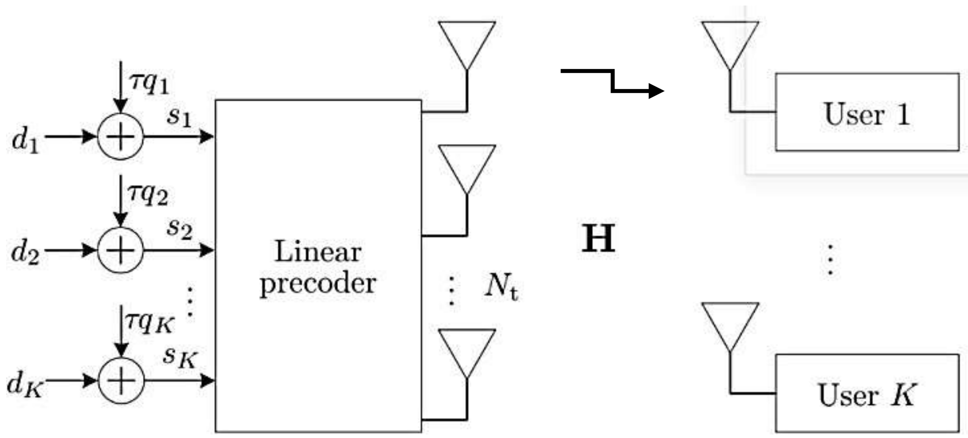

Figure 3. 1:MU-MIMO linear down link pre-coding for single antenna user [45].

The resulting received signal for user k is given by

$$y_k = H_k U_k s_k + \sum_{j \neq k} H_k U_j s_j + n_k, \tag{3.6}$$

Where the second term in eqn. (3.14) represents the multi-user interference. The achievable rate of user k is when single-user identification and Gaussian signaling are used;

$$R_k = I(s_k; y_k) = \log_2 \frac{|I + H_k(\sum_{j=1}^{k} \Sigma j) H_k^H|}{|I + H_k(\sum_{j \neq k} \Sigma j) H_k^H|}, \tag{3.7}$$

Since DPC is not used, any device is subject to multi-user intrusion from the signal of every other user. As a result, in order to avoid multi-user interference, the pre-coding matrices must meet very strict requirements. Notice that in order to avoid interference-limited behavior, avoiding multi-user inference is ideal at high SNR.

In this research work it considers two linear pre-coding schemes that eliminate multi-user interference when $M \geq KN$: zero-forcing (ZF) and block diagonalization (BD). The pre-coding matrices $\{U_j\}_{J=1}^{K}$ for BD are chosen such that for all j(≠k)∈ $[1, K]$,

$$H_k U_j = 0, \tag{3.8}$$

While those for ZF are chosen so that

$$h_k, u_j, l = 0, \forall j (\neq k) \in [1, K], \forall_n, l \in [1, N] \tag{3.9}$$

$$h_k, u_j, l = 0, \forall l (\neq n) \in [1, n], \tag{3.10}$$

Where $u_{j,l}$ denotes the l^{th} column vector of u_j. Consequently, performing ZF in a system with K users with N (1>) antennas as equivalent to performing ZF in a channel with KN single antenna receivers.

3.6. Zero Forcing (ZF) Pre-coding

Thanks to its low complexity nature, ZF pre-coding is a well-known MIMO pre-coding process and ZF pre-coding can be applied without requiring any previous knowledge of noise statistics. With ZF, by projecting each stream to the orthogonal complement of the inter user interference, the multi-user interference is absolutely nullified. ZF approaches *MMSE* when $D_y \rightarrow \infty$. Therefore, P_{ZF} can be expressed as:

$$P_{ZF} = \frac{1}{\alpha} H^* (H^T H^*)^{-1} \tag{3.11}$$

Where $a = \sqrt{\frac{tr(BB^H)}{D_y}}$ B $= H^* (H^T H^*)^{-1}$

$$\mathrm{E}\{\|\sqrt{\eta_k} p_k q_k\|^2\} = \eta_k \tag{3.12}$$

The substitution of (3.20) into (3.3) gives the following received signal vector:

$$y^{ZF} = \frac{1}{\alpha} H^* (H^T H^*)^{-1} q + n \tag{3.13}$$

Let y_k, x_k, and n_k be the k^{th} elements of $K \times 1$ vectors y, x, and n respectively and we define the k^{th} column of P_{ZF} as:

$$P_{ZF} = H^* g_k \tag{3.14}$$

Where g_k is the k^{th} column of $(H^T H^*)^{-1}$.

$$y_k^{ZF} = \frac{1}{\alpha} h_k H^{T*} g_k q_k + \frac{1}{\alpha} \sum_{i=1,1\neq k}^{k} h_k H^{T*} g_i q_i + n_k \tag{3.15}$$

The resulting capacity is

$$C_{inst.,k}^{zf,dl} = E[\log_2(1 + SINR_k^{zf,dl})] \quad (3.16)$$

Equation (3.24) expresses the received signal in terms of a deterministic gain $\sqrt{\rho_{dl}\gamma_k\eta_k}$ multiplied by the symbol of interest, q_k , plus uncorrelated effective noise.

Where the effective SINR is given by

$$SINR_k^{zf,dl} = \frac{\frac{1}{\alpha^2}|h_k^T H^* g_k|^2}{\frac{1}{\alpha^2}\sum_{i=1,i\neq k}^{k} |h_k^T H^* g_i|^2 + 1} \quad (3.17)$$

Block diagonalization: when BD is employed, there is no multi-user interference because the pre-coding matrix for BD is chosen to be $H_k U_j = 0$ for k ≠j. Then the received signal for user k is given by

$$y_k = H_k U_{ks_k} + n_k. \quad (3.18)$$

Thus, BD converts the system into K parallel MIMO channels with effective channels with effective channel matrices $G_k = H_k U_k$, k=1 …, K the BD sum rate is given by.

$$C_{BD}(H, P) = \max_{Q_k : \sum_{k=1}^{K} tr\{Q_k\} \leq P} \sum_{k=1}^{K} \log_2 |I + G_k Q_k G_k^H|, \quad (3.19)$$

And the optimal rate is achieved asymptotically by uniform power allocation at high SNR since the channel can be decomposed into parallel channels. Hence, the sum rate is asymptotically given by

$$C_{BD}(H, P) \cong \text{KN} \log_2 P - \text{KN} \log_2 KN + \log_2 \prod_{k=1}^{K} |G_k^H G_k|, \quad (3.20)$$

3.7. Non-linear pre coding

Designed based on the concept of dirty paper coding (DPC), which shows that any known interference at the transmitter can be subtracted without the penalty of radio resources if the optimal **precoding** scheme can be applied on the transmit signal.

3.8. Dirty Paper Coding

Dirty paper coding (DPC) is a technique for pre-coding which involves pre-cancellation of interference in the transmitter. Costa added DPC [36]. While contemplating an AWGN channel with additive interference understood non-causally at the transmitter but not at the receptor. DPC was introduced to the MIMO broadcast channel, where it can be used for multi-user interference pre-cancellation by Caire and Shamai, and was shown to reach the sum power of 2 users, M > 1, N = 1 MIMO broadcast channel [37]. The optimality of the DPC was eventually increased to include the sum of MIMO transmitted channel bandwidth with an arbitrary number of users and antennas [38-40] and, more recently, the full capacity area [41]. The following figure displays a block diagram of non-linear pre-coding at BS.

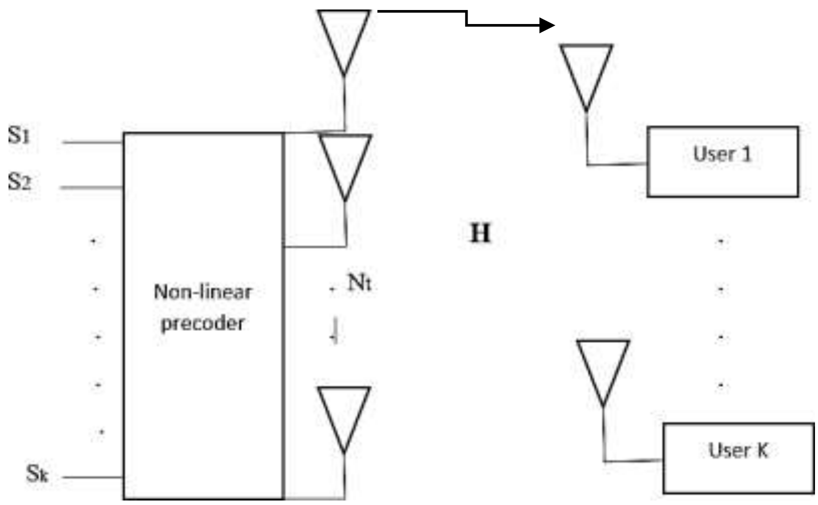

Figure 3. 2: MU-MIMO non-linear down link pre-coding for single antenna user [42].

As DPC is used, we now describe the transmitting signal let sk(CNx1) be the vector of the N-dimensional data symbol intended for consumer k and its pre-coding matrix is Uk(CNx1). The transmission signal vector x can then be represented (roughly) as

$$x = U1s1(U2s2 \oplus \cdot \cdot \cdot \cdot \cdot \oplus(Uk\text{-}2sk\text{-}2(Uk\text{-}1sk\text{-}1 \oplus Uksk))) \qquad (3.21)$$

Where ⊕ represents the amount of non-linear dirty paper. Here, without loss of generality, we have assumed that the encoding process is carried out in a numerical order that is descending. Dirty-paper encoding in other fading conditions at the k-th DPC-linear pre-coding offset, such as Ricean and spatially correlated fading However, since certain point-to-point MIMO models do not generally extend well to the MIMO broadcast channel, one must be cautious about channel models. For eg, spatial correlation in point-to-point channels catches the effect of sparse dispersion on the transmitter and/or receiver and is a function of the arrival-angel. The angle-of-arrival is usually different for each receiver in a broadcast channel since they are normally not geographically co-located; as a result, for all receivers, using the same correlation matrix. Receiver results in cancellation of $U_{k+1}s_{k+1},\ldots,U_k s_k$, and thus the effective received signal as user k is:

$$\tilde{y}_k = H_k U_k s_k + \sum_{j=1}^{k-1} H_k U_j s_j + n_k, \tag{3.22}$$

The multi-user interference that is not cancelled by the DPC is the second term. If the s_k are chosen Gaussian, user k's rate is given by:

$$R_k = \log \frac{|I + H_k(\sum_{j=1}^{k} \Sigma_j) H_k^H|}{|I + H_k(\sum_{j=1}^{k-1} \Sigma_j) H_k^H|} \tag{3.23}$$

Where $\Sigma_j = U_j E[s_j s_j^H] U_j^H$ denotes the transmit covariance matrix of user j. Since DPC is optima, the sum capacity of the MIMO BC can be expressed as:

$$C_{DPC}(\text{H,P}) = \max_{\sum_k tr(\Sigma_k) \leq P} \sum_{k=1}^{k} \log \frac{|I + H_k(\sum_{j=1}^{k} \Sigma_j) H_k^H|}{|I + H_k(\sum_{j=1}^{k-1} \Sigma_j) H_k^H|} \tag{3.24}$$

Where the maximization is performed over the transmit covariance matrices $\Sigma_1, \Sigma_2, .., \Sigma_k$. The MIMO broadcast channel and MIMO multiple access channel (MAC) duality causes the sum power to be written as[38] alternatively.

$$C_{DPC}(\text{H,P}) = \max_{\sum_k tr(Q_k) \leq P} \log_2 |I + \sum_{k=1}^{K} H_k^H Q_k H_k|, \tag{3.25}$$

Where Q_k represent the NxX transmit covariance matrices in the dual MAC.

No closed-form solution to either (which is a convex problem) is known to exist, but it has been shown that C_{DPC}(H,P) converges (absolutely) to the capacity of the point-to-point MIMO channel with transfer matrix H whenever $M \geq KN$: when $M \geq KN$ and H has full row rank,

$$\lim_{P \to \infty} [C_{DPC}(\text{H, P}) - \log_2 |I + \frac{P}{KN} H^H H|] = 0 \tag{3.26}$$

At high SNR, we are now able to make a few significant assumptions about the optimal covariance matrices. Since

$$\log_2 |I + \frac{P}{KN} \sum_{k=1}^{K} H_k^H H_k| = \log_2 |I + \frac{P}{KN} H^H H| \tag{3.27}$$

Choosing each of the dual MAC covariance matrices as $Q_k = \frac{P}{KN} I$ in (3.9) achieves sum capacity at asymptotically high SNR. Thus, uniform power distribution in the dual MAC is asymptotically optimal through the KxN antennas. It is also possible to determine the optimal form of the downlink covariance matrices $\Sigma_1, \ldots, \Sigma_k$ or equivalently of the downlink pre-coding matrices $U_1, \ldots, U_k$. When $N = 1$, Zero-forcing DPC asymptotically archives sum capacity. Zero-forcing DPC, which is implemented via the QR-decomposition of the concatenated channel matric H in [37], implies that the pre-coding matrices $U_1, \ldots, U_k$ are chosen to completely eliminate multi-user interference terms, U_1 has no constraint on it, U_2 must be orthogonal to H_1, U_3, must be orthogonal to H_1, and H_2, and so forth. If multi-user interference is eliminated, the machine decouples into K parallel channels and is asymptotically efficient simply by using equal power distribution over all channels due to the well-known assumption that water loading over parallel channels at high SNR gives little benefit. As a result, the affine approximation for the sum rate can be found as.

$$C_{DPC}(\mathrm{H}, \mathrm{P}) \cong \mathrm{KN} \log_2 P - KN \log_2 KN + \log_2 |HH^H|, \quad (3.28)$$

Where ≅ refers to equivalence in the limit (i.e., the difference between both sides converges to zero as P → ∞). Since the MIMO broadcast and the $M \times KN$ point-to-point MIMO channel are equivalent at high SNR, the high SNR results developed in [43] directly apply to the sum capacity of the MIMO broadcast channel. Due to the presumption that $M \times KN$, the MIMO transmission is equal to the $M \times KN$ MIMO channel with CSI at the transmitter, which is equivalent to the $KN \times M$ MIMO channel with or without CSI at the transmitter, it is important to be cautious about ordering the equivalent point-to-point MIMO channel. The CSI level at the transmitter determines the rate offset of the $M \times KN$ point-to-point MIMO channel when $M \times KN$ is used. Finally, note that the high potential of the SNR sum rate only depends on the K and N product and not on its unique values; this is not the case for linear precoding.

3.9. Digital Modulation techniques

the digital modulation provides high information capacity and quicker system availability with great quality communication, that's why, the applications of various digital modulation techniques continue to grow, with the growth and evolvement of the digital communications industry. In recent times, the growth of multimedia facilities for mobile wireless communication has contributed to a great advancement in the field of wireless communication. Digital modulation technology is one of the commonly used techniques that enables digitized data to be transmitted or transmitted through analog radio frequency (RF) channels. For uninterruptible communication, the data transmission rate should be maximal. But with high rates, the risk of error is higher.

Modern modulation techniques exploit the fact that digital baseband data can be transmitted by varying both the envelope and the phase/frequency of a carrier wave. Since two degrees of freedom are provided by the envelope and the phase, such modulation techniques map baseband data into four or more possible carrier signals in [46]. For transmission over the channel, digital modulation consists of mapping the information bits into an analog signal. These bits of information are extracted from the source of the information, which may be a digital source or an analog source passed through an A/D converter. To obtain the data bit sequences, both digital and A/D converted analog sources can be compressed.

Mathematical formula for capacity for this modulation techniques are given by

$$Capacity = B\log_2\left(1 + \frac{L * SNR * HH'}{M}\right) \dots\dots\dots\dots\dots\dots\dots\dots (3.29)$$

$L = \log_2 m$, where m is array of modulation and L is number of bits.

CHAPTER 4

RESULTS AND ANALYSIS

This chapter will present the simulation results for downlink massive MIMO system. It is observed that the performance analysis simulation for different cases such as,

Case 1. Change in capacity with the increase of the number of users.
Case 2. Change in capacity with the increase of the SINR lastly.
Case 3. Change in capacity with the increase of a number of base station antenna.

The simulation algorithm analysis is done step by step in the flow chart shown in Figure 4.1.

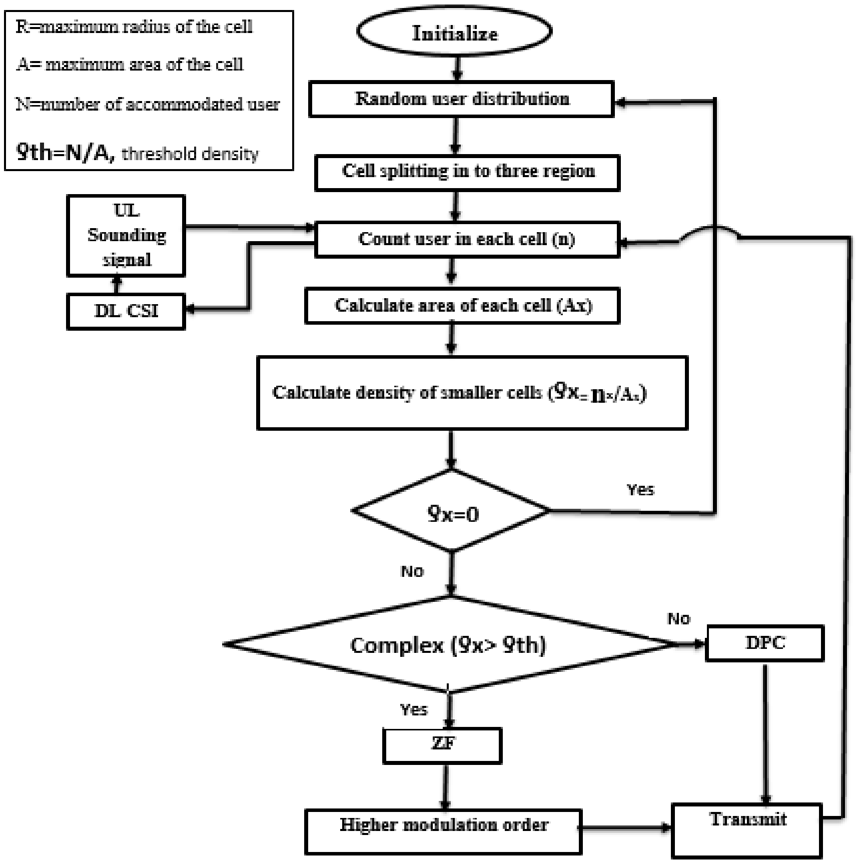

Figure 4. 1: Flow chart of system design

However, the limitation of models is that the number of users K is not greater than the number of antennas. All results are shown in terms of,

- The Sum rate versus the number of antenna arrays.
- The Sum rate versus the number of users.
- The capacity versus Signal-to-Interference Ratio (SINR).
- The capacity versus number of users.

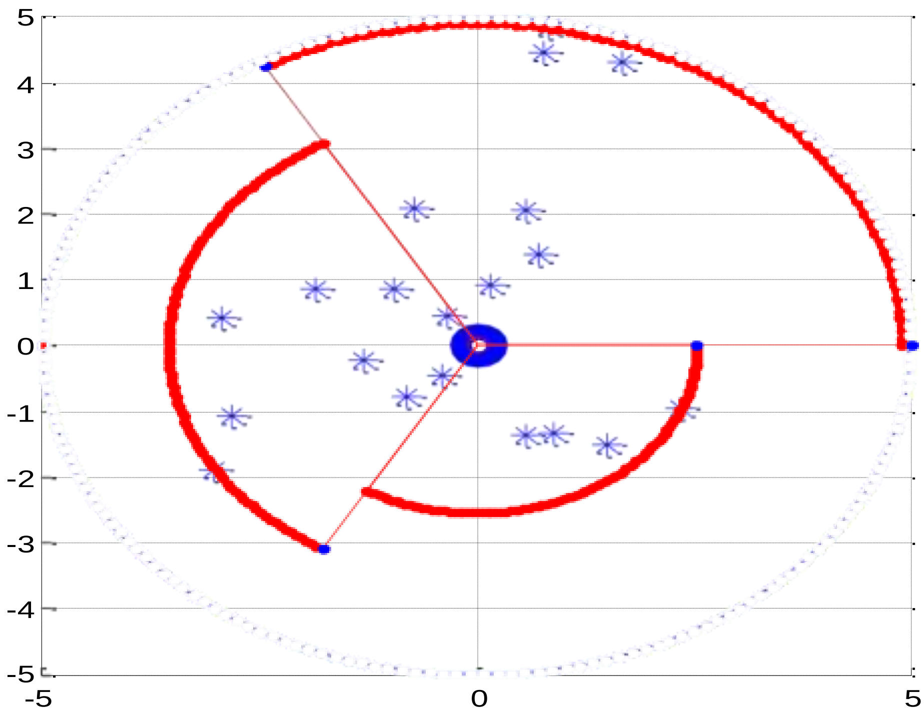

Figure 4. 2: Adaptive Sectorization of system design.

From system design Figure 4.1 by using directional antennas on a base station, each pointing in different directions, it is possible to sectorize the base station so that several different cells are served from the same location. One way to increase to subscriber capacity(b/s/Hz) of a cellular network is replacing the omni-directional antenna at each base station by sector antennas of 120 opening. Each sector can be considered as a new cell, with its own (set of) frequency channel(s). The base station can either be located at

- The center of the original (large) cell, or
- The corners of the original (large) cell.

The use of directional sector antennas substantially reduces the interference among co channel cells. This allows denser frequency reuse.

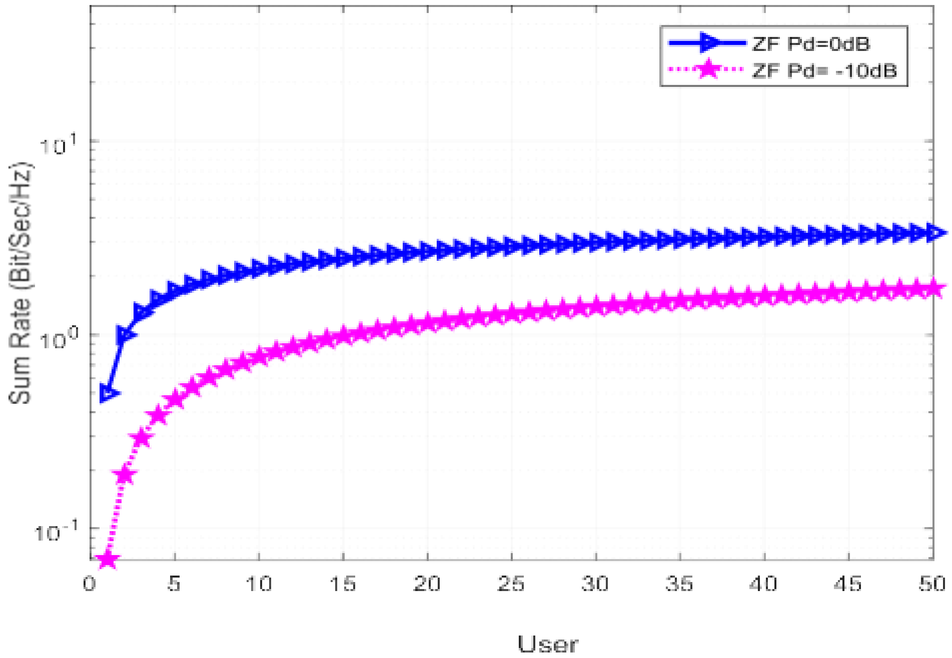

Figure 4. 3:Sum-Rate Vs user when Zero-forcing power is 0dB and -10dB.

At the given transmit power of (Pd=0 dB and Pd= -10 dB) the user range of K increases from (K= 0 to K=50) the sum rate of the zero forcing with high transmit power is always better than that of low transmit power. Compared to the unidirectional and sectorization that have no precoding, the simulation result work shows, ZF with precoding, for the given transmit power, have the better capacity and the number of a user high enough.

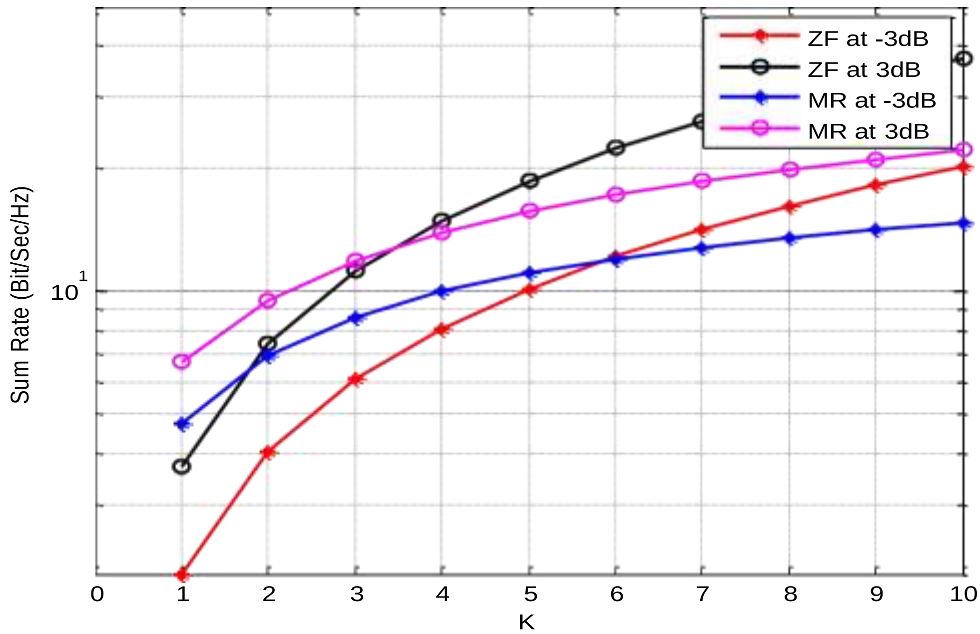

Figure 4. 4: Zero-Forcing (ZF) and Maximum Ratio (MR) at -3dB and 3dB.

Figure 4.4 indicates that the sum rate of a single cell of massive MIMO as a function of the number of active users in the cell into two case.

Case 1 when the power is low (ZF= -3dB and MR= -3dB). A user (k=1) the maximum ratio (MR)) attains the highest sum-rate than zero forcing instantly zero forcing shows the better sum rate than MR when the user is (K>6).

Case 2 At the same time, when the given power is high (ZF=3dB and MR=3dB) maximum ratio perform the better sum-rate than zero forcing but zero-forcing attain the highest Rate when the user is greater than three(K>3).

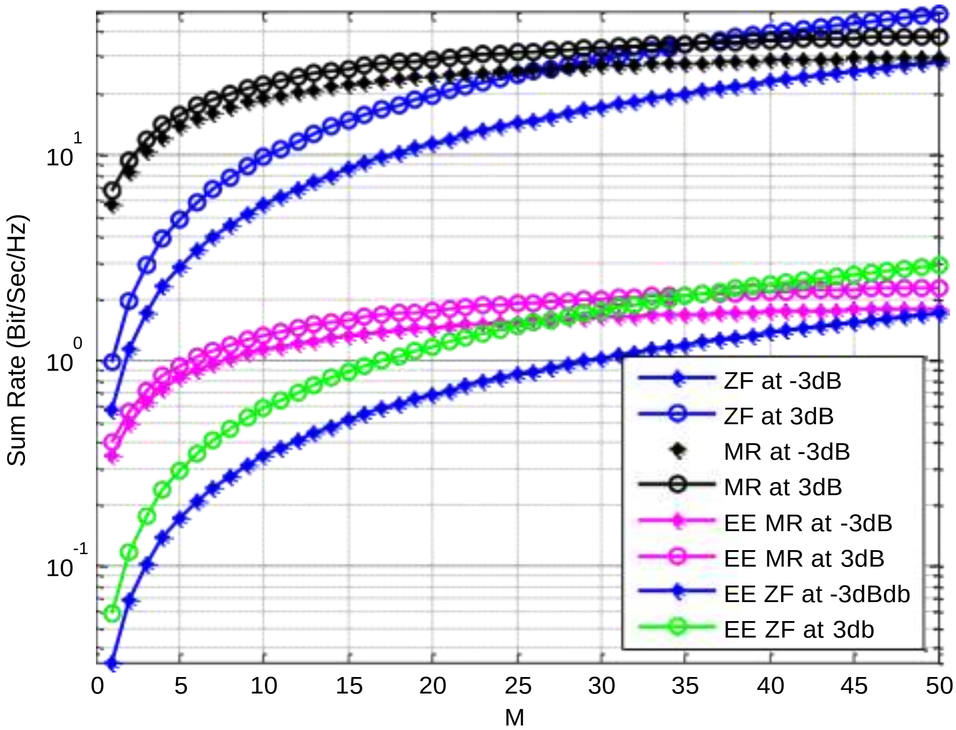

Figure 4. 5: The relationship between capacity of zero-forcing (ZF) and maximum ratio (MR) at power of -3dB and 3dB in Sum rate Versus user.

In this Figure 4.5 at the given transmit power of (Pt= -3dB and Pt= 3dB) the zero forcing and maximum ratio can be compared with themselves at highest transmit power and lower transmit power the capacity of higher transmit power perform well. in addition to this the energy efficiency of higher transmit power of zero forcing and maximum ratio can attain the upper capacity as the number of antennas increases from (M=0 to M=50).

Figure 4. 6:The relationship between energy efficiency of zero-forcing (ZF), match filter (MF) and maximum ratio (MR) at power of -3dB and 3dB in Sum rate Vs user.

The same result can be seen from Figure 4.5 in this Figure 4.6 at the transmit power of (-3dB and 3dB) that means at higher and lower transmit power the comparison between match filter, zero forcing and maximum ratio within itself at the normal condition and by applying energy efficiency the capacity can be always better at higher transmit power as the number of antennas increase from (M=0 to M=100).

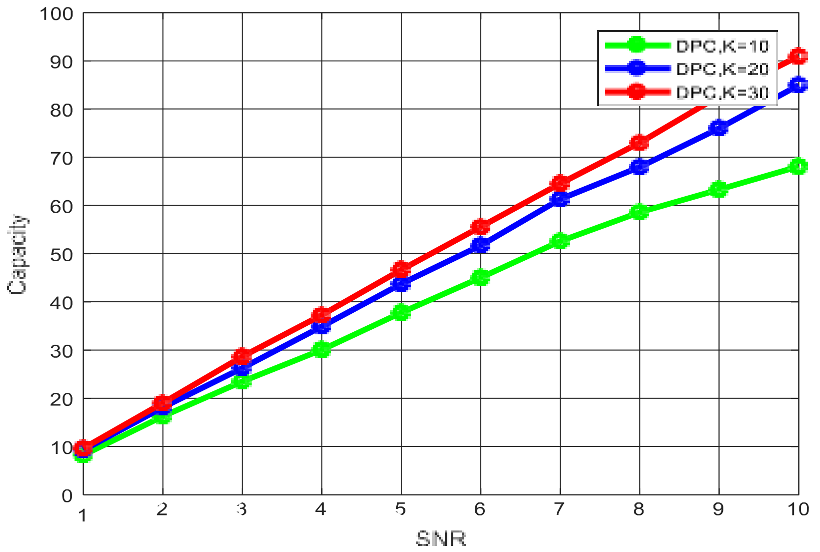

Figure 4. 7:Capacity Vs signal to noise ratio (SNR) in dirty paper coding when user (K=10, K=20, K=30).

One of the conventional solutions to increase the system capacity is cell densification hence Massive MIMO system can be used as another network solution to increase the overall system capacity.

Massive MIMO can provide a good capacity even at low SNR starting from very low SNR below 0dB there is a small improvement as the SNR increases.

From this Figure it seen that the capacity of dirty paper coding with different value of user it continuously increases through different point of SNR because the capacity of dirty paper coding is directly proportional to that of SNR.

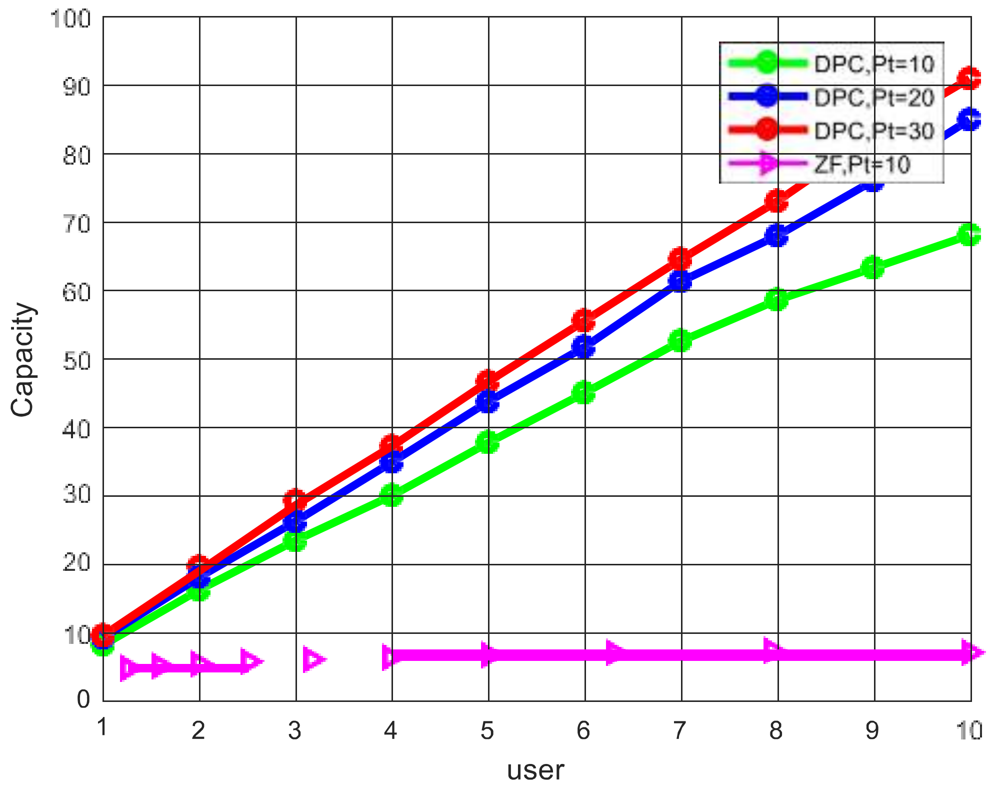

Figure 4. 8: Comparation of Dirty paper coding (DPC) and Zero forcing at transmit powerof Pt=10dB, Pt=10dB, Pt=20dB, Pt=30dB through capacity Vs User.

The capacity of zero forcing is decreased from that of dirty paper coding when the transmit power of Pt=10dB because it suppressed the inter user interference to zero when the user increases from the initial point to final that is (K=1 to K= 10) the zero forcing does not change stay as it is but the dirty paper coding can show variation from each other when the transmit power of (Pt=20dB) it shows better capacity than that of zero forcing but poor capacity than that of DPC when (Pt=30dB).

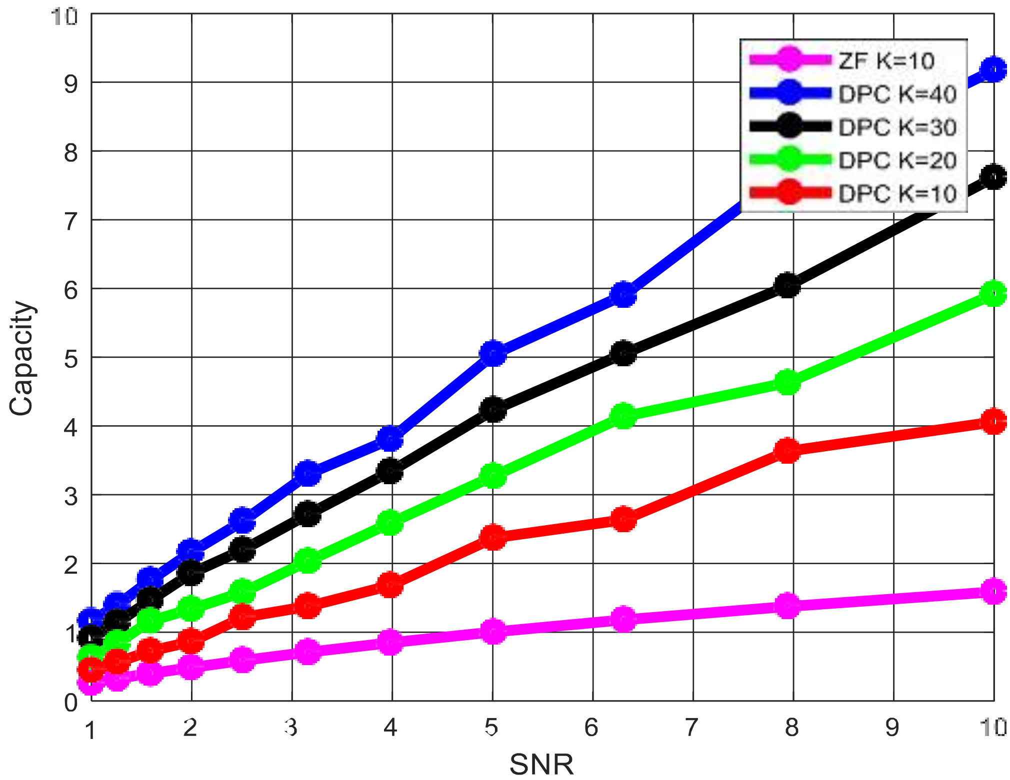

Figure 4. 9: Adaptive comparation of Zero forcing and Dirty paper coding when User(k=10, K=20, K=30, K=40) through Capacity versus SNR.

In Figure 4.7 it seen that the capacity of dirty paper coding with different point of user in the sector it continuously increases through different point of SNR. In Figure 4.8 when it compared dirty paper coding with zero forcing with different transmit power it seen within the system design Figure 4.1 the base station has low complexity so it chose dirty paper coding the zero forcing interference are often suppressed by dirty paper coding and it give best capacity than that of zero forcing within the sector so dirty paper coding can attain the upper capacity than that of zero forcing then it is often transmit the signal.

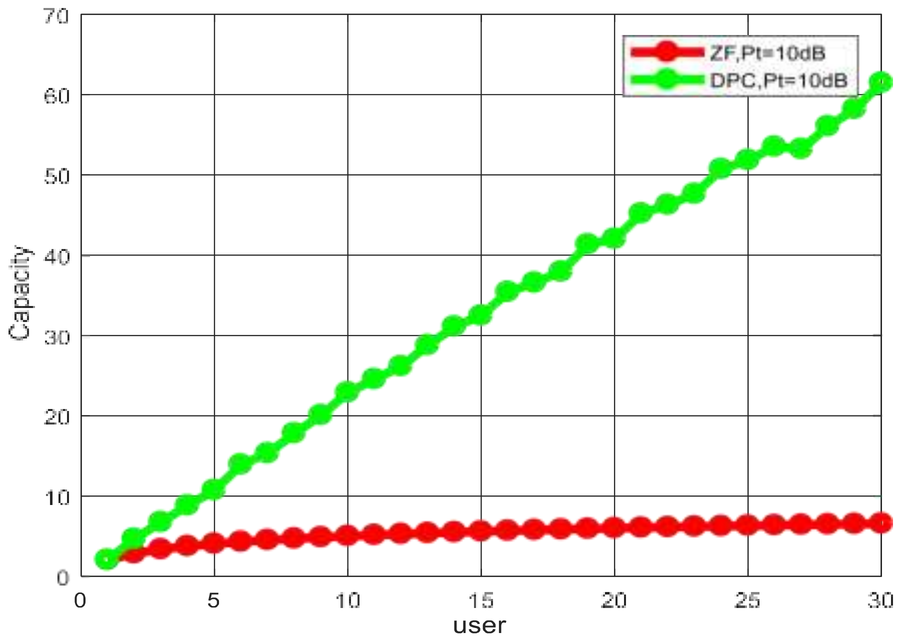

Figure 4. 10: Adaptive comparation of Zero forcing and Dirty paper coding throughCapacity versus User.

From Figure 4.8, the capacity of dirty paper coding is best performed than that of zero forcing with different transmit power during this system design Figure 4.1 it shows that the users are counted within the sector if its density is different from zero the system check the complexity when it checks the complexity it assigns the precoder that's linear or nonlinear during this case the system chose the low complexity precoders that's DPC then the system are often transmit the signal. From this we conclude that when the user increases from (K=0 to K=30) DPC have better capacity than that of ZF. particular number of users with(16QAM).

Table 4. 1 Performance comparison of power level at 10dB.

Number of User, K	Capacity(b/s/Hz)	
	ZF	DPC
5	5	10
10	5	22
15	6	32
20	7	42

The graphical comparation of zeroforcing and dirty paper coding can be shown in Figure 4.11 bellow. The capacity of DPC can give higher performance than ZF.

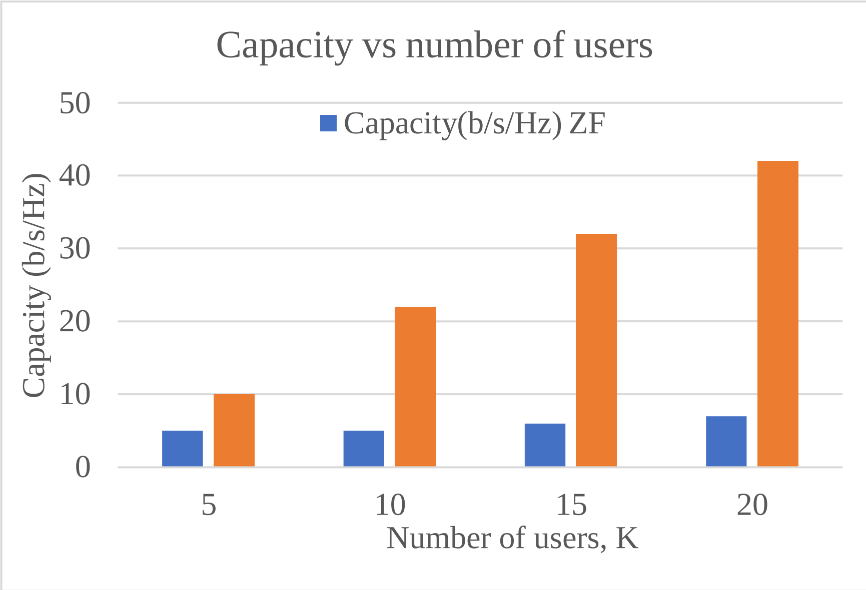

Figure 4. 11: Performance comparison of power level at 10dB

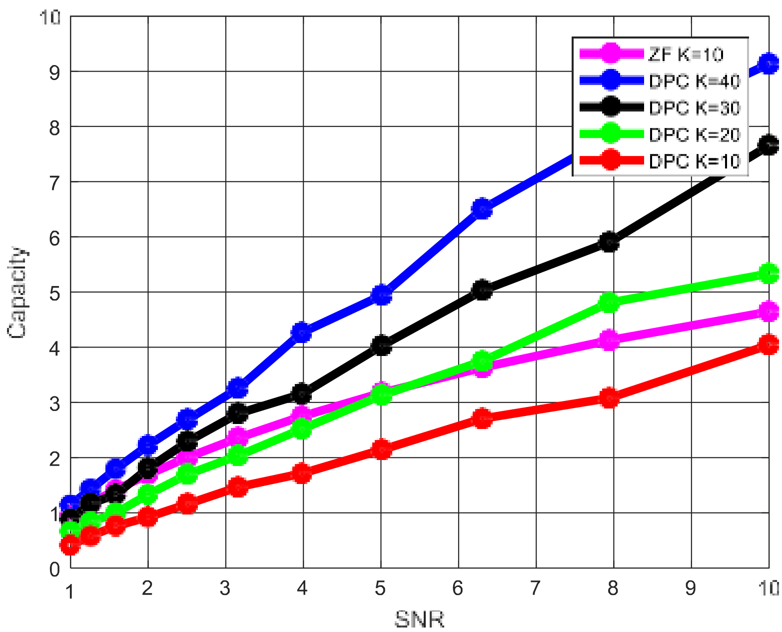

Figure 4. 12: The adaptivity of zero forcing and dirty paper coding through capacity versus SNR by using modulation scheme(4QAM).

In the system design Figure 4.1 the system can count the users in the sector and its density different from zero, then it can check the complexity, in this case the system has complex so the system design can assign zero-forcing to transmit the signal but it's difficult to transmit so, higher modulation order can be applied on it.

The simulation result shows that When higher modulation order applied on zero forcing, in this case Quadrature amplitude modulation (4QAM), and by increasing SNR somewhat it improves the capacity of zero-forcing to the middle from that DPC as shown in Figure 4.12.in addition to this when the modulation order increases to 16QAM the zero forcing dominates that of dirty paper coding with the given value of different users as shown in Figure 4.13 bellow.

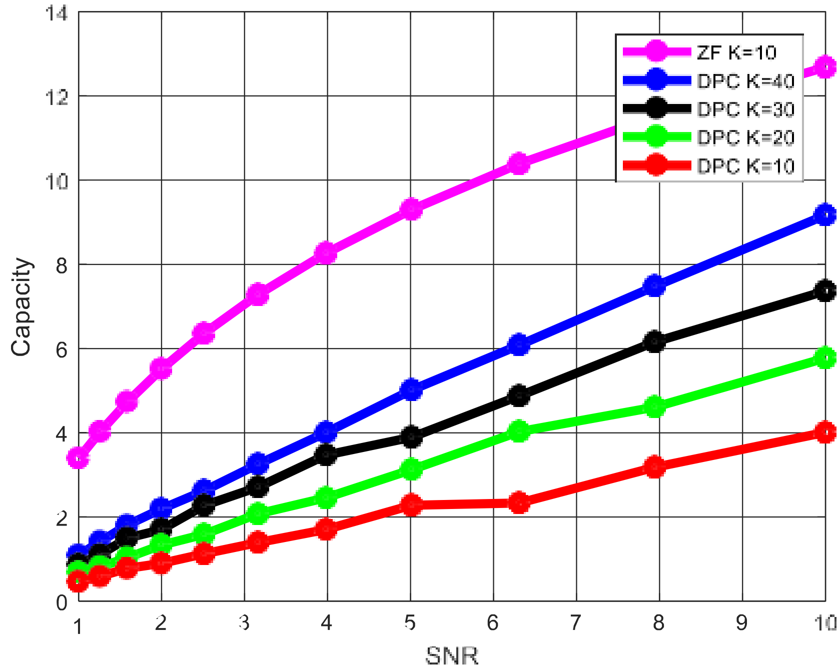

Figure 4. 13: The adaptivity of zero forcing and dirty paper coding through capacity versus SNR by using modulation scheme(16QAM).

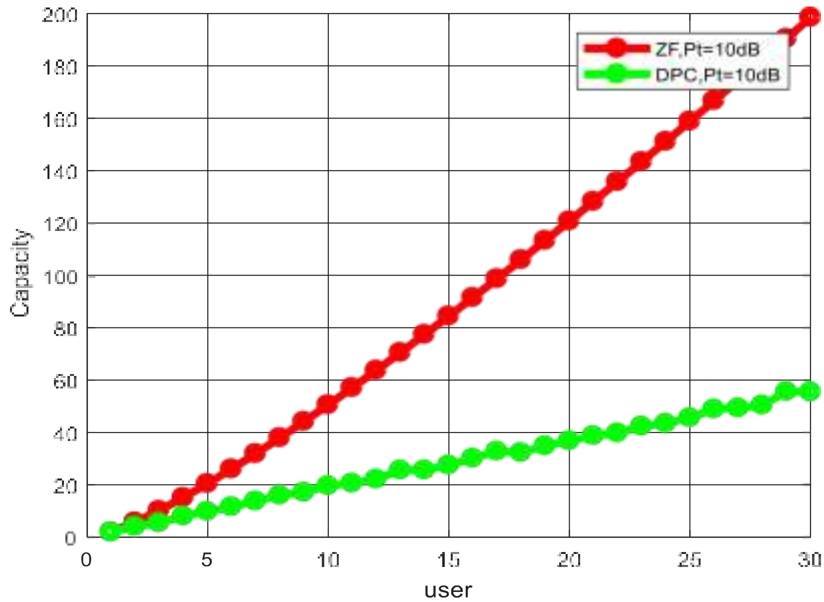

Figure 4. 14: The adaptivity of zero forcing and dirty paper coding through capacity versus user by using modulation scheme (4QAM).

As number of users(K=20) increasing for a particular power level(10dB), for both ZF and DPC the capacity(b/s/Hz) is increasing but the performance of DPC is lower than ZF for a particular number of users with (4QAM).

Figure 4. 15: The adaptivity of zero forcing and dirty paper coding through capacity versus user by using modulation scheme(16QAM).

As number of users(K=20) increasing for a particular power level(10dB), for both ZF and DPC the capacity(b/s/Hz) is increasing but the performance of DPC is lower than ZF for a particular number of users with(16QAM)

Table 4. 2: Performance comparison of ZF and DPC with 4QAM and power level at 10dB.

Number of User,	Capacity(b/s/Hz)	
K	ZF	DPC
5	10	12
10	20	18
15	40	30
20	60	38

The graphical comparation of zero forcing and dirty paper coding can be shown in Figure 4.16 bellow. When higher modulation scheme (4QAM) is applied, the capacity of ZF can give higher performance than DPC.

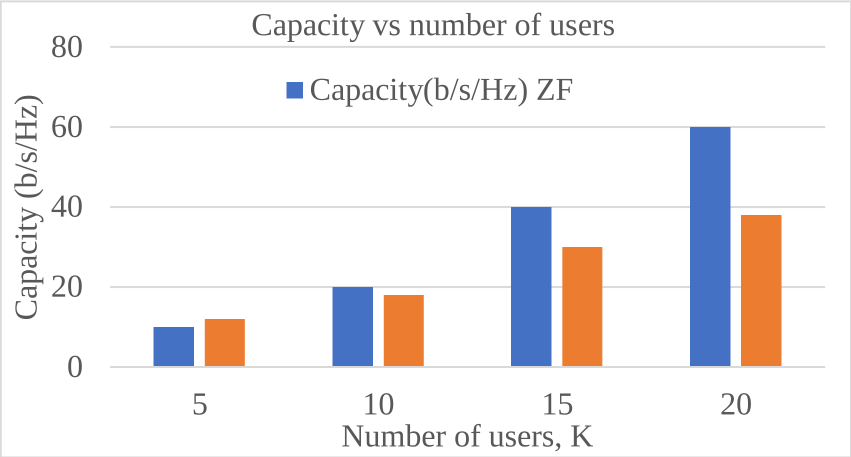

Figure 4. 16: Performance comparison of ZF and DPC with 4QAM and power level at 10dB.

Table 4. 3: Performance comparison of ZF and DPC with 16QAM and power level at 10dB.

Number of User, K	Capacity(b/s/Hz) ZF	DPC
5	20	10
10	50	20
15	80	30
20	120	40

The graphical comparation of zero forcing and dirty paper coding can be shown in Figure 4.17 bellow. When higher modulation scheme (16QAM) is applied, the capacity of ZF can give higher performance than DPC.

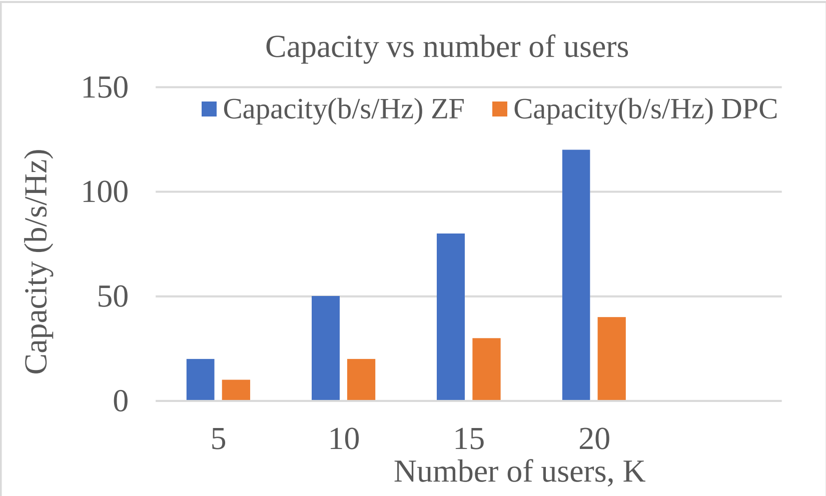

Figure 4. 17: Performance comparison of ZF and DPC with 16QAM and power level at 10dB.

Comparing the result shown in Table 4.1 and Table 4.2 by increasing the number of symbols of QAM, 16QAM modulation performance is better for both ZF and DPC but the ZF has better performance than DPC. This shows the speed of communication can be improved by ZF precoding.

CHAPTER 5

CONCLUSION AND FUTURE WORK

5.1. Conclusion

A massive MIMO device offers the ability to concurrently maximize spectral efficiency (in terms of bits/s/Hz) and boost energy efficiency (in terms of bits/J). This system is able to use basic processing at the base station, such as ZF and DPC, and use uplink channel estimation. In this thesis, analysis and evaluation of linear pre-coding and nonlinear pre-coding for massive MIMO has been done.

For efficiency, the number of BS antennas is crucial. Conversely, due to user interference, the amount of terminal antennas degrades efficiency. The mathematical complexity of SINR grows as the number of terminals increases. It can be seen that at a high number of terminals, ZF gives lower complexity, while DPC gives greater complexity. At high transmission power, ZF gives better output, while DPC gives better performance at low transmission power. However, at a higher modulation order than DPC, ZF provides the best results. Apart from large MU-MIMO will use basic processing, the propagation environment does not have much effect on the performance of the device. Therefore, a massive MIMO system is a key in next wireless system. It presents advantages in terms of the Sum rate and capacity.

5.2. Recommendations for Future Work

Here is the list of recommendations to the possible extensions of the works of this thesis research:

- Massive pre-coding MIMO structures built in this study consider only a pre-coding scheme. One broadband network of one single cell. These schemes can be expanded by further work for a device (i.e. expanding it to broader networks) with more than two cells that The quality of spectrum use should be increased.
- The massive MIMO system with linear and nonlinear pre-coding increases the output with distinct parameters when the number of antennas has been increased with a realistic channel model without interference such as the Nakagamim fading channel.

- Upon downlink transmission, linear and nonlinear pre-coding is assumed. The hybridization of elements that occur in linear and nonlinear transmission beamforming, which is a key to improved spectral and energy performance in very large antenna arrays, is therefore beneficial to research and coordinate.
- In this work, linear and nonlinear pre-coding can be achieved, but by using CSI to solve the signal recovery in the uplink is the future work.
- In this work, an orthogonal transmitting approach was considered that could influence the efficiency of spectrum utilization; working with non-orthogonal would be considered in the future work.

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Appendix

Appendix of first fig 0db and -10db

```
close all;
clear all;
M=600;%number of base station antennas
K=0.5;%number of users

rr=0:1:M;%Range of number of antennas from 0 to 600 for plotting
ss=K
Pd_dB = -0;
Pd1_dB = -10;
pd2_db = -20;
pd3_db = -30;
Pd = 10^(Pd_dB/10);
Pd1 = 10^(Pd1_dB/10);

figure;
P1=semilogy(rr,Rsum_zf,'b->','LineWidth',2);
hold on;
P2=semilogy(rr,Rsum_zf1,'m:p','LineWidth',2);
P3=semilogy(rr,Rsum_zf1,'m:p','LineWidth',2);
P2=semilogy(rr,Rsum_zf1,'m:p','LineWidth',2);
%  P3=semilogy(rr,Rsum_MF,'r:d','LineWidth',2);
% P4=semilogy(rr,Rsum_MF1,'g:*','LineWidth',2);
grid on
xlabel('User');
ylabel('Sum Rate (Bit/Sec/Hz)');
% sTitle = sprintf('Performance ZF by using matrix normalization at Pd=0db and -10dB');
% title(sTitle);
leg1='ZF Pd=0dB';
leg2='ZF Pd= -10dB';
leg3='ZF Pd= -10dB';
 leg3='MF at 0dB';
leg4='MF at -10dB';
legend(leg1,leg2);
axis([0,50,0,50]);




clc;
clear all;
```

```
close all;
NT=30;NR=20
u1=5;
u2=10;
u3=15;
% Number of transmit/receive antennas
sel_ant=NT;
I=eye(NR,NR);
I1=eye(u1,u1);
I2=eye(u2,u2);
I3=eye(u3,u3);
sq2=sqrt(NT);
SNRdBs = [1 10];

for i_SNR=1:length(SNRdBs)
SNRdB = SNRdBs(i_SNR);
SNR_NT = 10^(SNRdB/10)*NT;
end
H = (randn(NR,NT)+j*randn(NR,NT))/sq2;
H1  =  (randn(u1,NT)+j*randn(u1,NT))/sq2;
H2=   (randn(u2,NT)+j*randn(u2,NT))/sq2;
H3= (randn(u3,NT)+j*randn(u3,NT))/sq2;

 SNR_linear=10.^(SNRdBs/10);
DPC_Capacity(i_SNR) = real(log2(det(I+H*diag(SNR_NT)*H')))
 DPC_Cap=DPC_Capacity';
 DPC1_Capacity(i_SNR) = real(log2(det(I1+H1*diag(SNR_NT)*H1')))
 DPC1_Cap=DPC1_Capacity';
 DPC2_Capacity(i_SNR) = real(log2(det(I2+H2*diag(SNR_NT)*H2')))
 DPC2_Cap=DPC2_Capacity';
 DPC3_Capacity(i_SNR) = real(log2(det(I3+H3*diag(SNR_NT)*H3')))
 DPC3_Cap=DPC3_Capacity';
 user=1:1:10;
    Cap=[8.24
       16.30
       23.52
       30.07
       37.79
       45.06
       52.61
       58.61
       63.31
       68.10]
   Cap2=[9.28
        18.14
         26.31
         34.93
         43.77
         51.73
         61.33
```

```
        67.99
        76.04
        84.97]
    Cap3=[9.63
         19.04
          28.66
          37.26
          46.67
          55.56
          64.54
          73.02
          82.69
          90.95]

 figure (1)
  plot(user,Cap,'-go','linewidth',3); hold on
  plot(user,Cap2,'-bo','linewidth',3); hold on
  plot(user,Cap3,'-ro','linewidth',3); hold on
  xlabel('SNR'); ylabel('Capacity');grid on;
  legend('K=10','K=20','K=30')
  grid on
  legend('Pt=5','Pt=10','Pt=15')
```

Sectorization of cell

```
clc;
clear all;
close all;
R = 5;% radius of largest base station
M =100000; %// points on boundary and asuming only two kilometers coverage
NT=100;
N=20;
Pmax=10;
pt=Pmax/3;

%n=360/30;%number of sector using z reference angle
C = [0 0];

t  = linspace(0, 2*pi, M)';

 % th=360*rand(N,1);
th  =2*pi*rand(N,1);

r  = R*rand(N,1);

xR = [R*ones(M,1); r] .* cos([t; th]) + C(1);
yR = [R*ones(M,1); r] .* sin([t; th]) + C(2);
   %H1 = (randn(N,NT)+j*randn(N,NT))/sq2;
 th=sort(th,1,'ascend');
 th=roundn(th,-1);
```

```
k=1;i=1;
    rr(k,1)=th(i);

    rr(k,2)=1;
    for j=i+1:length(th)
        if rr(k,1)==th(j)

            rr(k,2)=rr(k,2)+1;
            j=j+1;

        else
            k=k+1;
            rr(k,1)=th(j);
            rr(k,2)=1;
            j=j+1;

        end
        i=j+1;
    end
 rr % number of users at some position
 A1=(pi*(R^2))/3;% area of 3 reference sectors
 TotalArea=(pi*(R^2)); % total area of the cell
 Roh=N/TotalArea; %threshold density
 den=Roh/3% Threshold density for a single sector

 %thU=Roh;
pt1=0;
pt2=0;
pt3=0;
u1=0;   uu1=0;
u2=0;   uu2=0;
u3=0;  uu3=0;
corner1=(2*pi)/3;%120 degree
corner2=(2*pi)/1.5;%240
corner3=2*pi;%360 degree
for i=length(rr):-1:1
     u1=u1+rr(i,2);%Add the second dim array value

     if rr(i,1)<0
         u1=u1-rr(i,2);
%          p1=6;
          break;

     end
end

  for i=length(rr):-1:1
     uu1=uu1+rr(i,2);
     if rr(i,1)<corner1
```

```
            uu1=uu1-rr(i,2);
            break;
    end
  end

  for i=length(rr):-1:1
    u2=u2+rr(i,2);%Add the second dim array value

    if rr(i,1)<corner1
        u2=u2-rr(i,2);
        break;
    end
  end

  for i=length(rr):-1:1
    uu2=uu2+rr(i,2);
    if rr(i,1)<corner2
            uu2=uu2-rr(i,2);
            break;
    end
  end

  for i=length(rr):-1:1
    u3=u3+rr(i,2);%Add the second dim array value

    if rr(i,1)<corner2
        u3=u3-rr(i,2);
        break;
    end
  end
  for i=length(rr):-1:1
    uu3=uu3+rr(i,2);
    if rr(i,1)<corner3
            uu3=uu3-rr(i,2);
            break;
    end
  end

  NU1 = u1-uu1; % number of users at first sector
NU1

NU2=u2-uu2;
NU2
NU3=u3-uu3;
NU3
%Max of a sector
Rmax=[0 0 0];
for i=1:1:N
   if th(i)<=2.094
       if r(i)>Rmax(1)
```

```
            Rmax(1)=r(i);
        end
    else
        if th(i)<=4.188
            if r(i)>Rmax(2)
                Rmax(2)=r(i);
            end
        else
            if th(i)<=6.283
                if r(i)>Rmax(3)
                     Rmax(3)=r(i);
%                      PL=247.41+35.22*log(Rmax(3)); % Maximum pathloss using Ukumura
Hatta model
% pr_min=pt/PL % minimum Received power cheived throug maximum pathloss and
transmit power
% PLx=247.41+35.22*log(r);% Pathloss of each user
% ptx3=PLx*pr_min
                end
%
            end
        end
    end
end

Rmax
% sq2=sqrt(NT)
% H = (randn(N,NT)+j*randn(N,NT))/sq2;
% DPC=1;
%  ZF=2;
SNRdBs = [0:10];
x=0;
Ntt=NT/3

                      m=NT/3
                        %SNRdBs = [1:NT/3];
                        x=0;
                        sq2=sqrt(NT/3)

                         H = (randn(N,NT)+j*randn(N,NT))/sq2;
                         I=eye(N,N);
%                          DPC_Capacity_cell(i_SNR) = real(log2(det(I+H*SNR_sel_ant*H')))";
                        for i_SNR=1:length(SNRdBs)
                        SNRdB = SNRdBs(i_SNR);
                        SNR_sel_ant = 10^(SNRdB/10)/Ntt;
                        I1=eye(NU1,NU1);
                        %NT=1:NT

                         %H1 = (randn(NU1,round(NT/3))+j*randn(NU1,round(NT/3)))/sq2;
                        H1 = (randn(NU1,NT/3)+j*randn(NU1,NT/3))/sq2;
```

```
            %kk= diag(10^(SNRdB/10)/NT)
            if rho1<=den
                DPC_Capacity(i_SNR) = real(log2(det(I1+H1*SNR_sel_ant*H1')));
          %DPC_Capacity = real(log2(det(I+H*pt*H')))

           rate1_DPC=DPC_Capacity' % DPC rate
           rate1=DPC_Capacity
         else
              % m=NT/3
%            NT=1:NT/3;
           % rate1=ZF % use vector form ZF normalization R=k*log2(1+(pt(M-k+1)/k)
         k=NU1
%            pt=pt/3
%            m=1:m
        % for k=1:NU1
         DPC_Capacity(i_SNR) = real(log2(det(I1+H1*SNR_sel_ant*H1')));
          rate1_zf(i_SNR)=k*real(log2(det(I1+SNR_sel_ant/(trace(inv(H1*H1'))/pt))))''

         rate1_rzf(i_SNR)=k*real(log2(det(I1+(SNR_sel_ant*(NT/3-k+1)/k))))''%
vector form ZF normalization R=k*log2(1+(pt(M-k+1)/k)
         rate1_zf=rate1_zf;
       rate1_rzf=rate1_rzf'
       rate1_DPC=DPC_Capacity'
       rate1=rate1_rzf
         % end
            end
            DPC_Capacity_cell(i_SNR) = real(log2(det(I+H*SNR_sel_ant*H')))'';

            end
%
           %for sector two

            sq2=sqrt(NT/3)
            for i_SNR=1:length(SNRdBs)
            SNRdB = SNRdBs(i_SNR);
            SNR_sel_ant = 10^(SNRdB/10)/Ntt;
            I2=eye(NU2,NU2);
            %NT=1:NT

             %H1 = (randn(NU1,round(NT/3))+j*randn(NU1,round(NT/3)))/sq2;
            H2 = (randn(NU2,NT/3)+j*randn(NU2,NT/3))/sq2;
            %kk= diag(10^(SNRdB/10)/NT)
            if rho2<=den
                DPC_Capacity(i_SNR) = real(log2(det(I2+H2*SNR_sel_ant*H2')));
          %DPC_Capacity = real(log2(det(I+H*pt*H')))

           rate2_DPC=DPC_Capacity' % DPC rate
           rate2=DPC_Capacity
         else
              % m=NT/3
```

```
%                NT=1:NT/3;
                % rate1=ZF % use vector form ZF normalization R=k*log2(1+(pt(M-k+1)/k)
             k=NU2
%                pt=pt/3
%                m=1:m
             % for k=1:NU1
             DPC_Capacity2(i_SNR) = real(log2(det(I2+H2*SNR_sel_ant*H2')))";
              rate2_zf(i_SNR)=k*real(log2(det(I2+SNR_sel_ant/(trace(inv(H2*H2'))/pt))))"

             rate2_rzf(i_SNR)=k*real(log2(det(I2+(SNR_sel_ant*(NT/3-k+1)/k))))"%
vector form ZF normalization R=k*log2(1+(pt(M-k+1)/k)
             rate2_zf=rate2_zf;
           rate2_rzf=rate2_rzf';
           rate2_DPC=DPC_Capacity';
           rate2=rate2_rzf
             % end
                end
                end

                  %for sector three
                   sq2=sqrt(NT/3)
                for i_SNR=1:length(SNRdBs)
                SNRdB = SNRdBs(i_SNR);
                SNR_sel_ant = 10^(SNRdB/10)/Ntt;
                I3=eye(NU3,NU3);
                %NT=1:NT

                 %H1 = (randn(NU1,round(NT/3))+j*randn(NU1,round(NT/3)))/sq2;
                H3 = (randn(NU3,NT/3)+j*randn(NU3,NT/3))/sq2;
                %kk= diag(10^(SNRdB/10)/NT)
                if rho3<=den
                   DPC_Capacity(i_SNR) = real(log2(det(I3+H3*SNR_sel_ant*H3')));
               %DPC_Capacity = real(log2(det(I+H*pt*H')))

                rate3_DPC=DPC_Capacity' % DPC rate
                rate3=DPC_Capacity
              else
                  % m=NT/3
%                NT=1:NT/3;
                % rate1=ZF % use vector form ZF normalization R=k*log2(1+(pt(M-k+1)/k)
             k=NU3
%                pt=pt/3
%                m=1:m
             % for k=1:NU1
              DPC_Capacity3(i_SNR) = real(log2(det(I3+H3*SNR_sel_ant*H3')))";
              rate3_zf(i_SNR)=k*real(log2(det(I3+SNR_sel_ant/(trace(inv(H3*H3'))/pt))))"

             rate3_rzf(i_SNR)=k*real(log2(det(I3+(SNR_sel_ant*(NT/3-k+1)/k))))"%
vector form ZF normalization R=k*log2(1+(pt(M-k+1)/k)
             rate3_zf=rate3_zf;
```

```
               rate3_rzf=rate3_rzf';
                rate3_DPC=DPC_Capacity';
                rate3=rate3_rzf
                R_DPC_cell=DPC_Capacity_cell
                  % end
                      end
                       end
                       R_total=(rate1+rate2+rate3)/3;
xR = [R*ones(M,1); r] .* cos([t; th]) + C(1);
yR = [R*ones(M,1); r] .* sin([t; th]) + C(2);
%  th=sort(th,1,'ascend');
% th=roundn(th,-1);
th=sort(th,1,'ascend');
th=roundn(th,-1);
figure(1), clf, hold on

plot(xR(1:M),yR(1:M),'w.')               %// to show Base station maximum coverage(circle
boundary )

%// random points

grid
axis equal
x0=0;
y0=0;
r=5;
%
teta=-pi:0.01:pi;
 n=6;
% n=input('number of sectors:');

 x=r*cos(teta)+x0;
y=r*sin(teta)+y0;
plot(x,y)
hold on
scatter(x0,y0,'or')
axis square
%.........................................---------------
% divide your circle to n sectors
% n=3
tet=linspace(-pi,pi,n+1);
xi=r*cos(tet)+x0;
yi=r*sin(tet)+y0;
for k=1:numel(xi)
plot([x0 xi(k)],[y0 yi(k)],'w.')
hold on
end

%      if th>0 & th<=1.0471
           x1=Rmax(1);
```

```
        y1=0;
        x2=Rmax(1)*(-0.5);
        y2=Rmax(1)*0.866;
        r1=Rmax(1);
        plot([0,x2],[0,y2],'r')
        plot([0,r1],[0,0],'r')
         plot([0,5],[0,0],'w.')
        d = sqrt((x2-x1)^2+(y2-y1)^2); % Distance between points
%           a = atan2(x2-x1,-(y2-y1));
        a = atan2(-(x2-x1),y2-y1); % Perpendicular bisector angle
         b = asin(d/2/Rmax(1)); % Half arc angle
         c = linspace(a-b,a+b); % Arc angle range
         e = sqrt( r1^2-(d^2)/4); % Distance, center to midpoint
         x = (x1+x2)/2-e*cos(a)+Rmax(1)*cos(c); % Cartesian coords. of arc
         y = (y1+y2)/2-e*sin(a)+Rmax(1)*sin(c);
        Rm1= Rmax(1)

%     end

         %%%%%% For 60 degree to 120 degree
%            if th>1.0471 & th<=2.094
        x1=Rmax(2)*(-0.5);
        y1=Rmax(2)*0.866;
        x2=Rmax(2)*(-0.5);
        y2=Rmax(2)*(-0.866);

        r2=Rmax(2);
         plot([0,x2],[0,y2],'r')
         plot([0,x1],[0,y1],'r')

        d = sqrt((x2-x1)^2+(y2-y1)^2); % Distance between points
%           a = atan2(x2-x1,-(y2-y1));
        a = atan2(-(x2-x1),y2-y1); % Perpendicular bisector angle
         b = asin(d/2/Rmax(2)); % Half arc angle
         c = linspace(a-b,a+b); % Arc angle range
         e = sqrt(r2^2-(d^2)/4); % Distance, center to midpoint
         x = (x1+x2)/2-e*cos(a)+Rmax(2)*cos(c); % Cartesian coords. of arc
         y = (y1+y2)/2-e*sin(a)+Rmax(2)*sin(c);

         %%%%%%%%%%%%%%%%% 3rd sector%%%%%%%%%%%%%%%
         x1=Rmax(3)*(-0.5);
         y1=Rmax(3)*(-0.866);
        x2=Rmax(3)*1;
        y2=Rmax(3)*0;
        plot([0,x2],[0,y2],'r')
         plot([0,x1],[0,y1],'r')

        r3=Rmax(3);
        d = sqrt((x2-x1)^2+(y2-y1)^2); % Distance between points
%           a = atan2(x2-x1,-(y2-y1));
```

```
          a = atan2(-(x2-x1),y2-y1); % Perpendicular bisector angle
           b = asin(d/2/Rmax(3)); % Half arc angle
           c = linspace(a-b,a+b); % Arc angle range
           e = sqrt(r3^2-(d^2)/4); % Distance, center to midpoint
           x = (x1+x2)/2-e*cos(a)+Rmax(3)*cos(c); % Cartesian coords. of arc
           y = (y1+y2)/2-e*sin(a)+Rmax(3)*sin(c);
           r7=5;
          x1=5;
          y1=0;
          x2=-5;
          y2=0;
%              plot([x1,x2],[0,y2],'r')
          d = sqrt((x2-x1)^2+(y2-y1)^2); % Distance between points
%             a = atan2(x2-x1,-(y2-y1));
          a = atan2(-(x2-x1),y2-y1); % Perpendicular bisector angle
           b = asin(d/2/r7); % Half arc angle
           c = linspace(a-b,a+b); % Arc angle range
           e = sqrt(r7^2-(d^2)/4); % Distance, center to midpoint
           x = (x1+x2)/2-e*cos(a)+r7*cos(c); % Cartesian coords. of arc
           y = (y1+y2)/2-e*sin(a)+r7*sin(c);
  %%%%%%% whiting 180 arc again %%%%%%%%%%
           r7=5;
           x1=-5;
          y1=0;

          x2=5;
          y2=0;
%              plot([x1,x2],[0,y2],'r')

          d = sqrt((x2-x1)^2+(y2-y1)^2); % Distance between points
%             a = atan2(x2-x1,-(y2-y1));
          a = atan2(-(x2-x1),y2-y1); % Perpendicular bisector angle
           b = asin(d/2/r7); % Half arc angle
           c = linspace(a-b,a+b); % Arc angle range
           e = sqrt(r7^2-(d^2)/4); % Distance, center to midpoint
           x = (x1+x2)/2-e*cos(a)+r7*cos(c); % Cartesian coords. of arc
           y = (y1+y2)/2-e*sin(a)+r7*sin(c);

           km=max(NU1,NU2)
           k=1:km
           dpc_zf=0

for j=1:N-1 %the expected loss in raileigh fading due to zero forcing according to[DPC]
c=log2(exp(j/(NT-j)))
dpc_zf=dpc_zf+c
%cc(i)=dpc_zf(j)
cc(j)=dpc_zf
end
max_loss_zf=max(cc)
max(R_total)
```

```
%Difference_rat=R_total-
Net_Rate=max(R_total)-max_loss_zf
z=[max(R_total),Net_Rate]
% Rate calculation for the whole cell with DPC and R_ZF
sq2=sqrt(NT)
                    for i_SNR=1:length(SNRdBs)
                    SNRdB = SNRdBs(i_SNR);
                    SNR_sel_ant = 10^(SNRdB/10)/NT;
                    I=eye(N,N);
                    %NT=1:NT

                     %H1 = (randn(NU1,round(NT/3))+j*randn(NU1,round(NT/3)))/sq2;
                    H = (randn(N,NT)+j*randn(N,NT))/sq2;
                    %kk= diag(10^(SNRdB/10)/NT)
                    %if rho1<=den
                       DPC_Capacity(i_SNR) = real(log2(det(I+H*SNR_sel_ant*H')));
                  %DPC_Capacity = real(log2(det(I+H*pt*H')))
                    rate_rzf(i_SNR)=N*real(log2(det(I+(SNR_sel_ant*(NT-N+1)/N))))'';%
vector
                   rate_DPC=DPC_Capacity' % DPC rate
                   rate_reg_zf=rate_rzf'
                    end
Max_RT=max(R_total)
max_loss_zf
Net_Rate
K=5:5:55
max_rate=[17.1379
33.9487
50.3785
66.8082
81.7355
132.3771
148.043
127.7333
199.9168
154.3276
226.3492
]
Loss_ZF=[17.0646
33.6134
49.5824
65.3415
79.3767
128.892
143.1833
121.2355
191.5008
143.6948
213.1811
]
```

```
Net_Rate=[17.0646
33.6134
49.5824
65.3415
79.3767
128.892
143.1833
121.2355
191.5008
143.6948
213.1811
]
R_tatal_avg=mean(max_rate)

Net_loss=mean(Loss_ZF)
Rnet_avg=mean(Net_Rate)
R_DPC_cell=DPC_Capacity_cell'
hold off
 figure
 plot(SNRdBs,rate1,'k-s','linewidth',2)
 hold on
plot(SNRdBs,rate2,'g->','linewidth',2)
hold on
plot(SNRdBs,rate3,'b-*','linewidth',2)
hold on
plot(SNRdBs,R_total,'r-o','linewidth',2)

xlabel('SNRdB')
ylabel('Total rate (b/s/Hz)')
legend('Adaptive Rate1','Adaptive Rate2','Adaptive Rate3','Average Adaptive Rate')
grid
hold off
 figure
plot(SNRdBs,R_total,'r-o','linewidth',2)
hold on
plot(SNRdBs,rate_DPC,'g->','linewidth',2)
hold on
plot(SNRdBs,rate_reg_zf,'b->','linewidth',2)

xlabel('SNRdB')
ylabel('Total rate (b/s/Hz)')
legend('Adaptive Total Rate','DPC (cell) ','ZF(cell) ')
grid
hold off
figure
bar(z)
grid
hold off
figure
plot(K,max_rate,'r-o','linewidth',2)
```

```
hold on
plot(K,Net_Rate,'g-*','linewidth',2)
%  hold on
%  plot(K,Loss_ZF,'k->','linewidth',2)
xlabel('Number of Mobile Terminals')
ylabel('Total rate (b/s/Hz)')
legend('Max rate','(Max Rate)-(Max ZF loss)')
grid



clear all;

clc;

M=50;

K=10;

% M=input('Enter the number of base station antennas:');% M=1:1:600;

% K = input('Enter the number of users:'); % K=200;

% ff=1:1:K

rr=M;

MM=1:M

ss=1:1:10

Pd_dB = -3;

Pd1_dB =3;

Pd = 10^(Pd_dB/10);

Pd1 = 10^(Pd1_dB/10);

%Zero Forcing(ZF)

Rsum_zf = ss.*log2(1 + Pd*(rr-ss)/ss)

Rsum_zf1 = ss.*log2(1 + Pd1*(rr-ss)/ss);

for i=0:1:Pd*(rr-ss)/ss

mm=erfc(sqrt(Pd*(rr-ss)/ss))%// signal to noise ratio for BPSK

end

% yyy(i)=mm

% Matiching Filter (MF)

Rsum_MF= ss.* log2(1 + Pd*(rr+1)./(Pd*(ss-1)+ss));
```

```
EE=Rsum_MF./ptotal
Rsum_MF1 =ss.* log2(1 + Pd1*(rr+1)./(Pd1*(ss-1)+ss));
figure;
P1=semilogy(ss,Rsum_zf,'r-*','LineWidth',2);
hold on;
P2=semilogy(ss,Rsum_zf1,'k-o','LineWidth',2);
P3=semilogy(ss,Rsum_MF,'b-*','LineWidth',2);
P4=semilogy(ss,Rsum_MF1,'m-o','LineWidth',2);
grid on
xlabel('K');
ylabel('Sum Rate (Bit/Sec/Hz)');
sTitle = sprintf('Performance analysis of MF and ZF by using matrix normalization at
Pd=0db and -10dB,M=600');
% title(sTitle);
leg1='ZF at -3dB';
leg2='ZF at 3dB';
leg3='MR at -3dB';
leg4='MR at 3dB';
legend(leg1,leg2,leg3,leg4);
axis([0,10,0,50]);
%Matrix normalization (Sum rate vs. number of K users) at -0dB
%and -10 dB for ZF and MF.
close all;
clear all;
M=50;
K=10;
% M=input('Enter the number of base station antennas:');% M=1:1:600;
% K = input('Enter the number of users:'); % K=200;
% ff=1:1:K
rr=M;
MM=1:M
```

```
ss=0:1:M
Pd_dB = 0;
Pd1_dB = 3;
Pd = 10^(Pd_dB/10);
Pd1 = 10^(Pd1_dB/10);
%Zero Forcing(ZF)
Rsum_zf = ss.*log2(1 + Pd*(rr-ss)/ss);
Rsum_zf1 = ss.*log2(1 + Pd1*(rr-ss)/ss);
% for i=0:1:Pd*(rr-ss)/ss
% mm=erfc(sqrt(Pd*(rr-ss)/ss))%// signal to noise ratio for BPSK
% end
% yyy(i)=mm
% Matiching Filter (MF)
Rsum_MF1 =ss.* log2(1 + Pd1*(rr+1)./(Pd1*(ss-1)+ss))
Rsum_MF= ss.* log2(1 + Pd*(rr+1)./(Pd*(ss-1)+ss));
Rsum_zf = ss.*log2(1 + Pd*(rr-ss)/ss);
Rsum_zf1 = ss.*log2(1 + Pd1*(rr-ss)/ss);
EE=Rsum_MF./ptotal
EE1=Rsum_MF1./ptotal
EE_zf1=Rsum_zf1./ptotal
EE_zf=Rsum_zf./ptotal
figure;
P1=semilogy(ss,Rsum_zf,'b-*','LineWidth',2);
hold on;
P2=semilogy(ss,Rsum_zf1,'b-o','LineWidth',2);hold on;
P3=semilogy(ss,Rsum_MF,'k*','LineWidth',2);hold on;
P4=semilogy(ss,Rsum_MF1,'k-o','LineWidth',2);hold on;
p5=semilogy(ss,EE,'m-*','LineWidth',2);
p6=semilogy(ss,EE1,'m-o','LineWidth',2);
p7=semilogy(ss,EE_zf,'-*','LineWidth',2);
```

```
p8=semilogy(ss,EE_zf1,'g-o','LineWidth',2);
grid on
xlabel('M');
ylabel('Sum Rate (Bit/Sec/Hz)');
sTitle = sprintf('Performance analysis of MF and ZF by using matrix normalization at Pd=0db and -10dB,M=600');
% title(sTitle);
leg1='ZF at -3dB';
leg2='ZF at 3dB';
leg3='MR at -3dB';
leg4='MR at 3dB';
leg5='EE MR at -3dB';
leg6='EE MR at 3dB';
leg7='EE ZF at -3dBdb ';
leg8='EE ZF at  3db';
legend(leg1,leg2,leg3,leg4,leg5,leg6,leg7,leg8);
axis([0,50,0,50]);
hold off
figure
p5=semilogy(ss,EE,'g-o','LineWidth',2);
hold on
 p6=semilogy(ss,EE_zf1,'b-o','LineWidth',1);
% p7=semilogy(ss,EE,'g-o','LineWidth',2);
% p8=semilogy(ss,EE,'g-o','LineWidth',2);
xlabel('M');
ylabel('EE');
axis([0,50,0,50]);
grid
```

Last result of simulation ZF over DPC

Mssive MIMO

```
clc; clear all;
close all;
NT=50; NR=10;
sel_ant=NT;
I=eye(NR,NR);
sq2=sqrt(sel_ant);
SNRdBs = [0:10] ;
x=0;cum = 0;
  z=4;
for i_SNR=1:length(SNRdBs)
SNRdB =SNRdBs(i_SNR);
SNR_sel_ant =z*10^(SNRdB/10)/sel_ant;
H = (randn(NR,NT)+j*randn(NR,NT))/sq2;
A=H'*H;
B=inv(A);
M=B*H';
     ZF_C(i_SNR) =z*real(log2(det(I+(SNR_sel_ant)) ) ) ;% ZF capacity
    x=x+1;
end

SNR=10.^(SNRdBs/10);
ZF_Cap=ZF_C';
%dirty paper
NT1=50
NT2=40
NT3=30
NT4=20;
NR1=20
NR2=20
NR3=20
NR4=20;
I1=eye(NR1,NR1);
I2=eye(NR2,NR2);
I3=eye(NR3,NR3);
I4=eye(NR4,NR4);
sel_ant1=NT1;
sq2=sqrt(sel_ant1);
SNRdBs1 = [0:10];

x=0;cum=0;

for i_SNR1=1:length(SNRdBs1)
SNRdB1 = SNRdBs1(i_SNR1);
SNR_sel_ant1 =10^(SNRdB1/10)/sel_ant1;

H1 = (randn(NR1,NT1)+j*randn(NR1,NT1))/sq2;
H2 = (randn(NR1,NT2)+j*randn(NR1,NT2))/sq2;
H3 = (randn(NR1,NT3)+j*randn(NR1,NT3))/sq2;
```

```
H4 = (randn(NR1,NT4)+j*randn(NR1,NT4))/sq2;

        DPC_Capacity1(i_SNR1) = real(log2(det(I1+H1*diag(SNR_sel_ant1)*H1')))
        DPC_Capacity2(i_SNR1) = real(log2(det(I2+H2*diag(SNR_sel_ant1)*H2')))
        DPC_Capacity3(i_SNR1) = real(log2(det(I3+H3*diag(SNR_sel_ant1)*H3')))
        DPC_Capacity4(i_SNR1) = real(log2(det(I4+H4*diag(SNR_sel_ant1)*H4')))

      x=x+1;
end
SNR1=10.^(SNRdBs1/10);
DPC_Cap1=DPC_Capacity1;
DPC_Cap2=DPC_Capacity2;
DPC_Cap3=DPC_Capacity3;
DPC_Cap4=DPC_Capacity4;

figure
plot(SNR,ZF_Cap,'m-o', 'LineWidth',4);hold on
plot(SNR1,DPC_Cap1,'b-o', 'LineWidth',4);hold on
plot(SNR1,DPC_Cap2,'-ko', 'LineWidth',4);hold on
plot(SNR1,DPC_Cap3,'-go', 'LineWidth',4);hold on
plot(SNR1,DPC_Cap4,'r-o', 'LineWidth',4);
xlabel('SNR'), ylabel('Capacity');grid on
legend('ZF K=10', 'DPC K=40','DPC K=30','DPC K=20','DPC K=10')

NR8=1:30;NT8=50
SNR=10;
sq2=sqrt(NT8)

for n=1:length(NR8)
    K=n;
    z=8;
    I5=eye(K,K);
    H5 = (randn(K,NT8)+j*randn(K,NT8))/sq2;
    DPC_Capacity5(n) =z*real(log2(det(I5+H5*diag(SNR/NT8)*H5')))
end
NR7=1:30;NT7=31
SNR=100;
sq2=sqrt(NT7)
for y=1:length(NR7)
    z=y;
    I6=eye(z,z);
    H6 = (randn(z,NT7)+j*randn(z,NT7))/sq2;
   % RnnZF = real( ( inv(H6'*H6)*H6' ) * ( inv(H6'*H6)*H6' )' ) ;
    ZF_C(y) =z*real(log2(det(I6+((SNR/NT7))) ) )
end
figure(2)
    plot(NR7,ZF_C,'-ro','linewidth',4)
    hold on
    plot(NR8,DPC_Capacity5,'-go','linewidth',4)
xlabel('user');ylabel(' Capacity');
```

```
legend('ZF','DPC')
grid on
%Matrix normalization (Sum rate vs. number of K users) at -0dB
%and -10 dB for ZF and MF.
close all;
clear all;
M=200;
K=10;
% M=input('Enter the number of base station antennas:');% M=1:1:600;
% K = input('Enter the number of users:'); % K=200;
% ff=1:1:K
rr=M;
MM=1:M
ss=0:1:M
Pd_dB = -3;
Pd1_dB = 3;
Pd = 10^(Pd_dB/10);
Pd1 = 10^(Pd1_dB/10);
%Zero Forcing(ZF)
Rsum_zf = ss.*log2(1 + Pd*(rr-ss)/ss);
Rsum_zf1 = ss.*log2(1 + Pd1*(rr-ss)/ss);
% for i=0:1:Pd*(rr-ss)/ss
% mm=erfc(sqrt(Pd*(rr-ss)/ss))%// signal to noise ratio for BPSK
% end
% yyy(i)=mm
% Matiching Filter (MF)

Rsum_MF1 =ss.* log2(1 + Pd1*(rr+1)./(Pd1*(ss-1)+ss))
Rsum_MF= ss.* log2(1 + Pd*(rr+1)./(Pd*(ss-1)+ss));
Rsum_zf = ss.*log2(1 + Pd*(rr-ss)/ss);
Rsum_zf1 = ss.*log2(1 + Pd1*(rr-ss)/ss);

EE=Rsum_MF./ptotal
  EE=Rsum_MF./ptotal
EE_zf1=Rsum_zf1./ptotal

EE_zf=Rsum_zf./ptotal

figure;
P1=semilogy(ss,Rsum_zf,'b-*','LineWidth',2);
hold on;
P2=semilogy(ss,Rsum_zf1,'b-o','LineWidth',2);hold on;
P3=semilogy(ss,Rsum_MF,'k-*','LineWidth',2);hold on;
P4=semilogy(ss,Rsum_MF1,'k-o','LineWidth',2);hold on;
p5=semilogy(ss,EE,'g-*','LineWidth',2);
p5=semilogy(ss,EE_zf,'b-o','LineWidth',2);
p5=semilogy(ss,EE_zf1,'m-o','LineWidth',2);
grid on
xlabel('M');
ylabel('Sum Rate (Bit/Sec/Hz)');
```

```
sTitle = sprintf('Performance analysis of MF and ZF by using matrix normalization at
Pd=0db and -10dB,M=600');
title(sTitle);
leg1='ZF at 0dB';
leg2='ZF at -10dB';
leg3='MF at 0dB';
leg4='MF at -10dB';
leg5='EE MR';
leg6='EE ZF at 0db ';leg7='EE ZF at 3db';
legend(leg1,leg2,leg3,leg4,leg5,leg6,leg7);
axis([0,50,0,50]);
hold off
figure
p5=semilogy(ss,EE,'g-o','LineWidth',2);
hold on
 p6=semilogy(ss,EE_zf1,'b-o','LineWidth',1);
% p7=semilogy(ss,EE,'g-o','LineWidth',2);
% p8=semilogy(ss,EE,'g-o','LineWidth',2);
xlabel('M');
ylabel('EE');
axis([0,50,0,50]);
grid
```

Dirty paper over zero-forcing

Mssive MIMO

```
 clc; clear all;
close all;
NT=50; NR=10;
sel_ant=NT;
I=eye(NR,NR);
sq2=sqrt(sel_ant);
SNRdBs = [0:10] ;
x=0;cum = 0;

for i_SNR=1:length(SNRdBs)
SNRdB = SNRdBs(i_SNR);
SNR_sel_ant = 10^(SNRdB/10)/sel_ant;
H = (randn(NR,NT)+j*randn(NR,NT))/sq2;
A=H'*H;
B=inv(A);
M=B*H';

    ZF_C(i_SNR) = real(log2(det(I+(SNR_sel_ant)) ) ) ;% ZF capacity
    x=x+1;
end
SNR=10.^(SNRdBs/10);
ZF_Cap=ZF_C';
%dirty paper
NT1=50
NT2=40
```

```
NT3=30
NT4=20;
NR1=20
NR2=20
NR3=20
NR4=20;
I1=eye(NR1,NR1);
I2=eye(NR2,NR2);
I3=eye(NR3,NR3);
I4=eye(NR4,NR4);
sel_ant1=NT1;
sq2=sqrt(sel_ant1);
SNRdBs1 = [0:10];
x=0;cum=0;
for i_SNR1=1:length(SNRdBs1)
SNRdB1 = SNRdBs1(i_SNR1);
SNR_sel_ant1 = 10^(SNRdB1/10)/sel_ant1;

H1 = (randn(NR1,NT1)+j*randn(NR1,NT1))/sq2;
H2 = (randn(NR1,NT2)+j*randn(NR1,NT2))/sq2;
H3 = (randn(NR1,NT3)+j*randn(NR1,NT3))/sq2;
H4 = (randn(NR1,NT4)+j*randn(NR1,NT4))/sq2;

    DPC_Capacity1(i_SNR1) = real(log2(det(I1+H1*diag(SNR_sel_ant1)*H1')))
    DPC_Capacity2(i_SNR1) = real(log2(det(I2+H2*diag(SNR_sel_ant1)*H2')))
    DPC_Capacity3(i_SNR1) = real(log2(det(I3+H3*diag(SNR_sel_ant1)*H3')))
    DPC_Capacity4(i_SNR1) = real(log2(det(I4+H4*diag(SNR_sel_ant1)*H4')))

   x=x+1;
end

SNR1=10.^(SNRdBs1/10);
DPC_Cap1=DPC_Capacity1;
DPC_Cap2=DPC_Capacity2;
DPC_Cap3=DPC_Capacity3;
DPC_Cap4=DPC_Capacity4;
figure
plot(SNR,ZF_Cap,'m-o', 'LineWidth',4);hold on
plot(SNR1,DPC_Cap1,'b-o', 'LineWidth',4);hold on
plot(SNR1,DPC_Cap2,'-ko', 'LineWidth',4);hold on
plot(SNR1,DPC_Cap3,'-go', 'LineWidth',4);hold on
plot(SNR1,DPC_Cap4,'r-o', 'LineWidth',4);
xlabel('SNR'), ylabel('Capacity');grid on
legend('ZF Capacity', 'DPC capacity','DPC capacity2','DPC capacity3','DPC capacity4')

NR8=1:30;NT8=50
SNR=10;
sq2=sqrt(NT8)

for n=1:length(NR8)
```

```
    K=n;
    I5=eye(K,K);
    H5 = (randn(K,NT8)+j*randn(K,NT8))/sq2;
    DPC_Capacity5(n) = real(log2(det(I5+H5*diag(SNR/NT8)*H5')))
end
NR7=1:30;NT7=31
SNR=10;
sq2=sqrt(NT7)
for y=1:length(NR7)
    z=y;
    I6=eye(z,z);
    H6 = (randn(z,NT7)+j*randn(z,NT7))/sq2;
   % RnnZF = real(  ( inv(H6'*H6)*H6' ) * ( inv(H6'*H6)*H6' )'   ) ;
    ZF_C(y) = real(log2(det(I6+((SNR/NT7))) ) )
end
figure(2)
    plot(NR7,ZF_C,'-ro','linewidth',4)
    hold on
    plot(NR8,DPC_Capacity5,'-go','linewidth',4)
xlabel('user');ylabel(' cap');
legend('ZF','DPC')
grid on
```