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ALGORITHMS FOR ZERO-FORCING BEAMFORMING IN MULTIPLE INPUT MULTIPLE OUTPUT 5G SYSTEMS

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ABSTRACT

Sharmista Paul Jui: Algorithms for Zero-forcing Beamforming in Multiple Input Multiple Output 5G Systems
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Zero-forcing beamforming is a method of spatial signal processing via which multiple antennas can null multiuser interference signals in wireless communications. In general, a signal processing technique which is used in sensor arrays for directional signal transmission or reception is known as beamforming or spatial filtering. In order to achieve spatial selectivity, beamforming can be used at both the transmitting and receiving ends. Compared with omnidirectional reception/-transmission, beamforming introduces the directivity of the array.

Multiple Input Multiple Output (MIMO) is a technique for multiplying the power of radio link using multiple transmitting and receiving antennas to take full advantage of communications channel and multipath propagation.

5G introduces a new era of communications networks, where MIMO is necessary to establish a good network performance and extended coverage. Zero-forcing beamforming can be one solution to reduce the short comings of long-term beamforming where interference consideration is not available. On basis of which different approaches are considered, the target of this thesis is to elaborate those algorithm in terms of throughput versus SNR.

Although several MATLAB codes are available on MIMO beamforming, they do not extensively cover the zero-forcing approach and its all variants. Thus, the objective of this thesis is to study different implementations of the zero-forcing method and to provide comparative numerical results between the considered approaches.

Keywords: MATLAB, Zero-forcing beamforming, MIMO, Algorithm

PREFACE

This master thesis "Algorithms for Zero-forcing Beamforming in Multiple Input Multiple Output 5G Systems" was done to complete Masters of Science (M.Sc) degree in Communication Systems and Networks under Information Technology Unit.

I would like to thank my university supervisor Dr.Jukka Talvitie for supporting me in this topic of interest and also helping me throughout the period of completion of my masters thesis.

I am very grateful to my company supervisor Mohammad Majidzadeh for his assistance in MATLAB simulation and inspiration to complete thesis.

Tampere, 10th October 2020

Sharmista Paul Jui

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LIST OF SYMBOLS AND ABBREVIATIONS

1G	First generation
2G	Second generation
3G	Third generation
4G	Fourth generation
5G	Fifth generation
AMPS	Advanced Mobile Phone System
AMTS	Advanced Mobile Telephone System
AWGN	Additive White Gaussian Noise
BD	Block Diagonalisation
BS	Base Station
CNR	Channel to interference noise ration
CSI	Channel State Information
EBB	Eigen Based beamforming
EBF	Eigen Beamforming
EZF	Eigen Zero-forcing
FDD	Frequency-division Duplexig
FDMA	frequency division multiple access
GoB	Grid of Beamforming
IMTS	Improved Mobile Telephone Service
IoT	Internet of Things
LoS	Line of Sight
LTE	Long Term Evolution
MIMO	Multiple Input Multiple Output
MISO	Multiple Input Single Output
MMSE	Minimum Mean Square Error
mmWave	millimeter wave
MTS	Mobile Telephone System
MU-MIMO	Multiuser MIMO
MUI	Multi-User Interference

NR	New Radio
OFDM	Orthogonal Frequency-division Multiplexing
PHY	physical layer
PTT	Push to Talk
RBD	Regularized Block Diagonalisation
REZF	Regularised Eigen based zero-forcing beamforming
Rx	Receiver
RZF	Regularised zero-forcing beamforming
SI system	international system of units
SINR	Signal to interference plus noise ratio
SISO	Single Input Single Output
SLNR	Signal to leakage Noise Ratio
SNR	Signal to Noise Ratio
SU-MIMO	Single-user MIMO
SVD	Singular Value Decomposition
TDD	Time-division Duplexig
Tx	Transmitter
UMTS	Universal Mobile Telecommunication System
WF	Water-Filling
WWWW	World-Wireless World wide Web
ZF	Zero-forcing
ZFBF	Zero-forcing Beamforming

1 INTRODUCTION

The vast and widespread use of connected mobile devices has led to tremendous social changes with important economic, cultural and technical impacts on a world that is becoming increasingly connected. Considering this huge connectivity and energy efficiency in terms of capacity, Fifth generation (5G) mobile networks are required to deal with increasing number of consumers and upgraded network users. In addition to data rate improvement, 5G is expected to trigger a massive Internet of Things (IoT) ecosystem where networks can meet the connectivity needs of trillions of smart devices, with the right trade-offs among speed, latency and cost.[1]

The upcoming 5G mobile networks are projected to have 10,000 times higher traffic with 10-100 times more devices and 1 ms or less latency compared with current technologies. Present mobile technologies are not enough to satisfy future high-traffic and data-rate mobile broadband demands. 5G mobile communication need to be a combination of new technologies, new system and new version of equipment so that it can reduce all limitations. [2], [3]

The transmission of radio waves in cmWave and mmWave wavelengths poses new challenges for wireless communication. Path loss usually depends on frequency and distance. In addition, atmospheric attenuation, strong penetration degradation and frequency fading somehow restrict communication in many scenarios.[4],[5] The greater path loss can be balanced either by increasing the transmit power or by increasing the antenna aperture size which can be achieved by utilizing multi-antenna systems like MIMO. [6],[7],[8] In solid state circuit increment of transmit power can be more challenging due to gain cost and frequency dependencies.[9] Only limited number of power generating devices are good for using in combined losses in system on chip at mmWave wavelengths whereas power combination losses can be higher for multiple power producing devices.[10]

MIMO can be used for beamforming techniques, which basically combines received signals at each antenna element to obtain particular physical direction for both transmitter and receiver site. Improved SNR, higher capacity, low power consumption and spatial filtering are the benefits of beamforming. [11] Here possibilities of beamforming can be in three different domain such as fully analog, fully digital and hybrid. Single stream can be transmitted by analog domain, while multi-streams can be transmitted by digital domain. Due to hardware complexity and power consumption, hybrid combination came out to show higher efficiency in power.

Beamforming can be utilized with precoding matrix for all methods. Present level scenarios also can involve Grid of Beamforming (GoB) or Eigen Based beamforming (EBB) which consider users independently but these methods don't try to suppress interference though the performance is good. From this interference mitigation perspective Zero-forcing (ZF) is being considered which refers to group of algorithms that will mitigate the interference in MU-MIMO transmissions. An idea came up based on the theory studies to elaborate ZF method and its different approaches.

This Masters thesis is pursued in a way where second chapter will describe evolution of 5G and every generation's core characteristics. Moreover, 5G is having strong connectivity with MIMO which is also described at the end of the chapter. Later on third chapter will elaborate multiple antenna systems for wireless communication. Basically the theory of MIMO is considered as point-to-point, multiuser and massive. On the other hand, fourth chapter will illustrate beamforming and its initial types based on architecture such as digital, analog and hybrid.

Finally different approaches of beamforming enlighten the theory which helps this thesis's motive and perspective, specifically ZF method and its different approaches also showed its connectivity with the rest of theories. Here every approaches of ZF beamforming describes algorithms with corresponding figures and variables which are needed to describe most beneficial approach of ZF beamforming.

Lastly there is a clear description of a system model which initialise all variables that are required to implement algorithm approaches via MATLAB coding. After that there is a brief discussion about numerical results comparison based on MATLAB implementation with or without using ZF.

2 EVOLUTION OF 5G

2.1 A brief history

In last decades, mobile wireless communication networks having experience of significant changes. The mobile wireless generation normally refers to some changes in nature of system, speed, technology, frequency, data capacity, latency etc. Every generation have some standards, techniques, features, capacities which basically differentiate one generation to other. First generation (1G) mobile wireless communication which used for voice calls only was analog. Whereas digital technology and text messaging is supported by Second generation (2G). Higher transmission rate of data, capacity increment and support of multimedia provided by Third generation (3G) mobile technology. Fourth generation (4G) is a combination of 3G with fixed internet that support wireless mobile internet and showed mobile technology evolution which helped to overcome the limitations of 3G. Bandwidth increment and Reduced cost of resources displayed by This generation.[12] 5G is the latest of all technologies and have all updated features which can't be expected earlier.

Mobile communication has faced fast reformation from 1G to 5G which happened due to increased number of users and service compatible transmission technology requirements. In 1980 mobile cellular era started with massive growth and considerate changes in mobile communication.

2.1.1 First Generation, 1G

In 1982 1G mobile phones first got introduced and it came out successfully in 1990. It was used only for voice services and it followed Advanced Mobile Phone System (AMPS) technology. AMPS was frequency modulated based system. It used frequency division multiple access (FDMA) with such a channel capacity of 30KHz with frequency band of 824-894MHz.[13] There is some basic features available for this generation based technologies. Normally it used analog signal and allowed voice calls in one country which having speed of 2.4kbps. It was having poor battery life, poor voice quality, large-sized phones, limited capacity, poor hand-off reliability and poor security. Generally offered spectrum efficiency was very low.

It introduced some mobile technologies like Advanced Mobile Telephone System (AMTS), Mobile Telephone System (MTS), Improved Mobile Telephone Service (IMTS), Push to Talk (PTT). It didn't have security at all because voice calls were played back in radio towers, to make this calls susceptible to unwanted eavesdropping by third parties.[12]

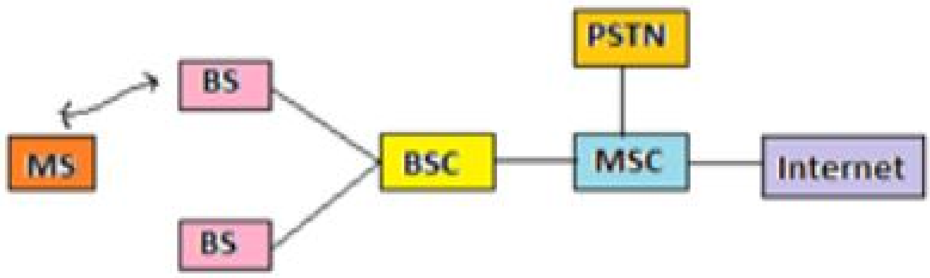


Figure 2.1. *Architecture of Advance Mobile Phone System [12]*

2.1.2 Second Generation, 2G

In late 1980s 2G based on GSM was emerged which used digital signals for voice transmission. As this technologies was having main focus in digital signals and delivered text and pictures message at low speed. It used bandwidth of 30-200 KHz and used packet switched or circuit switched domain based on upgrading of technologies. It provide data rate 64-144 kbps. It also ensure better quality and capacity, unable to handle complex data such as videos. It required strong digital signals to help mobile phones for being active. But there was no network coverage in any specific area which make digital signal weak.[13]

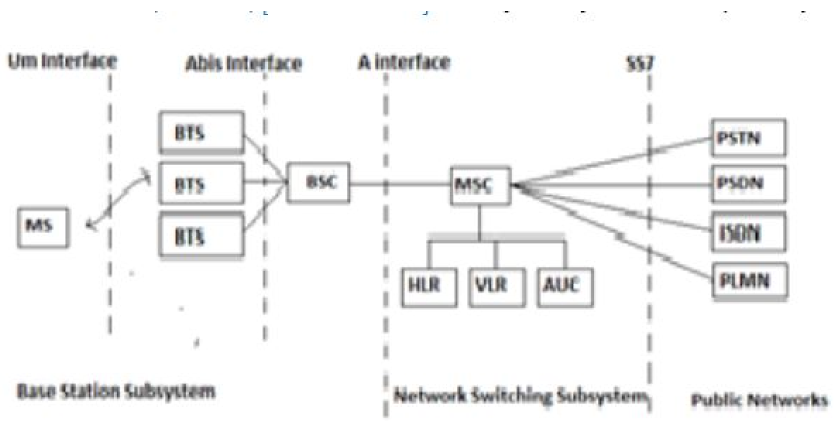


Figure 2.2. *Architecture of GSM System [13]*

2.1.3 Third Generation, 3G

In 2000 3G was launched which is based on GSM. Aim of this technology was offering high speed data. Technically it improved data up to 14 Mbps and used more packet switching. It increased clarity with the use of broad band wireless network. It supported a number of services, video connectivity, new facilities such as worldwide roaming. It operates in 2100 MHz and having a bandwidth of 15-20MHz which basically required for internet service, video chatting.[13]

Main features are having speed of 2 Mbps, increased bandwidth and data transfer rates to accommodate web-based application and audio and video files. It provides faster communication, send/receive large emails, large capacities and broadband capabilities. It was a challenge to build the infrastructure for 3G.

3G system was called as Universal Mobile Telecommunication System (UMTS) for Europe and for American 3G variant it was called CDMA2000. WCDMA is the air-interface technology for UMTS.[12]

2.1.4 Fourth Generation, 4G

4G offered a downloading speed of 100Mbps. 4G provided same feature like 3G including with multi-media newspapers, watching videos with more clarity and sending data faster than previous generations.[14] This technology also considered as Long Term Evolution (LTE). 4G was improved due to QoS and rate requirements set of upcoming application lie wireless broadband access, multimedia messaginf service, video chat, digital video broadcasting, minimal services as voice and data to use bandwidth.[15]

Main features of this technology are high quality networks, high security, give any kind of service required in any time and place, extended multimedia services, lower cost for each bit, increment of battery use. But here implementation is hard and needed complicated hardware structure. Next generation implementation required expensive equipment.[16]

2.1.5 Fifth Generation, 5G

5G was started from late 2010 which facilitated with such a technology that includes far better levels of connectivity and coverage. First priority of this technology is World-Wireless World wide Web (WWWW). It assumes to be complete communications which is not having any limitations.[17]

Main features of this technology are having high speed, high capacity, providing large broadcasting of data in Gbps, faster data transmission, high supportable to WWWW. It also supports interactive multimedia, voice, streaming video, internet and other services. It considered as more effective and attractive technology so far.[18]

5G technology having ability of binding together unlimited call volumes and limitless data broadcast via current operating system and it also shows data capabilities. 5G technology is a Creator of new era of best technologies and offer ultimate required network to the consumers which will help to rule world market. This technology provides high connectivity for network and extraordinary capability to support software and consultancy. 5G technology distributes internet access to nodes under a building and implement all wireless or wired connections. Now-a-days video chats and downloading of movies are became more time consuming with very high clarity. On the other hand 5G belongs to packet switched wireless system with wide area coverage and high throughput. 5G wireless uses Orthogonal Frequency-division Multiplexing (OFDM) and millimeter wave (mmWave) that enables data rate of 20 Mbps and frequency band of 2-8 GHz. Communication system of 5G technology is capable of supporting WWWW.

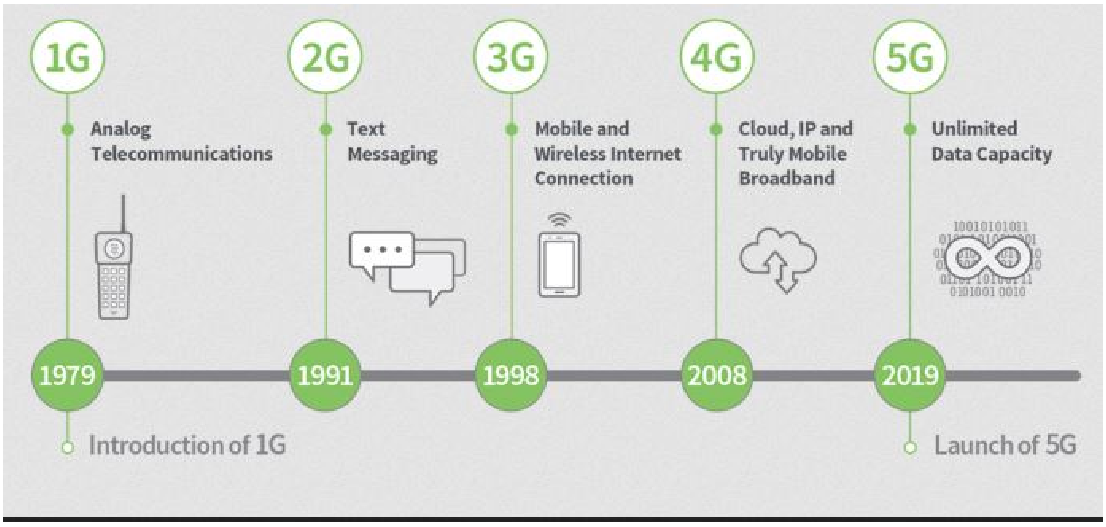


Figure 2.3. *Evolution of 5G [19]*

5G technology has some key goals by achieving them it looks complete. First goal is having significant fastest data speed because with this technology its near about 10Gbps. Another goal can be ultra-low latency where latency means the time it required to transfer packet of data to another device to one device. Most important goal is to make connected world which introduce IoT and it is expected to grow exponentially in near future. This technology is still a long way to become reality but it has most potential aspect to change the interaction among wireless devices completely. This way it shows a clear difference with 4G. More specifically table 2.1 is showing numerical changes which describe the expert level of 5G technology. Here order of increase also elaborate the advancement of 5G.[20]

There is a term of tactile internet which basically referring to cyber-physical tactile control

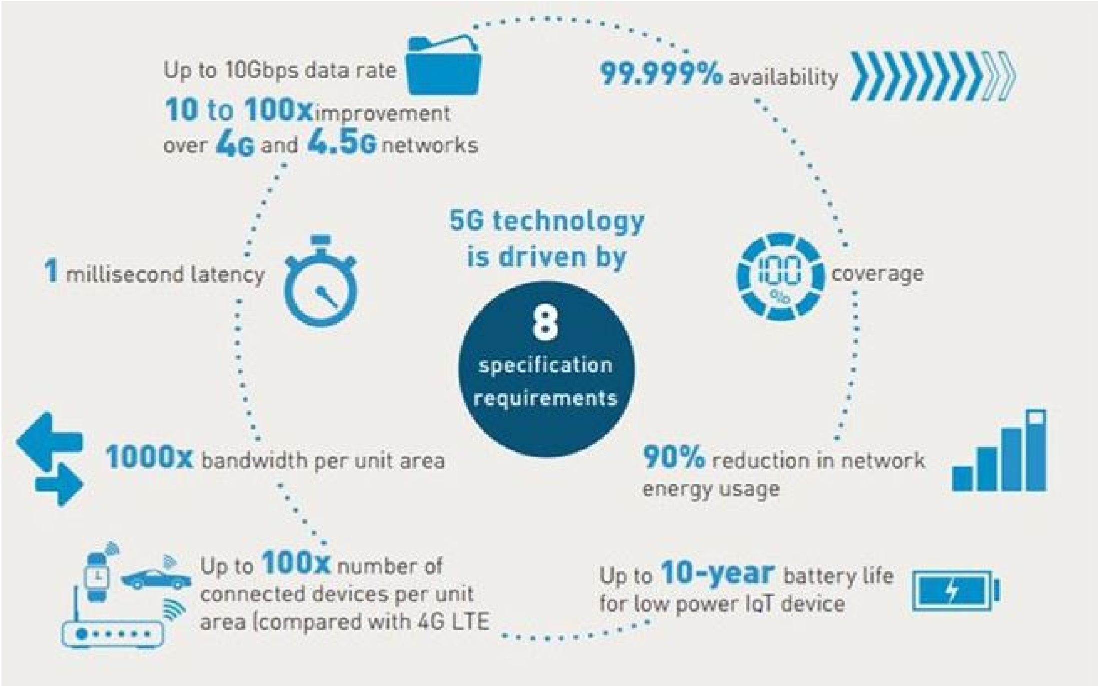


Figure 2.4. *Requirements of 5G [21]*

experiments. It will create and environment which will create a scenario in which human and devices can interact with each other in real time while moving. This kind of system requires reliable communication services with small latency. Latency requires for this systems is 1ms and it also requiring a physical layer (PHY) latency around 200-300 micro-second.[22], [23]

5G will play an important role in wireless regional area networks by providing internet access to sparsely populated areas. But here it will have low mobility and latency will not be main requirement.[24]

Table 2.1. *Comparison of $4G$ performance and $5G$ requirements [20]*

Performance indicator	$4G$	$5G$	Order of increase
Arca capacity [Mbits/s/m ^{2}]	0.1	$10-100$	$100-1000$
Connection density [devices/km ^{2}]	10^5	10^6-10^7	$10-100$
User data rate [Mbits/s]	10	$100-1000$	$10-100$
Latency [ms]	10	≤ 1	≥ 10
Lnergy efficiency (bits/Joule)	$-$	$-$	100

2.2 5G and MIMO

5G having some main aspects which are related to PHY, those are waveform design, mmWave and MIMO. The main motive behind mmWave is to use totally intact portion of the spectrum. mmWave technologies can achieve required data rates with the help of

MIMO.[25] Moreover high frequency operation, digital processing of signal may be limited in some cases, in which situation it required for analog processing.[26] MIMO technology can employ large number of antennas at base station and serves a considerable number of terminals that using same time-frequency resources.[27]. Traditional MIMO can serve limited amount of antennas whereas MU-MIMO consider to serve many antennas in the Base Station (BS). It opens a new transmission possibilities with a good qualities. This technology based systems are able to focus on radiated energy towards the intended directions while mitigate intra-cell and inter-cell interference.[28]

When its about to use mmWave in MIMO systems its normally reduces the size of antennas, increase the number of antennas per square meter.[25] Though MIMO technology is very promising, it also having some challenges which it needs to be faced. MIMO system needs to deal with pilot contamination which mainly generated by limited number of orthogonal pilots of base stations.[6] Due to channel reciprocity MIMO system needs to depend on Time-division Duplexig (TDD). But due to analog components of radio frequency chains there is some uncertainty which imbalance channel reciprocity which require calibration.[29], [30] This updated standards of MIMO always being different from previous mobile communication standards for which it demands major changes in base station design.[31], [30]

3 MULTIPLE-ANTENNA SYSTEMS FOR WIRELESS COMMUNICATIONS

3.1 MIMO

MIMO devices on both transmitters and receivers are categorized as point-to-point communication connects with multiple antennas. The use of multiple antennas on both transmitters and receivers clearly offers enhanced performance over diversity systems where either the transmitter or receiver has multiple antennas. In figure 3.1, a general outline of MIMO has shown.

Recent research has shown especially that MIMO systems can be important to cope up with increased amount of requirements in world.Basically its providing good amount of transmission diversity and utilises spatial multiplexing. Recent research has shown that without increasing the transmission power or bandwidth, MIMO systems can dramatically increase the data rates of wireless systems. The cost of this increased rate is the additional cost of installing multiple antennas, the space requirements of these extra antennas (especially on small handheld units), and the additional complexity necessary for multi-dimensional signal processing. Recent work in MIMO systems involves capability of these systems under different assumptions regarding knowledge of channels, optimal coding and decoding for these systems, and methods of transmission for un-coded systems.[32]

In addition, each transmitter can send several different data streams (spatial multiplexing), which results in a benefit in multiplexing. This systemically enhances the potential for spectral efficiency and flexibility within a cell. Consequently, there is a significant improvement in spectral quality (improvement in bits / s / Hz) and also reducing errors and maximizing the speed of data.

Methods of accessing channels are used in cellular networks to separate forward and reverse channels of communication over the same physical media. They are known as duplexing techniques, and the main duplexing schemes used in wireless communication are TDD and Frequency-division Duplexig (FDD).

TDD is the multiplexing of the time-division to extract the forward and reverse data. In TDD service, the BS learns the uplink channel from uplink drivers sent by terminals. Furthermore, due to reciprocal channel, if the base station discovered the uplink channel,

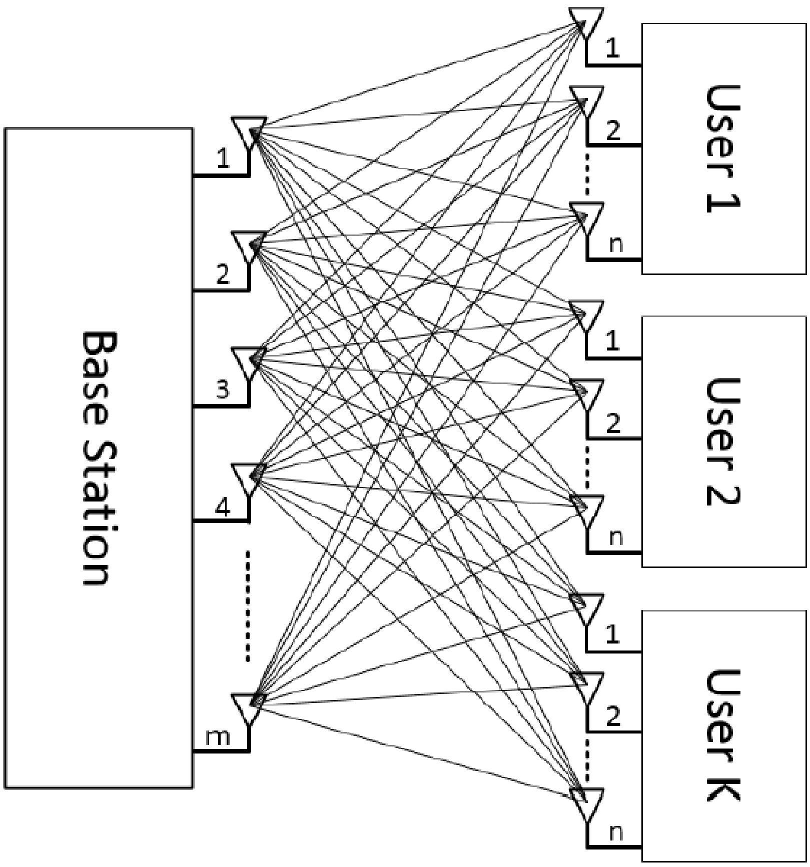


Figure 3.1. *General outline of a MIMO system.[33]*

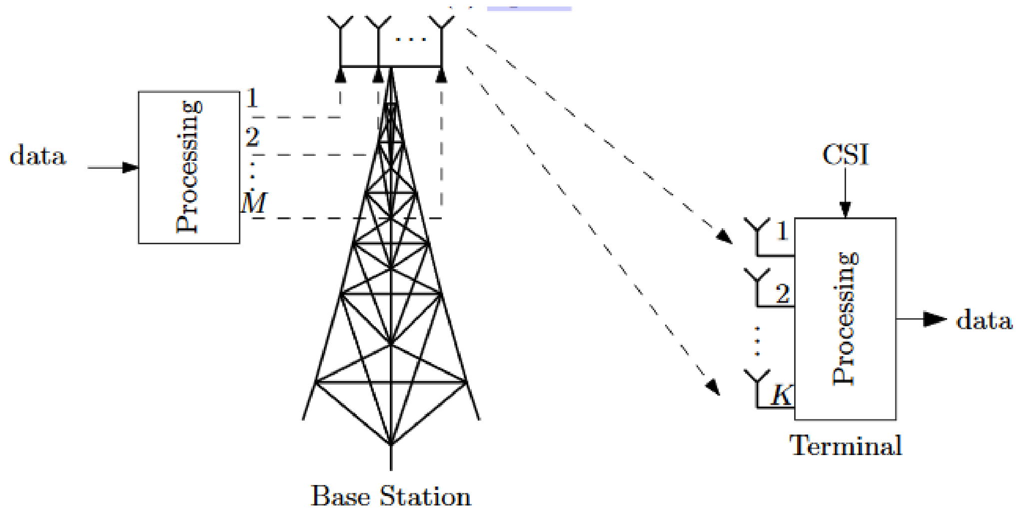
it will also do automatically valid estimation of the downlink channel, ignoring downlink driver transmission. For wireless massive MIMO systems, there is no standard yet specified, but the first choice is a TDD mode. Consequently, all the MIMO devices discussed in this work would be considered to run under TDD scheme.[34]

FDD means that base station and terminals work at different carrier frequencies and use multiplexing frequency-division to distinguish forward and reverse data. In FDD, the terminals learn downlink route from pilots which is sent by the base station and communicate the approximate Channel State Information (CSI) back to the through a control channel. This feedback can be very costly, except in special cases such as propagation of Line of Sight (LoS) where CSI can be quantified efficiently.[34]

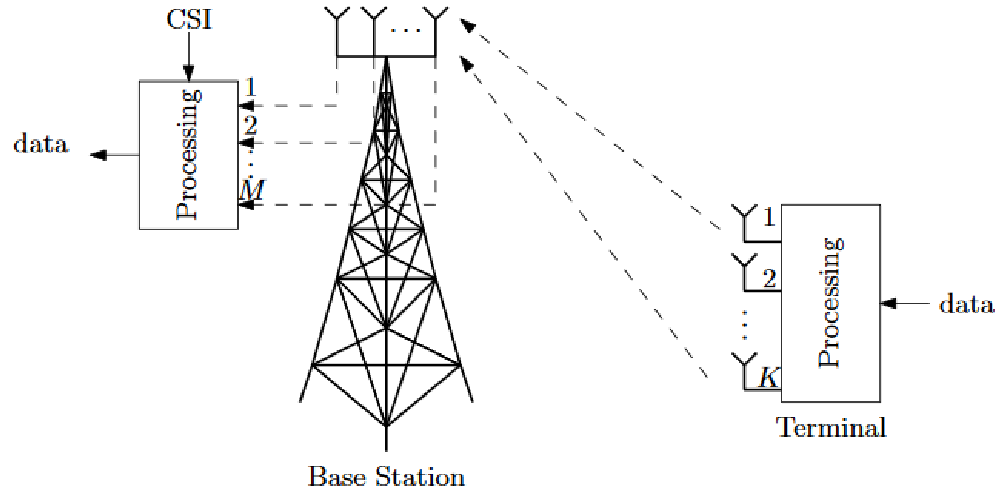
MIMO technology can be divided into point-to-point MIMO, multiuser MIMO and massive MIMO. Here first two patterns are already popular for ongoing generations, last one is one of the strongest candidate for 5G standard.

3.1.1 Point-to-point MIMO

Point-to-point MIMO is the most simple form of MIMO system where serving terminal and both are equipped with multiple antennas. Here terminals are orthogonal multiplexed. Figure 3.2 shows an example of simple point-to-point MIMO where having M numbers of antennas and terminal having K numbers of antennas.



(a) *Downlink*



(b) *Uplink*

Figure 3.2. *Point-to-point MIMO System having M-antenna and a terminal of K-antenna [35]*

Advantages of MIMO systems can be displayed by channel capacity.[34] In the presence of Additive White Gaussian Noise (AWGN) at receiver end, spectral efficiency can be counted in bit/s/Hz at uplink and downlink:

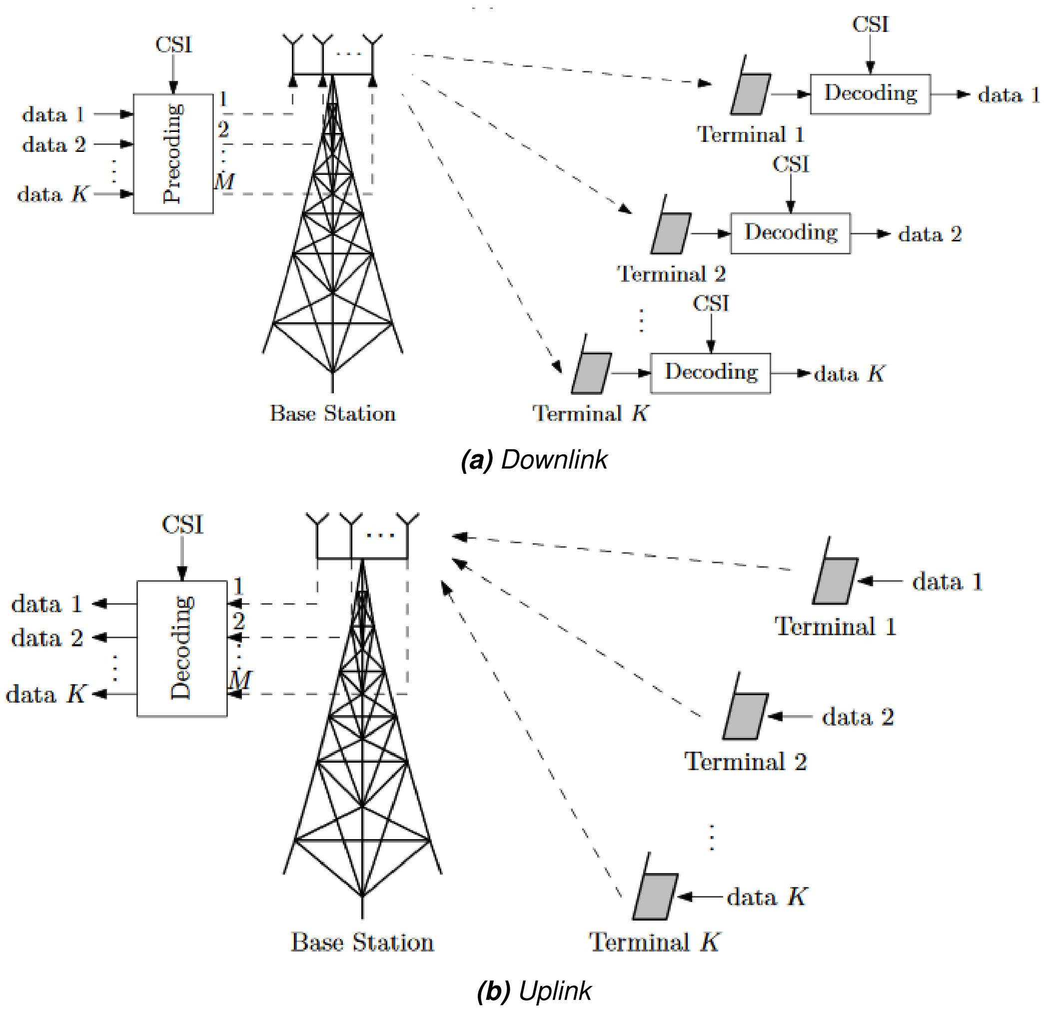
$$C_{\mathrm{ul}} = \log_2 \det \left(\mathrm{I}_M + \frac{\rho_{\mathrm{ul}}}{K} \mathbf{H}\mathbf{H}^{\mathrm{H}} \right) \tag{3.1}$$

$$C_{\mathrm{dl}} = \log_2 \det\left(\mathrm{I}_M + \frac{\rho_{\mathrm{dl}}}{M}\mathbf{H}\mathbf{H}^{\mathrm{H}}\right) \tag{3.2}$$

Here $\mathbf{H} \in \mathbb{C}^{M\times K}$ is multiple-access channel matrix, $\rho_{\mathrm{ul}} \in \mathbb{R}_+$ and $\rho_{\mathrm{dl}} \in \mathbb{R}_+$ are SNR per terminal for uplink and downlink, respectively. To make ρ_{ul} and ρ_{dl} constant, normalization done by M and K. Above equations are considering ideal situations and channel coding schemes for and terminals which almost not possible to achieve.[36]

3.1.2 Multiuser MIMO

MU-MIMO is a system which will use same time-frequency resources for a single to serve multiple terminals. Assuming terminals of MU-MIMO are single-antenna systems and are less complex than point-to-point MIMO K-antenna terminals. Basically, the single-antenna terminals are usually separated by several wavelengths and the terminals can't operate together, either in uplink or downlink. Here different terminals are spatially multiplexed. Figure 3.3 describes a simplified MU-MIMO system which is having $\mathbf{M}$-antenna base station and $\mathbf{K}$ single-sntenna terminals.



***(a)** Downlink*

***(b)** Uplink*

***Figure 3.3.** MU-MIMO System having M-antenna and a terminal of K-antenna [35]*

If TDD is the operation methods, then multiple-access and broadcast channel capacity in terms of uplink it will be same as 3.1 and for downlink it can be

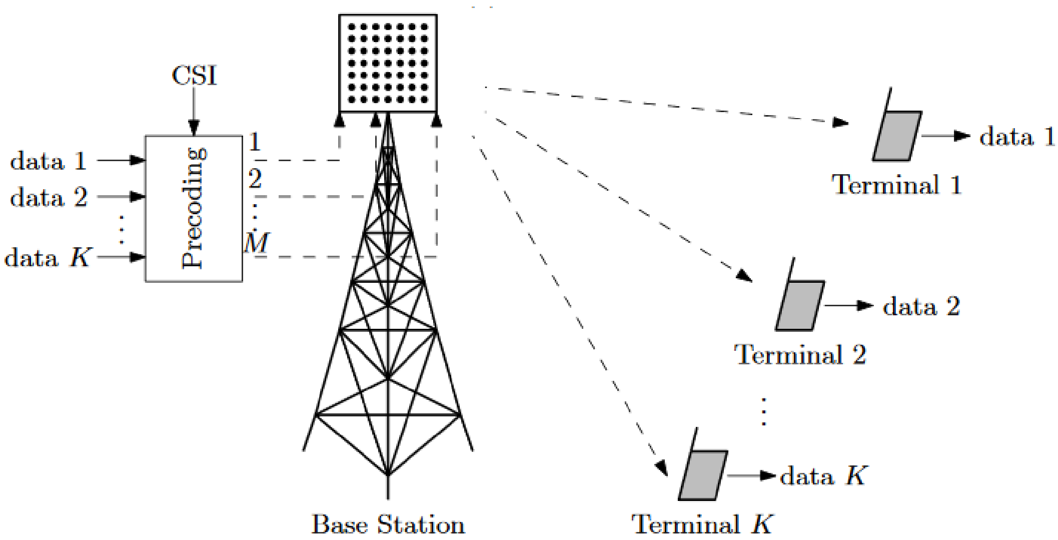
$$C_{\mathrm{dl}} = \begin{cases} \mathrm{maximize}_{\mathbf{p}\in\mathbb{R}_{+}^{K\times 1}} \log_2 \det\left(\mathbf{I}_M + \rho_{\mathrm{dl}}\mathbf{H}^{*}\,\mathrm{Diag}(\mathbf{p})\mathbf{H}^{\mathrm{T}}\right) \\ \text{subject to } 1_K^{\mathrm{T}}\mathbf{p} = 1 \end{cases} \tag{3.3}$$

where $\mathbf{H} \in \mathbb{C}^{M\times K}$ is describing multiple-access channel matrix, power calculation described by $\mathbf{p} \in \mathbb{R}_{+}^{K\times 1}$.$\rho_{\mathrm{ul}} \in \mathbb{R}_{+}$ and $\rho_{\mathrm{dl}} \in \mathbb{R}_{+}$ are SNR per terminal for uplink and downlink respectively. In these equations CSI knowledge has been assumed. For uplink knows about the channels and terminal should know about transmission rate which is permitted due to required capacity. On the other hand for downlink, both ends need to know about required capacity.[36] MU-MIMO having advantages compare to Point-to-point MIMO, its having less sensitivity and it requires single-antenna terminals.

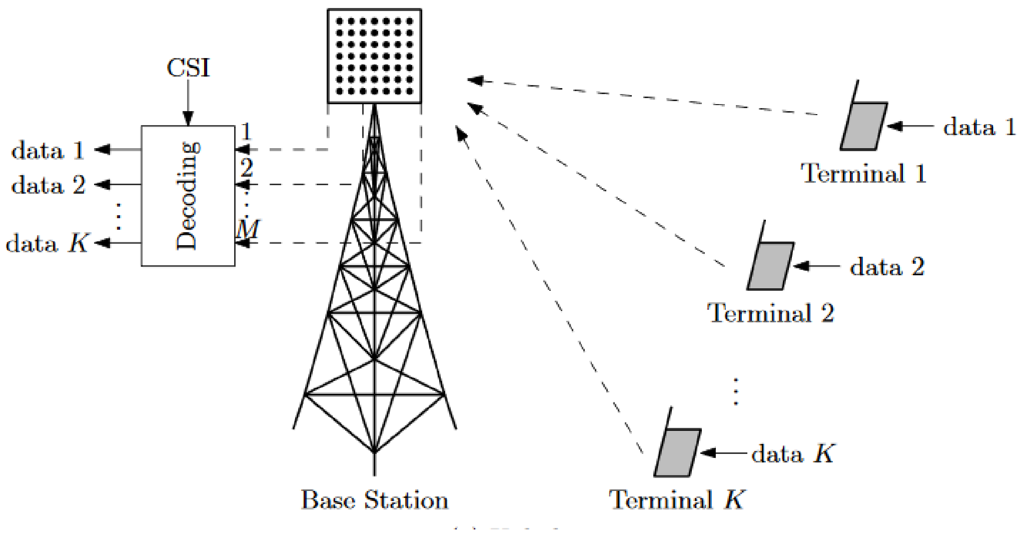
3.1.3 Massive MIMO

Massive MIMO is improved version of MU-MIMO as it aimed for the solution of the main issues of MU-MIMO. There are three fundamental differences between Massive MIMO and MU-MIMO. Here it consider that only BS can read about H for which single-antenna terminals may be cheaper than MU-MIMO. On the other hand M needs to be much higher than K which will show increasing capacity rate with reducing power of each separate antenna. Moreover linear digital signal processing is used by both ends.[27]

Here in figure 3.4, it shows a simple single-cell massive MIMO with M-antenna and a K single-antenna terminal. For both forward and reverse link, all terminals need to use full time-frequency resources continuously. The base station needs to extract exact signals transmitted by terminals for reverse link and also ensure the signals which are intended by particular terminal receivers. Here base station's multiplexing and de-multiplexing can be possible for utilization of large number of antennas and also utilization of CSI. [27]



***(a)** Downlink*



***(b)** Uplink*

***Figure 3.4.** Massive MIMO System having M-antenna and a terminal of K-antenna [35]*

4 BEAMFORMING AND DIFFERENT APPROACHES

4.1 Beamforming

Beamforming is a technique that directs a wireless signal to a particular receiving unit, rather than spreading the signal in all directions, as it would usually be. The resulting direct connection is quicker and more reliable than without beamforming.[37] In general, beamforming uses multiple antennas to monitor a wave-front path by properly measuring the magnitude and phase of individual antenna signals in a multiple antenna array.

4.1.1 Digital Beamforming

Digital beamforming can be explained by precoding or baseband beamforming. Before RF transmission the signal is precoded (amplitude and phase modifications) in the processing of the baseband. Multiple beams (one per user) can be generated from the same collection of antenna elements simultaneously. Digital beamforming enhances cell efficiency, since it is possible to use the same PRBs (frequency / time resources) to simultaneously relay data to multiple users.

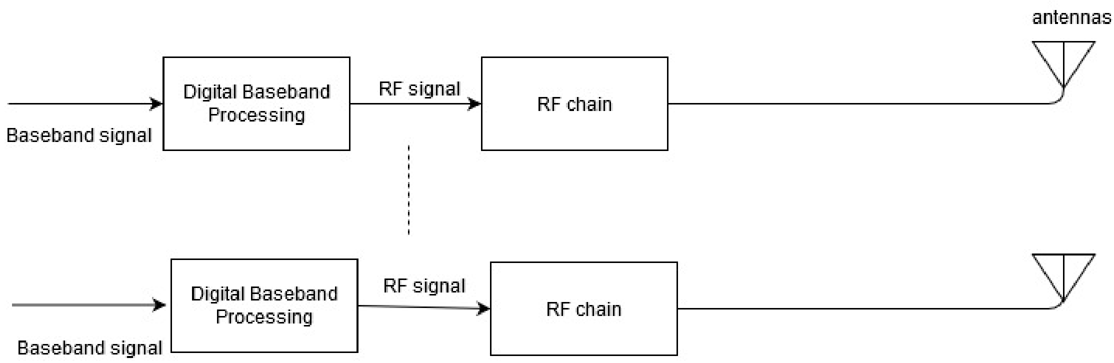


Figure 4.1. *Basic Diagram of Digital Beamforming [38]*

Figure 4.1 describing the whole digital beamforming structure. MU-MIMO technique is applicable with digital beamforming. However its preferred to be implemented in base station side due to reduce complexity and hardware cost.

4.1.2 Analog Beamforming

In this pattern of architecture, an analog beamformer is built with one RF chain and multiple shifters across the antenna elements.[39] In RF domain the signal phases of individual antenna signals are modified. Analog beamforming impacts the pattern of radiation and antenna array performance, thus increasing coverage the antenna gain boost that the analog beamforming provides partially overcomes the effect of high pathloss in mmWave.

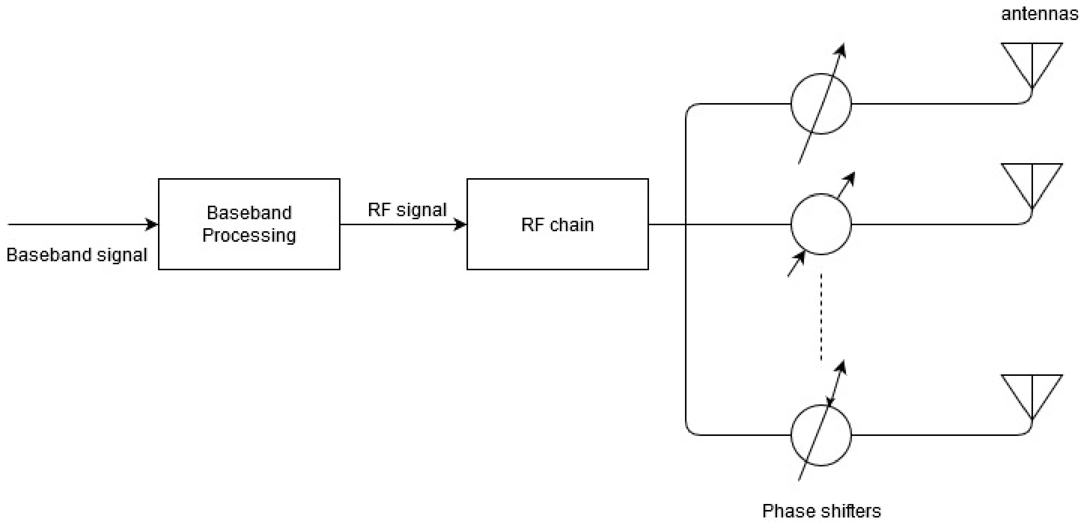


Figure 4.2. *Basic Diagram of Analog Beamforming [38]*

Figure 4.2 represents analog beamformer with one RF chain, this type of beamforming being used widely in range of system such as radar and short-range communication system as IEEE802.11 ad.[40] Benefits of this beamformer are cost effective and simple to implement. Moreover one RF chain can transmit one stream at a time.

4.1.3 Hybrid Beamforming

Its a combination of analog and digital beamforming. There is a form of hybrid beamforming which is decided to use in mmWave gNB(in 5G). For MU-MIMO or SU-MIMO, it can be designed to use analog beams in a coarse of beamforming, and using a digital beam inside analog beam as per required.

Figure 4.3 shows a fully connected system of hybrid beamforming where each RF chain is linked to a particular number of phase shifters and to all antennas. In sub-connected architecture each RF chain is assigned to a sub-array of phase shifters. Here full-connected beamformer having higher gain than sub-connected setup. But its complicated to implement.

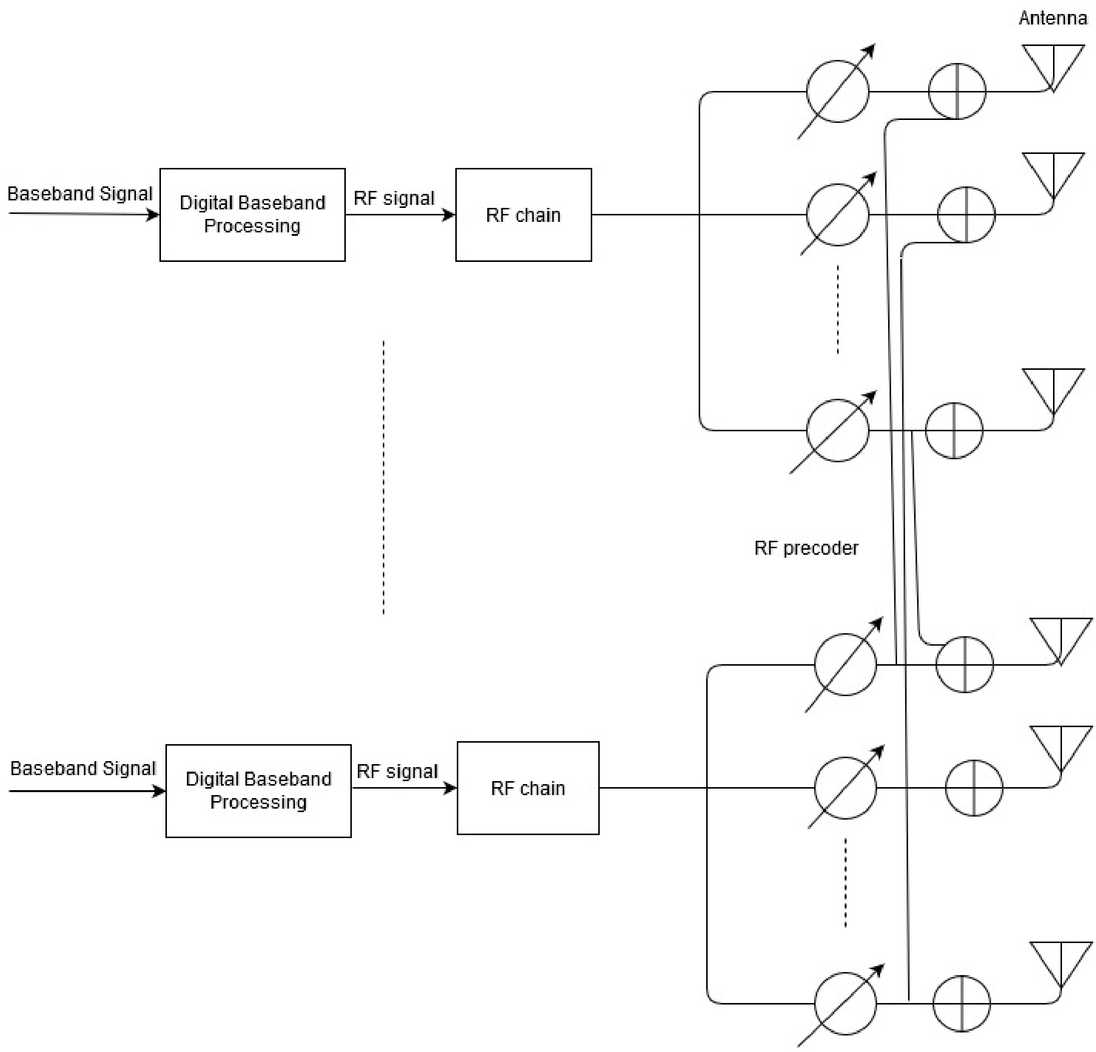


Figure 4.3. *Basic Diagram of Hybrid Beamforming [38]*

4.2 Eigen Beamforming

Eigen Beamforming (EBF) is the basic form of algorithm for downlink of Single-user MIMO (SU-MIMO). If channel matrix expressed with $\mathbf{H}$ for specific user end and its dimension will be $N_r \times N_t$ then it can be expressed as-

$$\boldsymbol{H} = \boldsymbol{U}\boldsymbol{D}\boldsymbol{V}^H \tag{4.1}$$

here $\mathbf{U}$ and $\mathbf{V}$ are unitary matrices that means, $\boldsymbol{U}^H\boldsymbol{U} = \boldsymbol{I}$ and $\boldsymbol{V}^H\boldsymbol{V} = \boldsymbol{I}$ whereas I is identity matrix. D is a diagonal matrix which diagonal components are singular value of H.

As eigen based beamforming will be generated with the value of singular values, then $\boldsymbol{D} = \mathrm{diag}\{\sqrt{\lambda_1}, \sqrt{\lambda_2}, \cdots, \sqrt{\lambda_r}\}$ where λ_i is the eigen values of $\boldsymbol{H}^H\boldsymbol{H}$. [41]

If required data is s and received data is $\hat{s}$, conjugate transpose of first column of U which is denoted as $\boldsymbol{u}_1^H$ and first column of V is $\boldsymbol{v}_1$, then

$$\hat{\boldsymbol{s}} = \boldsymbol{u}_1^H \boldsymbol{H} \boldsymbol{v}_1 \boldsymbol{s} = \boldsymbol{u}_1^H \boldsymbol{U} \boldsymbol{D} \boldsymbol{V}^H \boldsymbol{v}_1 \boldsymbol{s} = (\sqrt{\lambda_1}, 0, \cdots, 0) \begin{pmatrix} 1 \\ 0 \\ \vdots \\ 0 \end{pmatrix} \boldsymbol{s} = \sqrt{\lambda_1} \boldsymbol{s} \tag{4.2}$$

From equation 4.2 it will be cleared that required data will be received with gain $\sqrt{\lambda_1}$.

4.3 Zero-forcing Beamforming

Zero-forcing Beamforming (ZFBF) is spatial signal processing for multiple antenna wireless devices. For downlink, ZFBF algorithm permits a transmitter to transmit data for desired user and nullified the directions of unwanted user. On the other hand for uplink, ZFBF receives only desired signal and nullified the unwanted signals. It also known as null-steering which sum up the techniques of zero-forcing precoding.[42] When transmitter knows all about CSI of a particular downlink, ZF based precoding will gain system optimal capacity for sufficient numbers of users. Otherwise it will show decrements in resulting output of ZF based precoding. To gain full gain precoder need to have feedback overhead with respect to SNR. If CSI in transmitter is not correct there will be huge throughput loss due residual multiple users interference, then it can not be possible nullified the interference.[43] If there is a model of MIMO which will be having multi-user beamforming system of N_t for downlink, then received signal can be written as-

$$y_k = \mathbf{h}_k^T \mathbf{x} + n_k, \quad k = 1, 2, \ldots, K \tag{4.3}$$

where $\mathbf{x} = \sum_{i=1}^{K} s_i P_i \mathbf{w}_i$ is $N_t \times 1$ vector for transmitted data, n_k is noise value in scalar, $\mathbf{h}_k$ is downlink channel coefficient of $N_t \times 1$ vector, $\mathbf{w}_i$ is the linear precoding matrix.

For uplink this system's received signal will be

$$\mathbf{y} = \sum_{i=1}^{K} s_i \mathbf{h}_i + \mathbf{n} \tag{4.4}$$

where s_i will be the transmitted data for user i, n is noise,$\mathbf{h}_k$is downlink channel coefficient of $N_t \times 1$ vector, Here ZFBF prrecoding matrtix will gain after having perfect CSI where matrix will choose to be normalized rows of inverse of the channel matrix $[\mathbf{h}_1, \mathbf{h}_2, \cdots, \mathbf{h}_M]$. If CSI value become imperfect, then this matrix will not be orthogonal to the channel matrix.

4.4 Eigen based zero-forcing beamforming

Eigen Zero-forcing (EZF) beamforming is based on EBF but it will reduce ZF to handle Multi-User Interference (MUI). If we assume channel matrix of k-th user end as $\boldsymbol{H}_k$, then decomposed value with SVD will be:

$$\boldsymbol{H}_k = \boldsymbol{U}_k \boldsymbol{D}_k \boldsymbol{V}_k^H \tag{4.5}$$

For initial beamforming vector assuming largest eigenvalue is $\boldsymbol{v}_{K1}$. Here equivalent matrix will be $\boldsymbol{H}_{eq} = (\boldsymbol{v}_{11}, \boldsymbol{v}_{21}, \cdots, \boldsymbol{v}_{K1})^H$, from which we can calculate beamforming matrix as[44]

$$\boldsymbol{W} = \boldsymbol{H}_{eq}^H \left(\boldsymbol{H}_{eq} \boldsymbol{H}_{eq}^H\right)^{-1} \tag{4.6}$$

4.5 Regularised Eigen based zero-forcing beamforming

Regularised Eigen based zero-forcing beamforming (REZF) algorithm will be described like k number of user having rank named as $\boldsymbol{r}_1$. As per eigen value decomposition, $\mathbf{H}_k^H \mathbf{H}_k = \mathbf{V}\mathbf{D}\mathbf{V}^H$ will be found and then dominant eigen vectors of each user to form matrix $\boldsymbol{H}_{eq}$ -

$$\mathbf{H}_{eq} = \begin{bmatrix} \mathbf{V}_1^H (:, 1 : r_1) \\ \mathbf{V}_2^H (:, 1 : r_2) \\ \vdots \\ \mathbf{V}_K^H (:, 1 : r_K) \end{bmatrix} \in \mathbb{C}^{R \times N} \tag{4.7}$$

Here R is sum of rank of k number of user.Matrix of eigen vectors is $\boldsymbol{V}_k$ for user k. Then descending eigenvalues matrix $\mathbf{W}$ will be

$$\mathbf{W} = \mathbf{H}_{eq}^H \left(\mathbf{H}_{eq} \mathbf{H}_{eq}^H + \lambda \mathbf{I}_R\right)^{-1} \tag{4.8}$$

where λ is real constant which value depends on noise variance ad matrix dimension. Since $\mathbf{A} = \mathbf{H}_{eq} \mathbf{H}_{eq}^H + \lambda \mathbf{I}_R$ is hermatean and positive definite. Then we can rewrite the equation of $\mathbf{W}$,

$$\mathbf{W}\mathbf{A} = \mathbf{H}_{eq}^H \tag{4.9}$$

4.6 Block Diagonalisation

BD method is an improvement on the ZF method by increasing each transmission's spatial diversity. The signals are merged and sent from all transmitters. The recipient's Block Diagonalisation process then decodes the received signal to cancel unwanted symbols and other interference at the recipient.

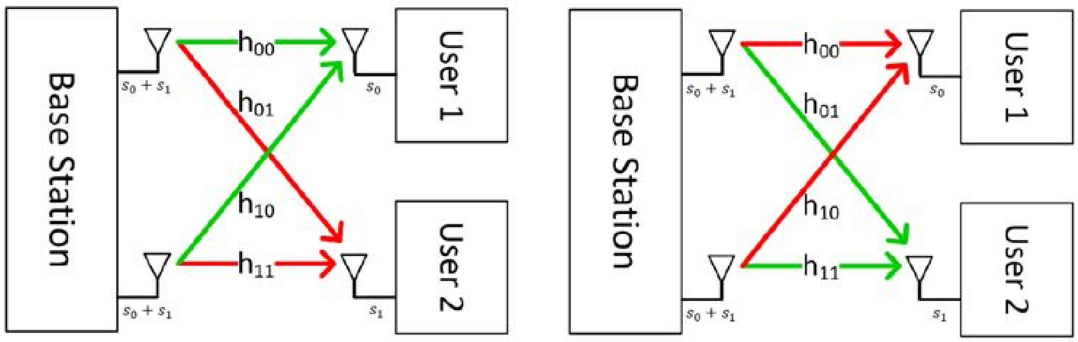


Figure 4.4. *BD taking benefits of the spatial diversity of MIMO systems*

Here in figure 4.4, BS wants to transmit data symbols from s_0 to Rx_1 and s_1 to Rx_2 and both symbols will be combined and transmitted from both transmitters. Therefore, we have twice the amount of useful streams that arrive at each receiver that contains the symbol we wanted. Consequently, spatial diversity is growing. The quantity of usable streams that arrive at the desired receiver is equal to the sum of transmit antennas. The receiver then requires a decoding method to isolate these previously combined symbols in order to obtain the correct symbols. For this reason, the value of s_1 discarded at Rx_1 and the value of s_0 cancelled at Rx_2.

The basic concept is to pick a precoding matrix $\mathbf{W}$, to get exact block diagonal matrics of $\mathbf{W}$ * $\mathbf{H}$. All interference and unused symbols will be exactly deleted due to having block diagonal matrix. This can be done by selecting $\mathbf{W}$ to be within each $\mathbf{H}$ value's nullspace (as H shifts for each target user). $\mathbf{W}$ will be found with unitary columns. Singular Value Decomposition (SVD) of channel matrix will be required to gain all of this conditions.

There are two precoding filter which will provide BD precoding algorithm via SVD operations. First precoding filter will eliminate the MUI with noise due to this operation nearly parallel SU-MIMO channels will be obtained. Second filter will be used in parallelise each user's streams.

4.6.1 Singular Value Decomposition

SVD is a mathematical function with will factorise a real and complex matrix which related to eigen decomposition function.[45] To generate factorization of a complex matrix, SVD operation diagonalise this matrix and give three matrices:

$$M = U\Sigma V^T \tag{4.10}$$

Here in 4.10 Σ means Diagonal matrix with the same dimensions as M with non-negative diagonal elements in decreasing order. The diagonal entries are the non-negative square roots of the eigenvalues of MM^T. Moreover U and V is a unitary eigenvectors matrix of MM^T with m by m and n by n dimension respectively.V^T is hermitian transpose of M. Here SVD needed to get MIMO channel capacity.

4.7 Regularised Block Diagonalisation

Regularized Block Diagonalisation (RBD) precoder removes the restriction of total number of receive antennas to be less than or equal to total number of transmit antennas and does not necessarily create nulls towards all the victim UEs, and is a generalization of the BD precoder. Here precoding matrix determined in two steps, firstly multi-user interference suppression by transmitting in the space spanned by the effective channel matrices of victim users with the power that is inversely proportional to the singular values of the combined channel matrix of these users.Next step is to determine the dominant eigen directions in the projection of the user's channel in the sub-space determined in the previous step. When N_u User ends are in the beneficiary set of BS k and assuming SU-MIMO for convenience, $\widetilde{H}_k$ is computed by excluding the k-th User end's channel from the composite channel matrix of scheduled user ends in the same cluster, i.e.H_{kk} omitted.

$$\tilde{H}_k = \begin{bmatrix} H_{1,k}^T & H_{2,k}^T \ldots\ldots.H_{k-1,k}^T & H_{k+1,k}^T \ldots\ldots..H_{N_{u,k}}^T \end{bmatrix}^T \tag{4.11}$$

Beamforming matrix for the transmission of k-th channel is given as $P_{k,k}^{cbf} = F_a \cdot F_b$, where F_a computed as $F_a = \mathrm{M_a D_a}$. Here $\mathrm{M_a}$ is a unitary matrix and D_a is a diagonal power loading matrix, all these components can be found from SVD operation on $\tilde{H}_k$

$$\widetilde{H}_k = \widetilde{U}_k \widetilde{\Sigma}_k \tilde{V}_k^H \tag{4.12}$$

$$\mathrm{M_a} = \tilde{V}_k and D_a = \left(\tilde{\Sigma}_k^T \tilde{\Sigma}_k + \frac{M_R \sigma^2}{P_k} I_{N_T} \right)^{\frac{-1}{2}} \tag{4.13}$$

M_R is the number of receive antennas $(N_r^{\star} N_u)$ and $\sigma^2$is the noise variance and I_{N_T} identity matrix of $N_T x N_T$ where N_T is transmit antennas at BS. P_k is total transmit power of BS k. The channel matrix $\left\| \widetilde{H}_k F_a \right\|^2$ is reduced and F_b can be found from SVD of the user's channel projected in the sub-space determined for MUI suppression.[46]

$$H_{k,k} F_a = U_k \Sigma_k V_k^H$$

$$F_b = V_k$$

Then the final precoding matrix will be

$$P_{k,k}^{cbf} = F_a V_k \tag{4.14}$$

4.8 Signal to Leakage Noise Ratio

SLNR uses an alternative approach to the other algorithms studied earlier.[47] Here leakage means interference caused by signal which is required for one particular signal but it leaked onto other unwanted users. This kind of activity ensures waste of power. The main perspective of this algorithm is to keep this leaked power near to zero as much as possible.Moreover SLNR precoding select beamforming coefficients to maximizeSLNR for all users randomly rather then perfectly cancelling out interference at each user.

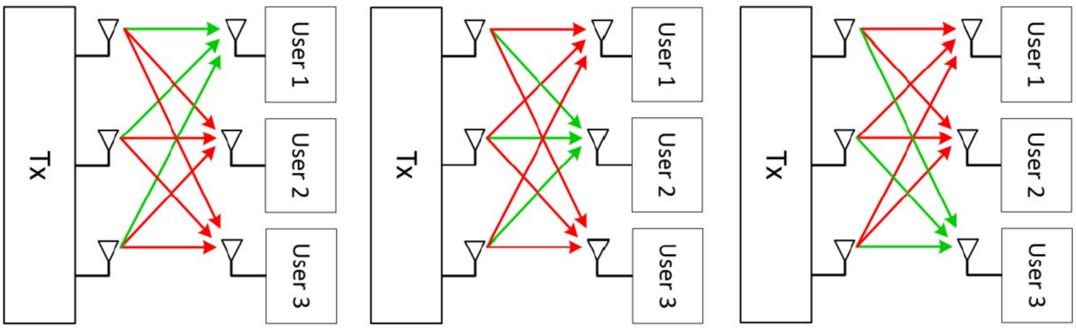


Figure 4.5. *SLNR algorithm, Red links showing leaked values.*

Figure 4.5 describes a MIMO scenarios where three users are randomly contacting BS. Like with BD here all transmitters also communicate with each user. For every user scenario, The required power will arrive at the correct receiver. Whereas some signals will be leaked onto other receivers which create co-channel interference. Here SLNR will make this unwanted power as low as it can and make the desired signal as large as possible. This algorithm is reverse of earlier algorithm, and that's why here Signal to interference plus noise ratio (SINR) at the site of input of receiver,

$$SINR_i = \frac{\|H_i w_i\|^2}{M_i \sigma_i^2 + \sum_{k=1,k\neq i}^{K} \|H_i w_k\|^2} \tag{4.15}$$

here $\|H_i w_i\|^2$ means equivalent power of desired signal component of user i. At very same moment part of transmitted power can be leaked onto other users. So we can explain leakage power featured to user i as $\sum_{k=1,k\neq i}^{K} \|H_k w_i\|^2$

Its equivalent to $LI = \left\|\widetilde{H}_i w_i\right\|^2$. Here received signal power needs to be huge in ratio with leakage power to satisfy the algorithm, then ratio will be

$$SLNR_i = \frac{\|H_i w_i\|^2}{M_i \sigma_i^2 + \left\|\widetilde{H}_i w_i\right\|^2} \tag{4.16}$$

For 4.16 equation M_i is number of received antennas and σ_i^2 is the variance of AWGN. If AWGN is assumed to be zero, then the power is equal to variance. Therefore SLNR operation does not require any dimension condition related to the number of transmit or receive antennas.

5 RESULT OVERVIEW

5.1 System Model

Here in modelling a system we choose a particular scenario where parameters are being defined and then executed with previously discussed beamforming approaches. Results will show the throughput as a function of SNR where multiple users and base stations are available. Generally throughput means a rate of production or rate of generated data. In terms of communication like Ethernet or packet data its defined as a successful message delivery over a communication channel.[48] As per theory knowledge it must to have higher number of throughput correspond to SNR, which will show algorithm success. Throughput usually measured in bits per second(bit/s) but for this model simulations consider per channel use.

Initially we implement a general scenario which is bearing several numbers of receiving antennas and transmitting antennas. Here we assume noise will be AWGN and for calculation easiness and it will be 1. Here we assume a range of SNR to get the variation in different algorithm and have a conclusion based on that. For channel, normally distributed random function which will show $\mathbf{N_t} \times \mathbf{N_r}$.

In first phase we are comparing ZF with WF power allocation and without WF. Here WF algorithm is a way in digital communications system to allocate power among different channels in MIMO system. This process is also similar to pouring water in cell. Total amount of WF power allocation is proportional to SNR and algorithm also shown in figure 5.1.[49]

In MATLAB SVD used for calculation to get Channel to interference noise ration (CNR) from square a diagonal matrix. Here we also take in account about interference which is not theoretically needed but we used it to make it practical. Here we first create precoding matrix for each streams and then with the help of this preceded matrix we also calculated interference which we are keeping for practical scenarios. As this value is considering against each streams all values need to be summed up. Signal can be generated with the value of channel and precoded matrix. As now we are having signal power values, interference amount and noise power value, we can calculate SINR. $SINR = \frac{S}{I+P_N}$ where S is the received signal, N is the noise and I is the interference power.

The throughput by definition is the maximum data rate transmitted by the communication system. In the theoretical limit it is equal to the Shanon channel capacity. The spectral

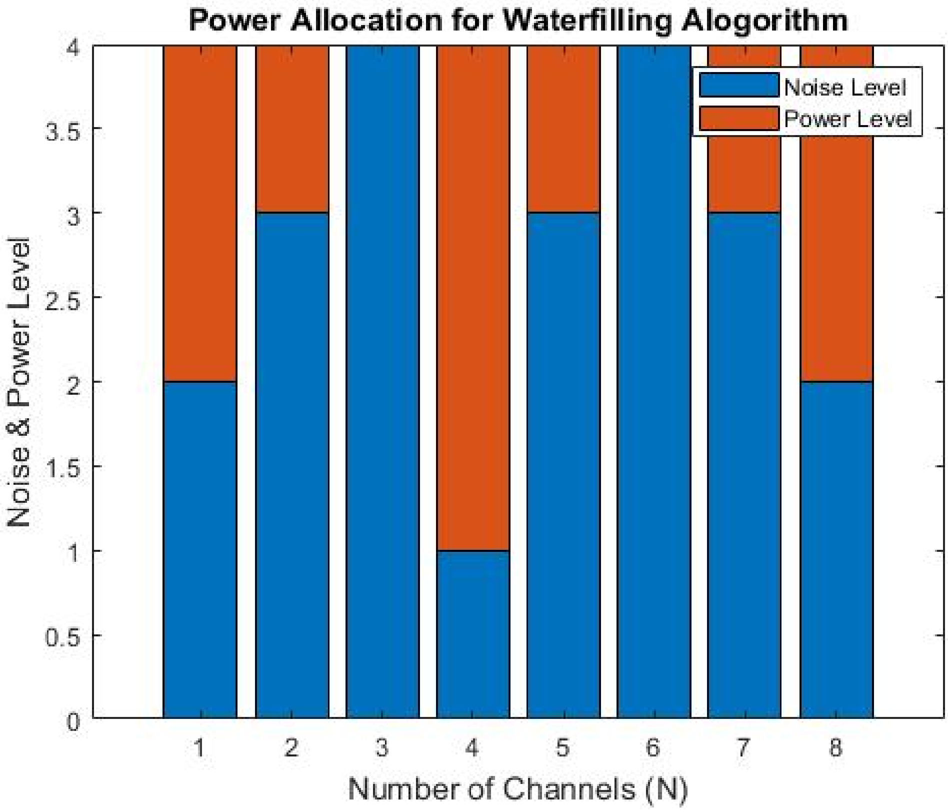


Figure 5.1. *WF power allocation algorithm*

efficiency Th is the ratio of the transmitted data rate $\mathbf{r_b}$ divided by the channel bandwidth B.

According to to Shanon, there is a relation between the spectral efficiency and SINR provided that the interference signal is like to noise such that: $Th = \log_2 1 + SINR$. So, in order to increase spectral efficiency for a given channel one has to increase its SINR. This is basically for Single Input Single Output (SISO).

According to figure 5.2 for multiple input multiple output wireless channel with $\mathbf{N_t}$ transmit antenna and $\mathbf{N_r}$ receive antenna, one can reuse the bandwidth of the channel many times such that the bandwidth multiplicity can reach up to min ($\mathbf{N_t}$ and $\mathbf{N_r}$). Then if $\mathbf{N_r}$=$\mathbf{N_r}$, then the bandwidth will be multiplied by $\mathbf{N_r}$. For the same SNR, one can increase the data rate by $\mathbf{N_r}$. So, the same channel for SISO with data rate of $\mathbf{r_b}$ can transmit data rate up to $\mathbf{N_r}$ $\mathbf{r_b}$ for $\mathbf{N_t} \times \mathbf{N_r}$ MIMO system. The multiplicity of the bandwidth can be achieved only if $\mathbf{N_t}$ independent paths exist in the space between the transmit and receive antenna arrays. This is called space division multiplexing which can be substitution. It can be done with bandwidth, the number of antennas, the signal power at receiver side, the interference power at receiver and the noise power at input of the receiver in the above Shanon formula to get the required channel capacity.

Later on EZF,REZF,SLNR are also implemented. Initial process for EZF,REZF were same but for SLNR required some more steps to add as its having equation related $\delta^2 I$ which means noise power to make EZF calculation more stabilized. EZF,REZF both are

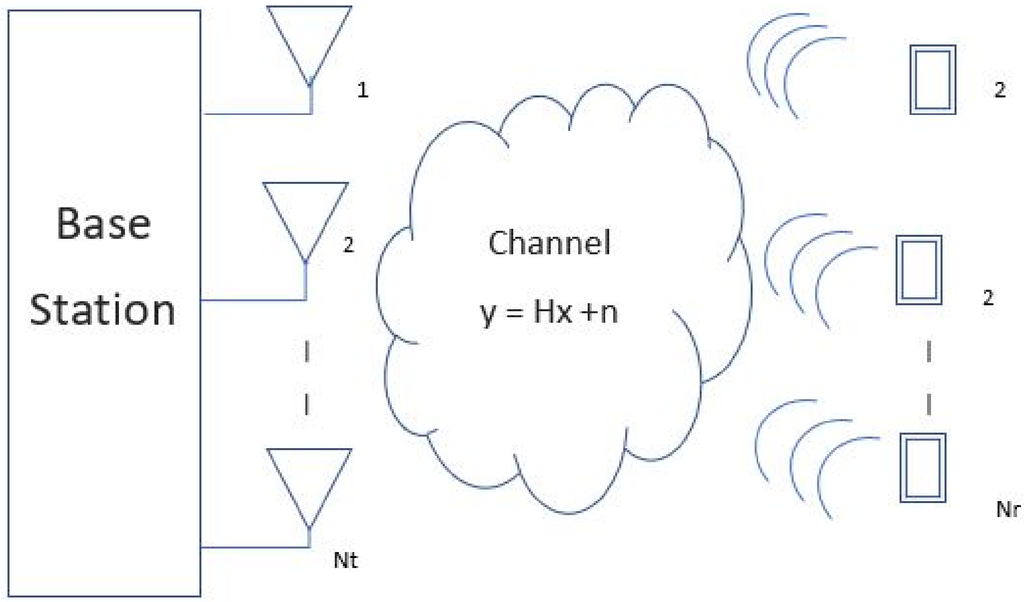


Figure 5.2. *General model scenario*

having equivalent channel $\mathbf{H_{eq}}$, which is basically conjugate transpose of eigenvector which can be decomposed from SVD equation.

In general if all approaches need to be simplified then it can be like, precoding algorithms generated based on individual approaches in a numerical programming environment. This was used to create a model simulation of throughput calculation of several theoretical scenarios. This can be got from changing different variables. The algorithm can be compared against themselves of against each other, to draw theoretical conclusions on their overall performances.

As there are some limitations in every approaches few assumption can be made on basis of theory. Transmission was models at a bit level in terms of channel, each bit which was sending must need to be precoded. In practical situation transmission occurs at a packet level so each packet of bits is precoded. Perfect CSI is difficult to achieve as algorithms performs optimally. A Multiple Input Single Output (MISO) model is assumed where multiple antennas used at base station (transmitter) and user(receivers) had one antenna each but multiple users communication the base station. Power level of transmission need to be same otherwise each receiver can efficiently receive data from each transmitter.

The nature of wireless channels are stochastic. So in each realization there will be a random value (scalar/vector/matrix). To have an average here is a need to have many samples of them. That's why we iterate the channel realization. And this makes the overall rate performance to become a smoother curve.

Here model designed with precoding algorithm by using MATLAB. This was generated so that a representation of result relating with throughput and SNR range can be displayed.

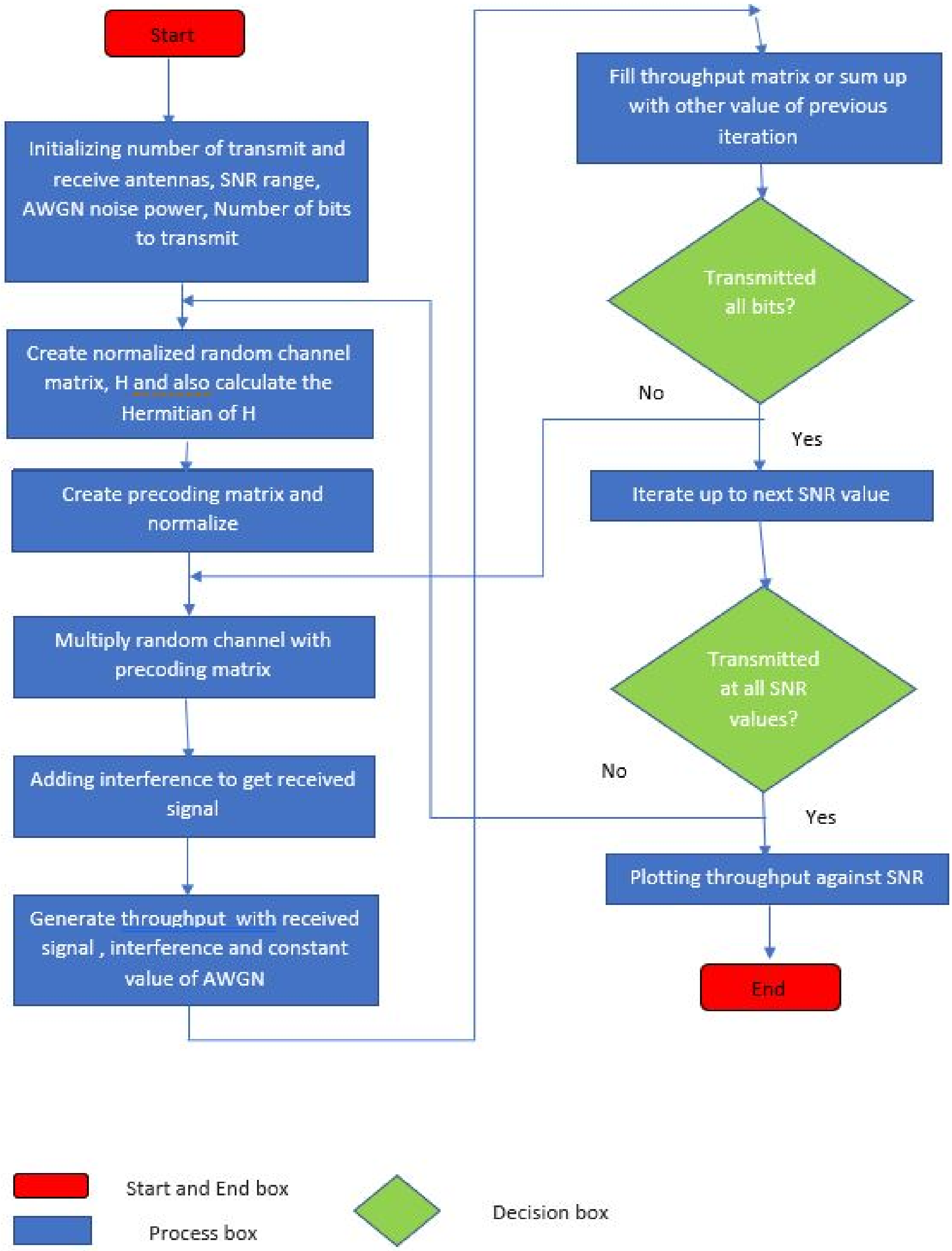


Figure 5.3. *General Block Diagram of implementation in MATLAB*

This could be received by changing some calculation and variables based on scenarios and different approaches.

Figure 5.3 shows a flowchart which provides a general view of MATLAB model worked. Here two 'for' loops are available. First cycle is about SNR ranges which will add the amount of AWGN added to transmitted signal depends on. The second cycle is dealing with number of symbols its going to transmit. Due to deal with stochastic channels it will average each integration's random value. CSI will generate $\mathbf{N_t}$ X $\mathbf{N_r}$ matrix. Each SNR iteration, each use of channel corresponds to individual matrix of $\mathbf{H}$.

5.2 Result Discussion

As in this scenario we assumed that multiple antennas will be used at transmitter side, and there will be multiple users connectivity available with base station. But each user will have only one receive antenna, that is why it shows similarity with MISO. There is consideration of memory-less components as very first received bits assumed to be dominant multipath. It is assumed that only AWGN acting on given SNR range. As it considered that only individual bit can be sent and it would be precoded separately. But in practical situation a packet consist of bits will be precoded.

First compared scenario is SVD algorithm and ZF with WF and without WF. As it is considering MU-MIMO scenario, multiple beams will be transmitted from BS. With variable iteration number output having several changes in Throughput corresponding to SNR.

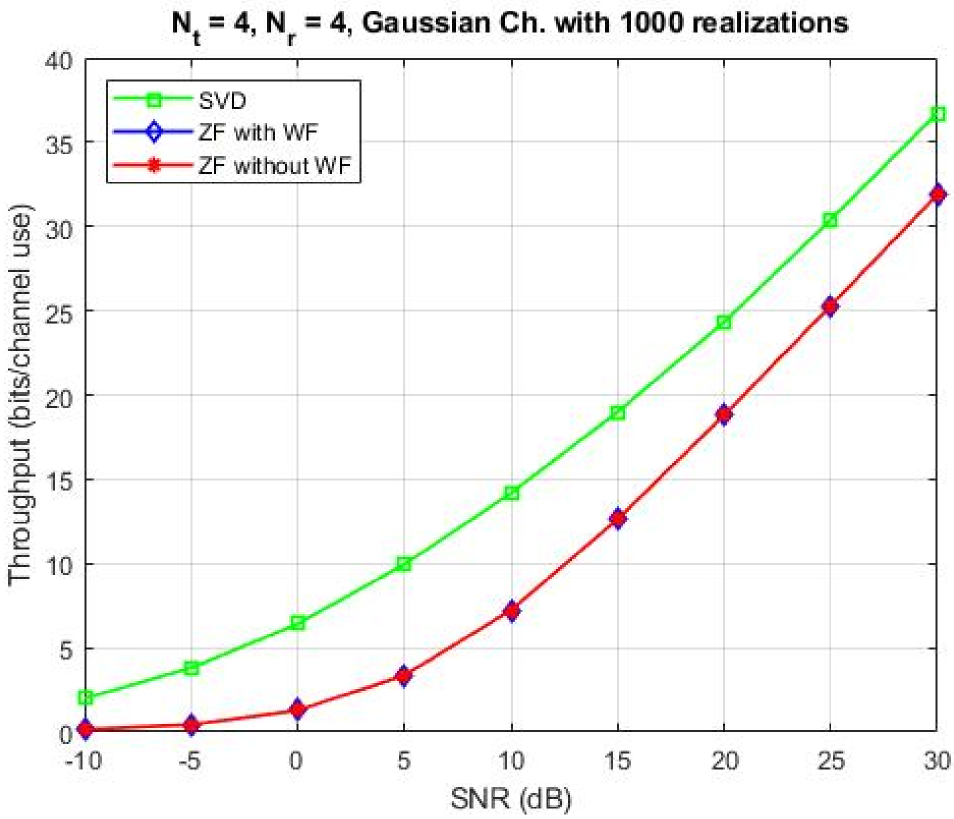


Figure 5.4. *Throughput vs SNR graph for MU-MIMO System,iteration value =1000*

In figure 5.4 represents graph that shows increasing of SNR is proportional to throughput changes. But throughput increment depending on the value of signal and SINR. Its gradual changes takes the average sum of every bit transmission.

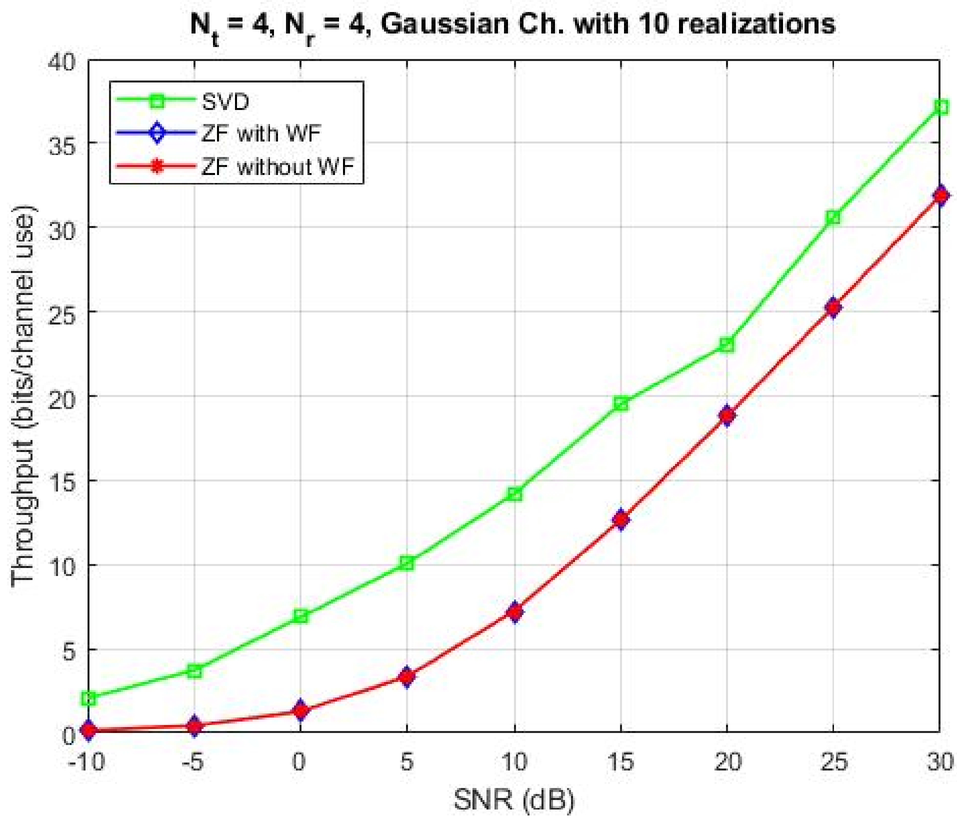


Figure 5.5. *Throughput vs SNR graph for MU-MIMO System,iteration value =10*

In figure 5.5, increment of SNR is proportional to throughput changes. But throughput gradual development is depending on the value of signal and SINR. It also having some variation in result due to having range of SNR. It also consider normalized matrix as pre-processing.

In figure 5.6, it shows a graph having gradual increment of SNR is proportional to throughput changes which is having sharp increase. Whereas SVD is not considering interference as per definition which is practically not possible to implement. Moreover ZF with or without WF having same result and same improvement and it also consider interference. So its more practical then SVD.

In figures 5.4, 5.5, 5.6, graphs are showing result where the value of iteration got decreased and it shows less smoothness in graphs. As assumed channel are having stochastic, it's having sharpness according to higher number of realization. On the other hand as its about MU-MIMO, so number of transmitting and receiving antennas will be large. So we tried to vary the numbers of these antennas for further cases with best iteration value.

Further investigation can be came out to compare three coding approached to each other in terms of changing antenna numbers of both end. Figure 5.7 shows that 4 individual antenna based users are connected to base station. As per algorithm execution there is no significant throughput changes due to spatial diversity.

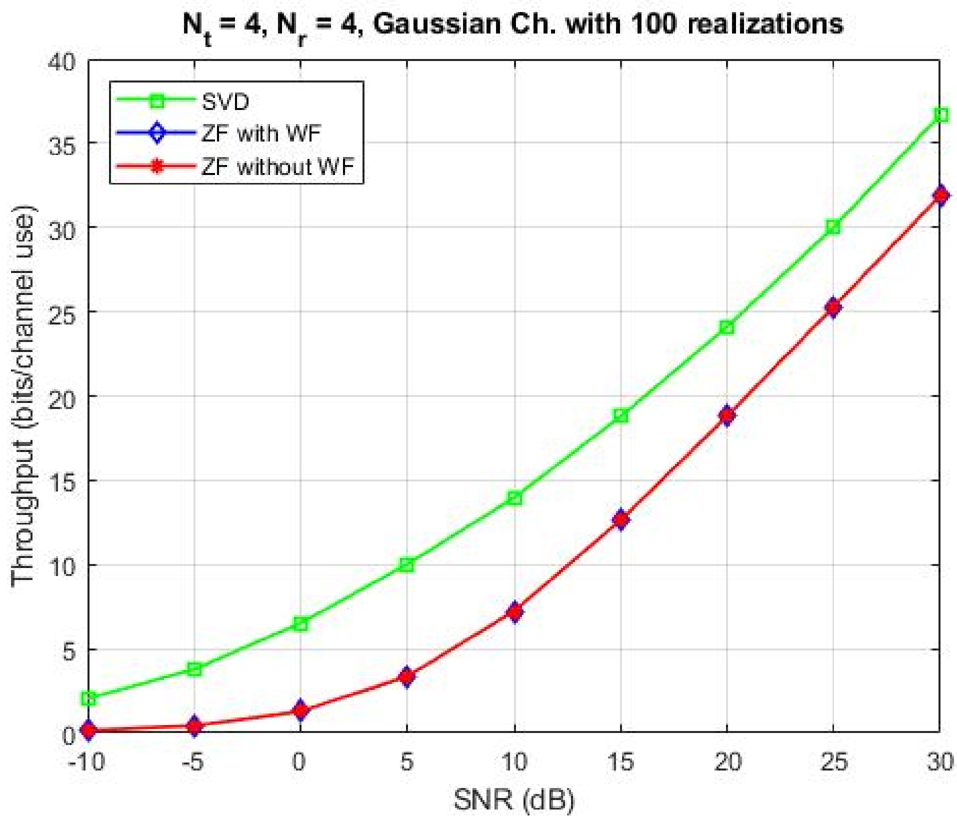


Figure 5.6. *Throughput vs SNR graph for MU-MIMO System,iteration value =100*

In figure 5.8 user number increased to 8 with 8 transmitter and 8 receivers in the channel. The amount of co-channel interfering streams got doubles for each receivers. That's why the differences among SVD and ZF with or without WF increased. Based on interference consideration make some differences as well. On practical basis ZF is better than SVD because it also consider noise with interference. Power allocation distributed by WF also showed gradual smooth approaches correspond to each bit transmission.

In figure 5.9 and 5.10 it tested with 16 and 32 users respectively with maximum of iteration number so that it can show smooth performance in terms of throughput corresponding to increasing SNR due to stochastic channel. Here SVD performs well comparing to two other approaches showing high diversity confirms hypothesis of this approach. But differences between ZF and ZF are getting increased which has impact due to interfering tendency of signals and also consideration both noise and interference. Though huge number of receiving antennas create a lower output on point of throughput but SVD is tough to implement in practical.

Here in figure 5.11 and 5.12 several downlink precoding methods for multi-user is implemented. There performances decided by the amount of throughput in graph corresponding to SNR variation. Here regularised ZF showing better throughput than REZF and EZF. Regularised ZF showing less complexity as eigen based method are dealing dom-

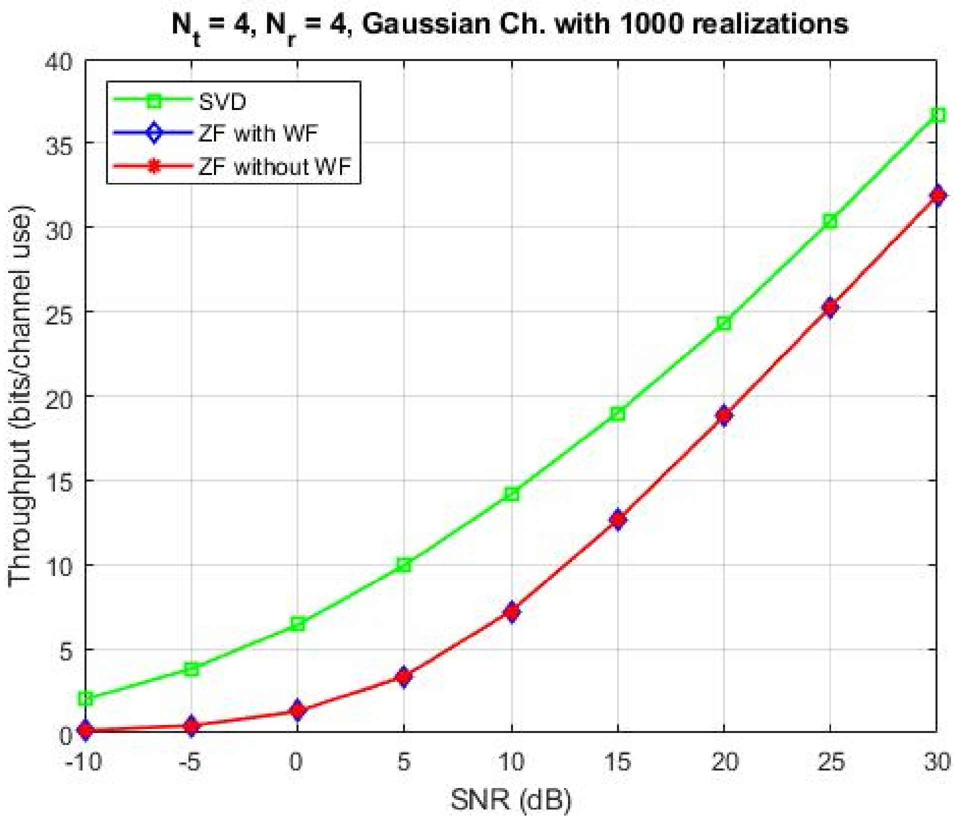


Figure 5.7. *Throughput vs SNR graph for MU-MIMO System,Transmitting antennas= 4 and Receiving antennas=4*

inant channel which having more complexity to implement. Moreover all ZF approaches without SVD is giving performance graph considering interference and noise though performance curve having variety of changes in range of throughput.

SLNR is complicated to implement as it required correct leakage amount of power. Its somehow showing near about constant values for throughput against variable SNR. As SLNR is probability oriented method and prioritise to generate precoding matrix W. But CSI is not instantaneous, SLNR predict precoding matrix which is not correct all the time. that's why its not getting near about zero values like SVD, ZF.

In terms of presenting all output in same plot, we assumed that every user is having one antenna. Because SVD is for SU-MIMO, whereas other approaches are good at single user as well as multiple user. Moreover all my perspective regarding results description, is based one same scenario. For this its easy to make a general comparison among all approaches.

In terms of implementing all approaches we need to normalised matrix and also need to have average value that create a visible changes in throughput range in terms of each bit transmission. Here Gradual raise in receiving antennas shows a raise in throughput

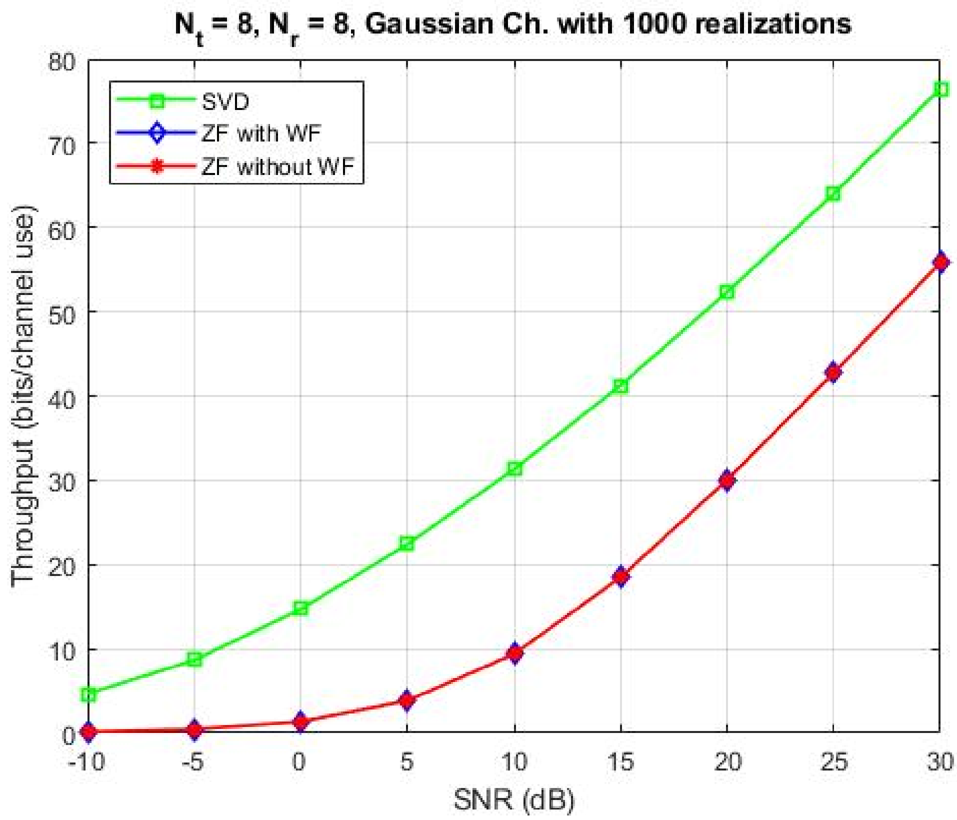


Figure 5.8. *Throughput vs SNR graph for MU-MIMO System,Transmitting antennas= 8 and Receiving antennas=8*

range. SVD, ZF with and without WF, eigen base ZF, and regularised ZF shows similar ranges of improvement in throughput respect to SNR. But rest of the two methods are having difference in throughput changes and bearing a big gap in between. On the other hand when we focus on regularised ZF it shows certain change when number of antennas in both hand is low. Each scenario bear 2:1 ratio in transmitting and receiving end. But bigger number of antennas also having some effect in these graphs.

Furthermore when the curve of regularized EZF and SLNR showed a different scenario. when its about lower SNR up to range on 10 dB it gradually develop performance rate but after that when the SNR is raising its throughput shows some saturation point of increment. Though these two approaches having gap in throughput ranges as well. As complication and complexity need to be less considerate, ZF approaches are good. For more specified way ZF with WF and without WF, eigen based ZF are the best implementation in terms of good throughput. Every and each approaches having some complexity but its appreciated which can be implemented practically and good for future network.

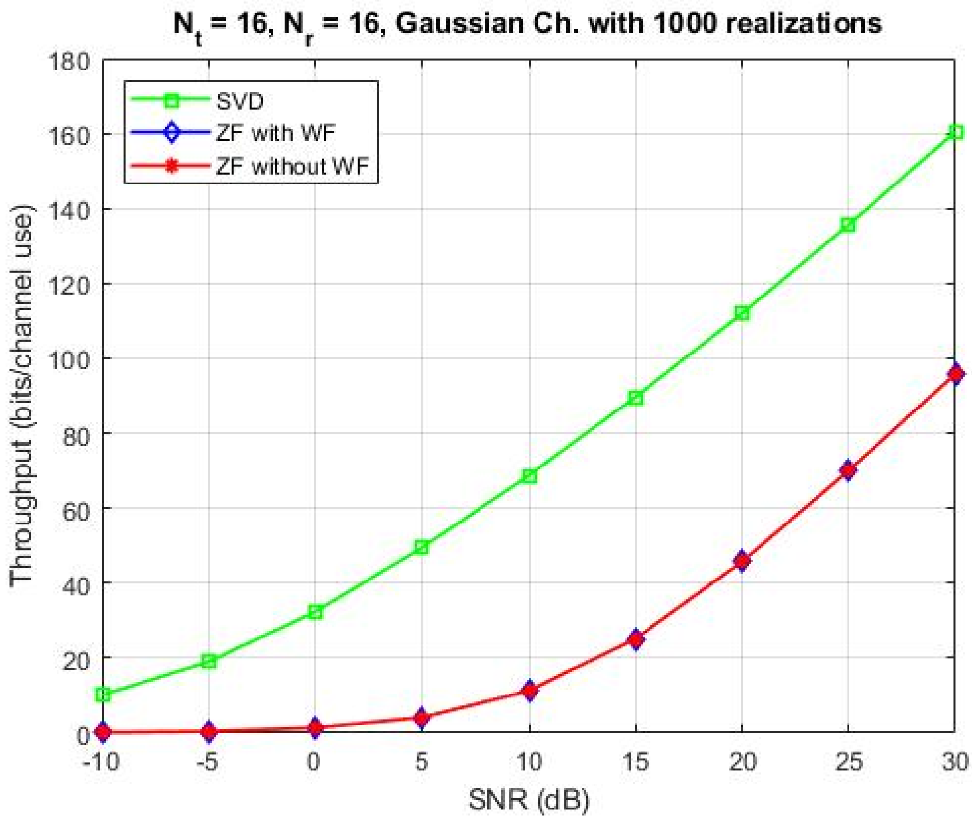


Figure 5.9. *Throughput vs SNR graph for MU-MIMO System,Transmitting antennas= 16 and Receiving antennas=16*

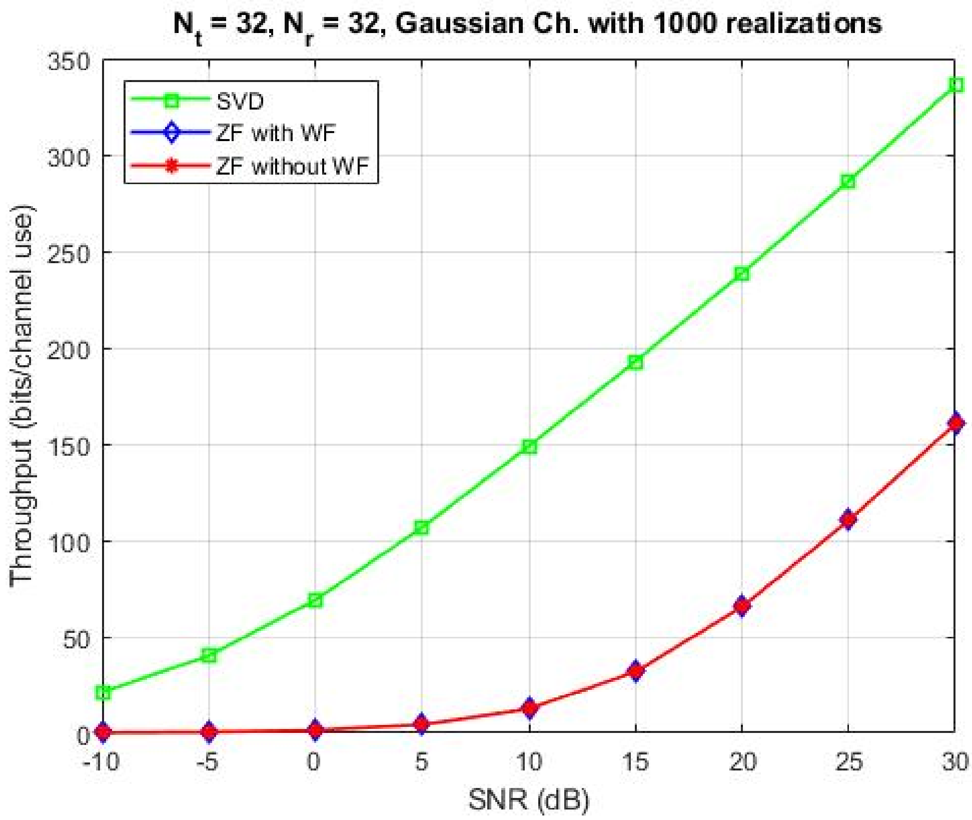


Figure 5.10. *Throughput vs SNR graph for MU-MIMO System,Transmitting antennas= 32 and Receiving antennas=32*

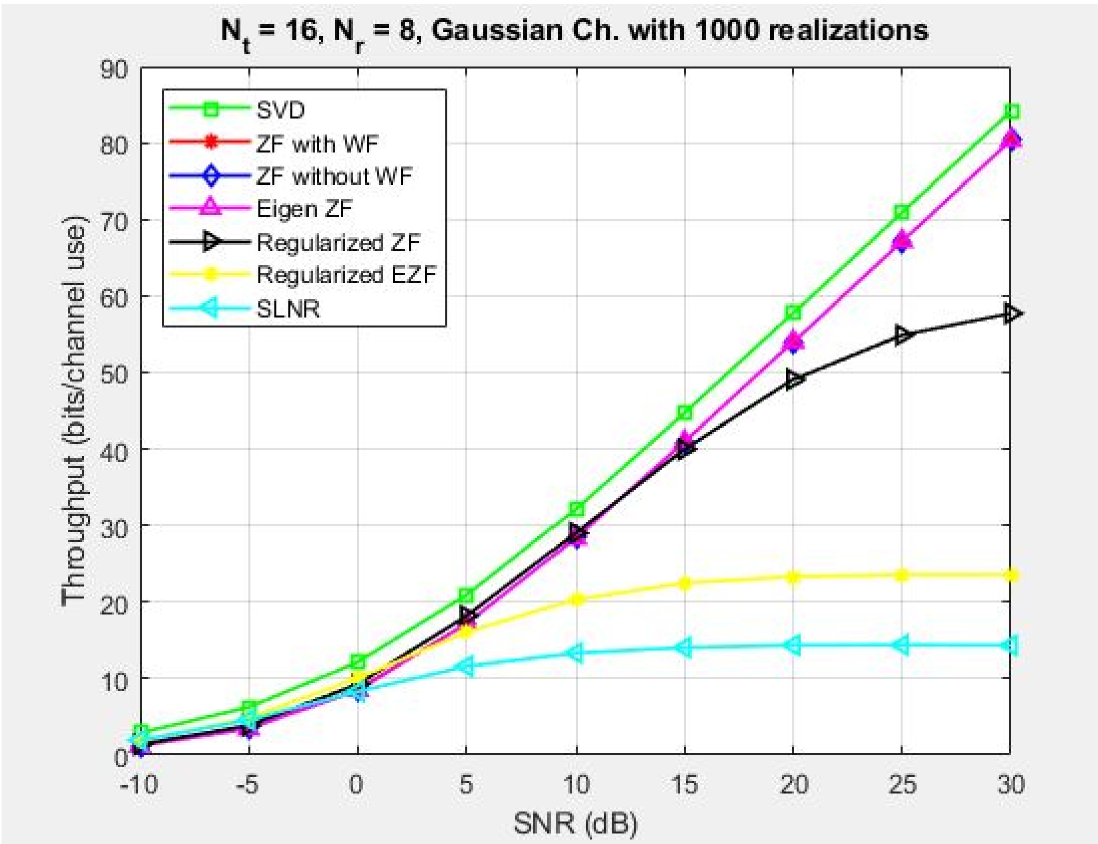


Figure 5.11. *Implementing all algorithm for Throughput vs SNR graph,Transmitting antennas= 16 and Receiving antennas=8*

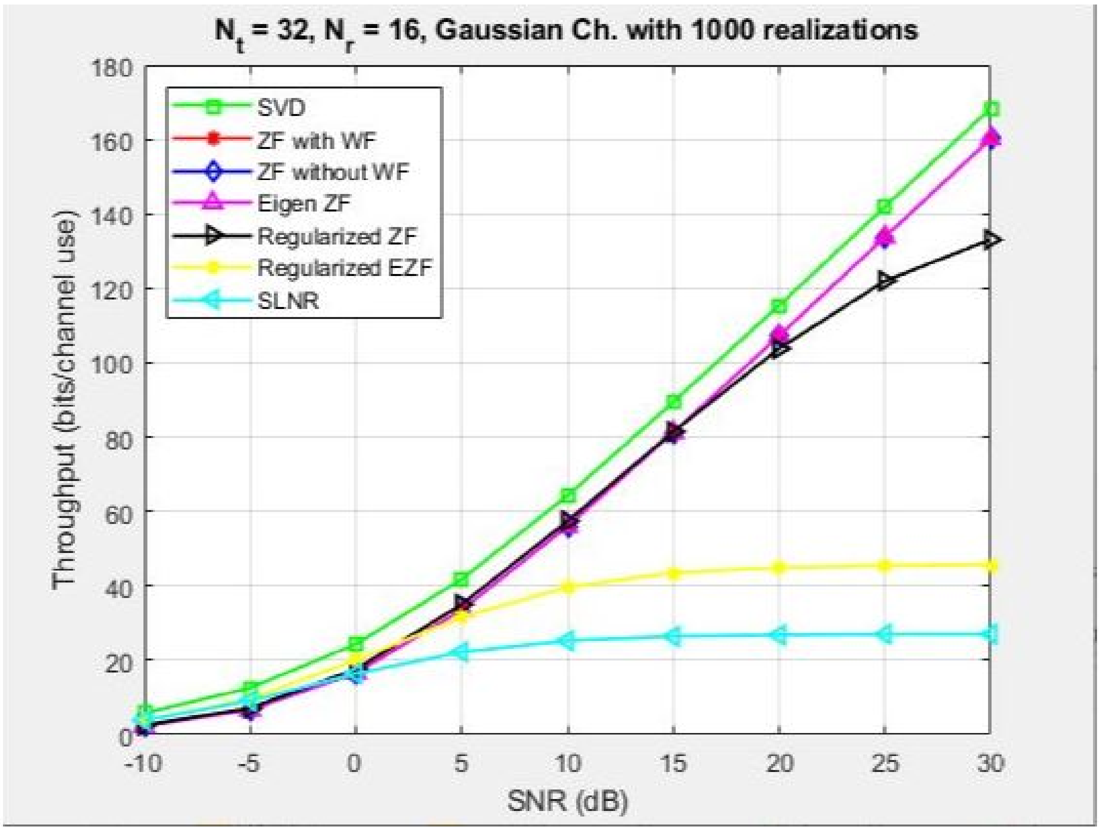


Figure 5.12. *Implementing all algorithm for Throughput vs SNR graph,Transmitting antennas= 32 and Receiving antennas=16*

6 CONCLUSION

Nowadays communications systems need to provide a huge capacity jump with increased quality of service. For this there is an important aspect considered in this thesis regarding beamformed MIMO systems. The main objective of the thesis was to study the theory and analyse about the coding techniques which related to co-channel interference problems and accuracy about output in receiving end in a MIMO system. This was studied through a software model considering pros and cons of a particular scenario with focus on ZF beamforming and its different approaches.

In this thesis, beamforming technology is considered to introduce a new era for 5G, and beyond. Beamforming technology has many advantages for high-end networks. Pre-coding based algorithms for ZF beamforming shows good performance with nulling interference of separate users near to zero. So we can manage to have low latency high availability in network that is having less impact of interference which is exactly required by new phase of network.

In the thesis there were different tested scenarios in terms of iteration numbers and antenna numbers for both ends (transmitter and receivers). Moreover after implementation of these changes in same scenario, a gradual changes found in output signal which clear about the aspect of reducing or increasing interference and leakage of a particular data transmit. In step-by-step process ZF got its attention why future requirements need to focus on this approach and there is a slight comparison available with SVD and SLNR. Here a suitable assumption made towards using ZF on basis of theory and software based coding.

In MATLAB simulation of algorithms like SVD, ZF with and without WF, EZF, REZF, Regularised zero-forcing beamforming (RZF), SLNR were implemented with different user numbers. All users were having one antenna though the scenario was based on MIMO. Here its assumed to take less number receiving antennas than transmitting antennas, because only REZF will qualify without this condition. Otherwise every other algorithm involves matrix dimension issues. SVD and ZF with and without WF shows good throughput counting with the increasing amount of SNR. Regularised ZF has an average performance output of success correspond to SNR. The rest of the two execution such as SLNR and REZF are not as good as expected as per theory. So, here it can be concluded that, ZF with and without WF are proven beneficial from the implementation aspect, as they are less complicated than the other ZF approaches.

In the given theoretical background it is discussed that ZF need to show best output in terms of throughput in its all approaches. However, SVD was giving good result in terms of increased SNR also while changing the numbers of iteration and users numbers. In terms of lower SNR there is a slight increment in throughput of REZF but it remains saturated later on with a minimal numbers of throughput corresponding to other approaches. More effective results shows for SVD and gradual changes for ZF approaches. In SLNR select beamformimng coefficient to get maximize values, so perfect cancellation of interference is not mandatory unlike other approaches.

The broad assumption in this thesis is that each transmitter knows CSI perfectly and instantaneously. Practically coding techniques are used in frequency domain. So it proves in a fundamental way that with perfect CSI all techniques work well. For future research different approaches with imperfect CSI should be considered.

To summarise, the selection of algorithm depends on the specific scenario. If low computational complexity is required with lowest amount of AWGN, then ZF is the best option. If performance need to be nearly error free with high quality of service, then SLNR can offer a good solution. For general basis SVD shows most effective result in many aspects, but due to lack of consideration of interference and noise it gets less priority.

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