

ZERO FORCING PRECODER BASED MULTIUSER MIMO SYSTEM USING K-MEAN GROUPING

*Thesis submitted towards the partial fulfilment of requirement
for the award of degree of*

Master of Engineering

In

Wireless Communication

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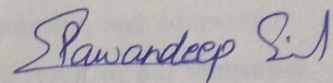
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DECLARATION

I Pawandeep Singh, hereby, declare that the work presented in the thesis entitled "Zero Forcing Precoder Based Multiuser MIMO System Using K-Mean Grouping" by me in partial fulfilment of the requirements for the award of degree of Master of Engineering in Wireless Communication from Thapar University, Patiala, is an authentic record of my own work under the supervision of Dr. Ankush Kansal, Assistant Professor, Electronics and Communication Engineering Department. The matter presented in this thesis has not been submitted in any other University/Institute for the award of any other degree.

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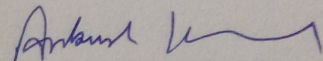


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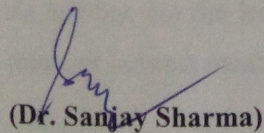
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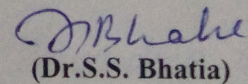
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ABSTARCT

In today's world, the demand for high speed data is increasing at fast pace as the number of wireless based applications are increasing day by day. Next generation wireless communication systems have to achieve very high throughput and provide security in order to fulfil the desire for faster and reliable communications. But present generation systems cannot achieve higher data rates because of scarcity in band limited spectrum for wireless communication. So the technique called Multiple Input Multiple Output (MIMO) comes for the rescue from such situation.

MIMO is the most promising technique for providing outstanding reliability and exceptionally high data rates. In this technology multiple antennas are used at the transmitter as well as receiver side which helps to exploit the various properties of the systems. Further, this system has been extended to the multiuser scenario. As in today's world, there has been very large number of users for the wireless communication system. But, there is large number of problems like reduced capacity, interference, security etc while accommodating all users in the system. So, there needs to be system which can accommodate large number of end users by providing them the reliability and the high data rates along with reduction of interference. This can be done by using large number of antennas at the base station and by using some user grouping algorithms, which group the users based on the various properties. Along with that, the precoding technique called Zero Forcing can be implemented to further improve the system by reducing the interference.

In this dissertation work multiuser MIMO system using Zero Forcing precoding along with the K-mean grouping algorithm has been used to improve the sum rate of the system for the downlink case. The total of 100 antennas at base station and 100 users having single antennas has been considered. For SNR of 15 dB, the sum rate for proposed precoder for ($g = 2$) is 11 bits/sec/Hz which is almost 1.7 times more than the conventional zero forcing algorithm.

Further in this dissertation work, the optimization of the user grouping has been done. The sum rate keeps on increasing while the user groups are increased from two to four. But suddenly when the number of groups created reaches five, the performance of the system decreases.

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LIST OF ACRONYMS

SISO	Single Input Single Output
SIMO	Single Input Multiple Output
MISO	Multiple Input Single Output
MIMO	Multiple Input Multiple Output
SU-MIMO	Single-User Multiple Input Multiple Output
MU-MIMO	Multiple-User Multiple Input Multiple Output
AWGN	Additive White Gaussian Noise
CSI	Channel State Information
CSIT	Channel State Information at Transmitter
CSIR	Channel State Information at Receiver
SNR	Signal to Noise Ratio
SINR	Signal to interference plus Noise Ratio
ZF	Zero Forcing
MMSE	Minimum Mean Square Error
SVD	Singular Value Decomposition
DPC	Dirty Paper Coding
BER	Bit Error Rate
RZF	Regularized Zero Forcing
BS	Base Station
MAC	Multiple Access Channel
BC	Broadcast Channel
SDMA	Space Division Multiple Access

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CHAPTER 1

INTRODUCTION

In this chapter, discussion about the basic wireless communication along with the depiction of the basic block diagram. Also, the various challenges faced for implementation of such systems is discussed.

1.1 Wireless Communication

Wireless communication is, by any means, the fastest growing sector in the field of communication. During the last two decades, it has seen an exponential growth, which leads to the two billion users of the wireless cellular networks. The parallel growing of the wireless techniques as well the invention of wireless devices has led to the revolution which ensures the bright future for such systems.

The informative signals which were basically used in earlier days were the torch signals, flashing mirrors and encryptions on the walls etc [1]. As the times passed by, along with the development of technology, the electrical signals came into use for sending the information over places using different wireless devices. So, this further led to the research for betterment of transmission of such signals. Consecutively, the different modulation techniques, along with source coding and channel coding techniques were developed.

Along with this development, various transmission techniques which involve the transmission through antennas were also invented. By varying number of antennas at transmitter and receiver it is possible to provide secure and reliable transmission of the signal. So, the transmission strategies like SISO, SIMO, MISO and MIMO were developed. But as mentioned above, the cellular systems have seen rapid growth as there are already two million users of such systems and the number is still growing. So, to accommodate all these users and to provide the quality service at the expense of money, more reliable systems have been developed. One of the prominent examples of such systems is multiuser MIMO (MU-MIMO) system, which accommodate large number of users providing good quality of signal. To further enhance the quality, massive multiuser MIMO systems have been developed lately which provide us with good quality of signal and helps in fast transmission by providing higher capacity than the conventional systems.

1.2 Wireless Communication Block Diagram

For complete understanding of wireless communication, a block diagram, which includes important blocks depicting the whole process from transmission to reception of the signal, is presented below.

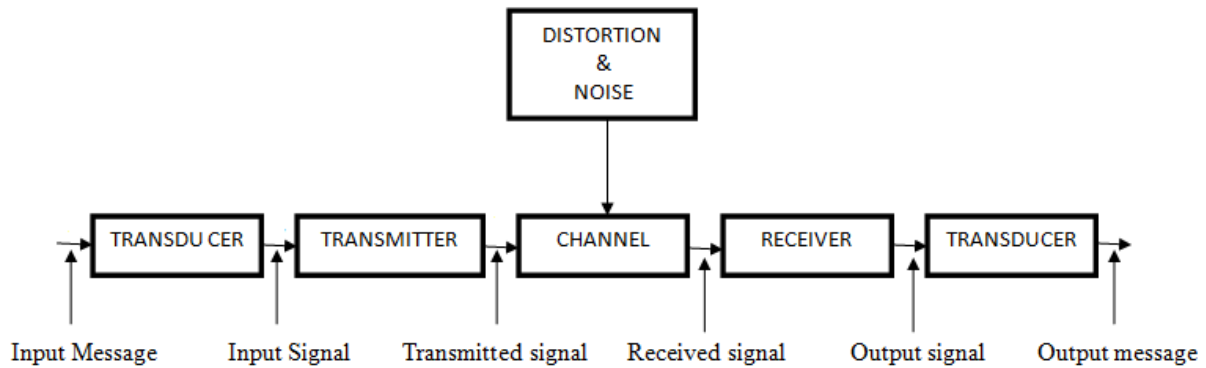


Fig 1.1 Wireless Communication Block Diagram

Transducer

It converts one form of energy into another form. In wireless communication, it converts the input message signal into the electrical signal of the required format and again converts this signal back from electrical signal to the required format at the receiver side.

1.2.1 Transmitter

Transmitter is a device which converts this electrical signal into the most suitable form for transmission over the wireless channel. At this device, various tasks for the transmission of the signal are performed such as modulation.

- **Modulation**

It is a process in which the various properties of the carrier signal of very high frequency are varied according to the modulating signal which carries the information. It is basically done to transmit data to far distances as high frequency signals are easy to transmit at large distances. So, the loss of information is reduced by modulation. It also helps to multiplex a large number of users on a single channel for transmission. The two main factors which affect the choice of modulation techniques are:

1. Power efficiency
2. Bandwidth efficiency

So among all modulation techniques, some are more bandwidth efficient and some are more power efficient.

- **Source Coding**

It is the type of coding done at the source where the information is generated. It helps to remove the redundant information coming along with the required signal. But, the removal of such information causes the reduction in the bandwidth requirement of the system. There are many different types of source coding like Huffman coding and Shannon Fano coding. These techniques encode the information data according to their probability of occurrence. The symbol which is occurring frequently have less number of bits dedicated to it whereas the symbol occurring less frequently has more number of bits assigned to it.

- **Channel Coding**

As its name specifies, it helps to reduce the probability of errors occurring during the transmission of data through the channel. Various channel coding techniques like parity check codes, linear block codes etc. help in detecting and correcting the errors at the receiver side. In this technique, each data symbol is protected by wrapping the data in some extra number of bits.

1.2.2 Channel

It is the medium for example the atmosphere in practical scenario, through which the signal passes while reaching the receiver. The characteristics of the channel define the fidelity of the received signal while it travels from transmitter to the receiver. A wireless channel behaves like a filter having impulsive response $i(t)$. So, the received signal $q(t)$ is

$$q(t) = x(t) * i(t) \quad (1.1)$$

Here, $x(t)$ is transmitted signal and $*$ defines the convolution. Ideally, it is shown as following

$$r(t) = A x(t - \tilde{t}) \quad (1.2)$$

The delay introduced is \tilde{t} . In frequency domain, signal is shown as

$$R(f) = A X(f) e^{-j2\pi f \tilde{t}} \quad (1.3)$$

$$H(f) = A e^{-j2\pi f \tilde{t}} \quad (1.4)$$

The magnitude response is given by A and $\phi = -j2\pi f \tilde{t}$ is the phase response of the channel.

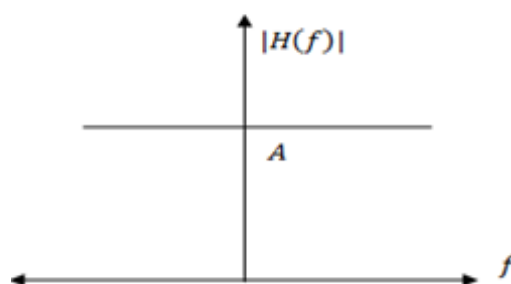


Fig 1.2 Magnitude Response of an ideal channel

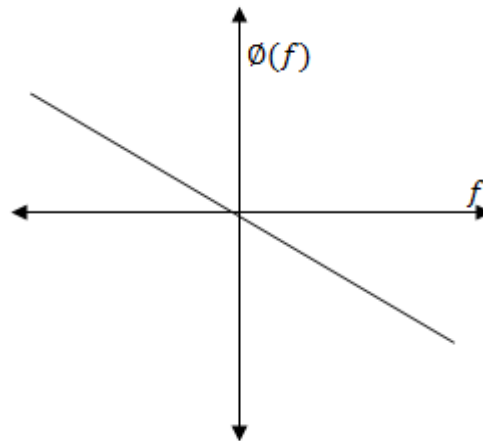


Fig 1.3 Phase response of an ideal channel

1.2.3 Distortion and Noise

- **Distortion**

Distortion occurs due to the characteristics impairment between channel and transmitted signal. When distortion in the signal persists, the shape of the signal gets modified. The two types of distortion which persists is amplitude and phase distortion.

Amplitude Distortion

It is the variation of magnitude over the band of frequencies for a given signal i.e. when the output amplitude of the signal is not the linear function of input signal. This type of distortion is definitely unwanted in audio, radio and telecommunication systems.

Phase Distortion

Due to the nonlinear response of the channel for the phase of the signal over the complete bandwidth of the signal, the phase distortion is introduced i.e. phase is not a linear function of frequency.

- **Noise**

Noise can be defined as the addition of the unwanted signal while the required signal is communicated from transmitter to the receiver. This presence of noise degrades the quality of signal received, thus signal decoding is not error free. As well as, it reduces the channel capacity of the system. Noise signal is random in nature i.e. it cannot be measured or predicted. So, it is an important task to model the noise present in the channel. Different type of noise present in channel is presented below:

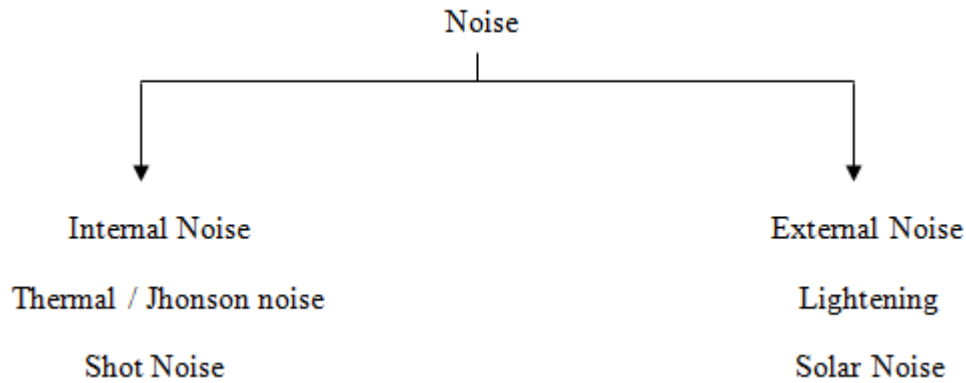


Fig 1.4 Types of Noise

- **Internal Noise**

Internal noise is generated because of haphazard movement of the electron within the circuit. So, it becomes difficult to avoid internal noise at any cost whereas the external noise which is caused due the various human activities can be controlled. As noise is a random process, so its modeling can be done using the Gaussian distribution. The distribution function is given as [2]

$$p(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(x-\mu_x)^2}{2\sigma^2}} \quad (1.5)$$

Here, μ_x denotes the mean and variance is denoted by σ^2 .

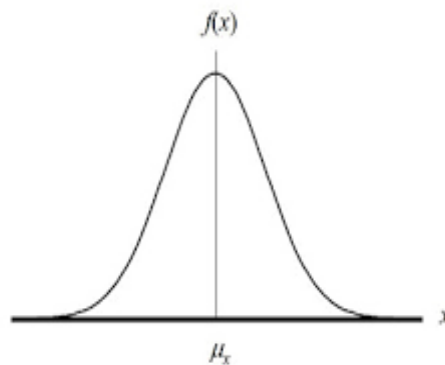


Fig 1.5 Gaussian Distribution [3]

1.2.4 Receiver

The receiver is a device where the exactly opposite operation of the transmitter is performed. This is basically done to recover the same signal which was transmitted. Then the transducer further converts the decoded form into the original form of the signal. The main functions which are to be performed by the receiver are following:

- **Equalization**

The process of multiplying the received signal by the inverse of $H(f)$; in order to remove the distortion introduced while transmission of signal. This method of removal of distortion is called the equalization which is shown as []

$$R_{eq}(f) = \frac{R(f)}{H(f)} \quad (1.6)$$

Where, $R_{eq}(f)$ is the received equalized signal and $R(f)$ is the received signal in frequency domain.

- **Demodulation**

It is the technique by which the message signal is separated from modulated carrier signal. All the techniques which are used during modulation, the same kind are applied at the receiver side too. For example if amplitude modulation is used at the transmitter then the amplitude demodulation should be used at the receiver.

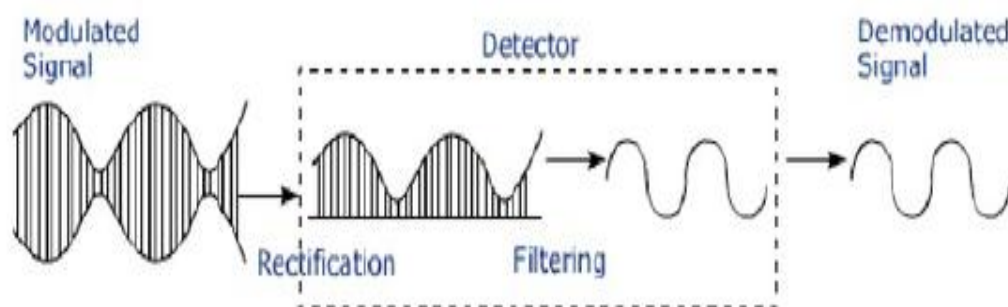


Fig 1.6 Amplitude Demodulation [4]

The main area of interest for individuals has been the capacity of the wireless channels which is discussed below:

1.3 Capacity of the Wireless Channels

The capacity of the wireless channel is defined as maximum data rate which can be transmitted through wireless channel such that the performance of the total system is still maintained by minimizing the errors and without any loss of the essential data. This could be possible if there is no condition on the complexity of the transmitter and receiver [1]. The idea about the channel capacity was first introduced by Claude Shannon in 1940 and the

mathematical proof was based on the information transferred mutually between transmitter and receiver [5].

1.3.1 Capacity of Time-Invariant Channels

These channels are the ones whose characteristics do not vary with time. Basically, the additive white Gaussian noise (AWGN) channel is time invariant channel. So, the capacity of such a channel having bandwidth B and transmitted signal power P is given by Shannon's theorem as [1]

$$C = B \log_2 \left(1 + \frac{P}{NB} \right) \quad (1.7)$$

Here, N is the spectral density of noise.

1.3.2 Capacity of Time-Variant Channels

These channels are the one whose characteristics vary with the passage of time. There are basically two different scenarios for knowledge of CSI of time variant channels.

- CSI only at receiver side
- CSI at both receiver and transmitter side

Depending on these two scenarios the channel capacity is computed differently i.e. for the CSI at the receiver side only and for CSI at the transmitter and receiver side.

1.3.2.1 CSI only at receiver side

In this case, knowledge about the CSI and distribution of the channel $p(\gamma)$ is known at the receiver side only, where γ is the signal to noise ratio. In this scenario, there are two different definitions for the capacity.

- **Shannon (Ergodic) Capacity**

It is the capacity averaged over the distribution of the channel CSI $p(\gamma)$. Due to this it is also called the ergodic capacity. In this scenario, due to the knowledge about channel at receiver only the transmitter send the signal at same rate to each receiver. Shannon capacity of time-varying channel is [1]

$$C = \int_0^{\infty} B \log_2(1 + \gamma)p(\gamma)d\gamma \quad (1.8)$$

- **Outage Capacity**

The transmitter selects minimum value of transmitted SNR γ_{\min} , and transmits signal by keeping in view this value. In this case, the outage capacity comes into play. Outage capacity is defined for the slowly varying channels and is given by $B \log_2(1 + \gamma_{\min})$ [1].

If the instantaneous value of SNR is greater than the threshold γ_{\min} , then the signal can be decoded at the receiver. But in case, this value is less than the threshold then it is not possible to decode it without errors and is counted as outage at the receiver [6].

1.3.2.2 CSI at Transmitter and Receiver side

Here, the signal will be sent when the signal strength is good and it can be decoded easily at the receiver. So, there is no chance of outage. Also, as the transmitter knows the condition of channel for all times, it can vary the rate of transmission accordingly i.e. if the channel is in good condition, the more transmission rate is permissible, however when it is not in good state, the same can be reduced. So, Shannon capacity could be given as

$$C = \int_0^{\infty} B \log_2 \left(1 + \frac{P(\gamma)\gamma}{\bar{P}} \right) p(\gamma) d\gamma \quad (1.9)$$

Where, $P(\gamma)$ denotes the power transmitted for SNR γ , and \bar{P} is the average power constraint given as [1]

$$\int_0^{\infty} P(\gamma) p(\gamma) d\gamma \leq \bar{P} \quad (1.10)$$

1.4 Challenges in Wireless Communication

- The bandwidth availability is the major challenge as it is limited and is costly.
- To share the various formats of data like audio, video, text, voice calls etc, increase in data rate is necessary.
- Effects caused by fading and other noises added during transmission causes the signal to deteriorate in quality.
- The theft of the information while transmission through the air which is accessible to each and every person
- As the number of users has been increasing at very high rate, the need to maintain the quality of the transmission while providing the increased data rate along with the mitigation of interference among users has become the challenge.

These have been the major challenges in the wireless communication. But the main problem is the increasing number of users with every passing day which lead to performance deterioration due to decrease in transmission rate. Along with that, the accommodation of all the users simultaneously in the system along with provision of increased data rate has become the problem. So in the next chapters, the discussion about this problem is carried out in detail.

1.5 Organization of the Thesis

Chapter 1: Introduction, discusses about basic wireless communication with depiction of the block diagram along with capacity of wireless channels. Also, the various challenges faced while implementing such systems is discussed.

Chapter 2: Literature Survey, briefs about the literature of related topics along with discussion of research related techniques.

Chapter 3: Precoded Multiuser MIMO Systems With User Grouping, discusses about MIMO and multiuser MIMO system model and capacity along with the discussion about various precoding and user grouping techniques.

Chapter 4: Analysis and Methodology, describes the capacity analysis of the multiuser MIMO system in uplink and the downlink case along with complete mathematical analysis. In uplink, the capacity is calculated in the low as well as high SNR region and in downlink, the improvement in sum rate for the system using user grouping for zero forcing precoder is examined.

Chapter 5: Simulations and Results, gives the simulation results for the techniques discussed in chapter 4.

Chapter 6: Conclusion and Future Scope, sums up the results concluded from the proposed technique and discusses the possibility of future work.

CHAPTER 2

LITERATURE SURVEY

In this chapter, the discussion about the development and further advancement of MIMO systems, multiuser MIMO systems for the improvement of the performance using various precoding and user grouping techniques have been discussed.

Josef A. Nossek *et al.* [7] depicted linear transmit processing for down linking MU-MIMO system in fading environment. The problem of MU-MIMO with CSI at transmitter for downlink processing is addressed. Firstly, design using the CSI for dealing with correlated fading for transmits processing is considered. Secondly, converting the transmit processing so that it can use long-term CSI. The ability to avoid multiuser interference in the high transmit power is given by the difference between use of full CSI and long-term CSI. The full CSI scheme removes the interference at high transmit power; whereas when there is more than one user to be served the long-term CSI is used as it produces finite interference.

In this paper, **Thomas Fugen** *et al.* [8] studied the wireless communication system with multiple antennas at the transmitter and receiver for the downlink case under realistic channel. So, with this system, the authors investigated the spatial properties of channel for the high speed communication systems. In this case, the multiuser interference affects the system performance due to spatial characteristics of the channel. So the authors presented the new approach for the interference reduction. This approach is based on street models having clusters far away and with line of sight. So, evaluation of systems with realistic conditions of interference for multiuser MIMO becomes easy.

In this paper, **Taesang Yoo** *et al.* [9] proposed that the capacity of MIMO broadcast channel can be maximized using DPC, but it is a very complex technique and difficult to implement. So, he investigated the ZF beam forming strategy for the large number of users. According to him, ZFBF being suboptimal technique will get the maximum capacity almost achievable to the DPC if the numbers of users are large in number. So, to prove this, he selected the active number of users who will communicate while performing ZFBF. These users are semi orthogonal to each other and are grouped for simultaneous transmission in order to enhance the throughput.

The spatial multiplexing gain and the diversity gain for the downlink multiuser MIMO systems can be exploited using the multiuser ZF beam forming and multiuser scheduling. So, the joint spatial and frequency proportional fairness scheduler scheme is given to improve the spatial multiplexing and diversity gain. For this, **Jianhua Zhang** *et al.* [10], gave three antenna selection techniques; random, optimal and suboptimal. Here, the optimal technique achieves higher performance but is more complex whereas the random technique achieve lower performance but is the least complex. So, the tradeoff between performance and complexity persists.

In this paper the comparison between the SU-MIMO and MU-MIMO is done by **Jun Zhang** *et al.* [11]. They considered the imperfect CSIT and found the ergodic rates for both of the scenarios for different assumptions of this CSIT. They came to the conclusion that; the SU-MIMO is more robust to such channel conditions of delay and average SNR than the MU-MIMO. So, they came to the conclusion of not activating the MU-MIMO system when the channel delay is much more than the desired value.

In this paper, the multiuser MIMO diversity is being improved in time, frequency and other spatial domains by the packet scheduler. It is being done to analyze and improve the average capacity and the SINR distribution in MU-MIMO system. According to **Zihuai Lin** *et al.* [12], outage probability for SU-MIMO is much more than MU-MIMO. So the systems using linear precoding improve the outage probability. Also, the ergodic capacity for the MU-MIMO is better than the SU-MIMO when linear precoding is done. However, when there is large number of users the conclusion does not hold for the systems.

In this paper, the user scheduling algorithm has been considered for the downlink multiuser MIMO network along with the use of linear precoding technique. In this, the base station and the users are equipped with the multiple numbers of antennas. Optimal precoding techniques are the DPC, but it is difficult to implement because of non linearity whereas with use of ZF and the block diagonalization precoding, interference can be reduced efficiently to make the system throughput high. But these linear precoding techniques are constrained due to the dimension of the systems, so the precoding techniques are necessary to implement. Finally, the greedy user algorithm has been purposed which incorporates the high performance almost equal to complex techniques, as proposed by **Shreeram Sigdel** *et al.* [13]

Haixia Zhang *et al.* [14] proposed a system for multiuser MIMO downlink along with multistream transmission. The covariance-based linear precoder and MMSE equalizer is

employed at transmitter and receiver respectively. For designing such precoders, availability of CSI is necessary. As only linear processing techniques are used for designing precoder, system complexity can be easily estimated. On transmitter side, computation process increases linearly as number of antennas increase. On receiver side, antenna length and number of antennas deployed determine the complexity to design the equalizers. The multiuser MIMO multistream downlink transmission is done by allowing cooperation between antennas of the same user.

Thomas L. Marzetta [15] proposed multi-user MIMO operation for multi cell scenario by deploying infinite number of base station antennas. The phenomenon of pilot contamination emerged in this case, which is not a problem in single-cell scenario. Frequency reuse factor in multi cell case is taken to be of one, three, or seven among the cells. So in this, transmission to multiple number of receivers is done but in different cells to avoid deterioration in system performance. Similarly, when base station receives signals from different individuals, it is done coherently so as to improve the performance of the system.

The capacity of MIMO-MAC systems in low SNR regime over Rician fading channels is investigated by **Shi Jin** *et al.* [16]. In this, the central receiver has perfect CSI, but each mobile transmitter has only partial CSI pertaining to its own channel statistics. The normalized minimum energy per bit $(E_b/N_0)_{min}$ which is required for reliable communication is derived. It helps to determine first-order behavior of capacity at low SNR values.

In this work, the knowledge about the feedback performance i.e. how frequently in time and frequency the feedback should be provided by the mobiles given by **Nihar Jindal** *et al.* [17]. By doing so, the mobile set sends the data bits to the base station. This determines the performance of the system by optimizing the multiuser MIMO spectral efficiency. The channel inaccuracy occurs because of variations in time and frequency in channel rather than quantization errors. The results show that, even if feedback of the channel is done at some intervals of time, spectral efficiency can be maximized by quantization of channels regularly and accurately.

Liang Li *et al.* [18] proposed two ordered and less complex multiuser scheduling schemes. Out of the two proposed algorithms, GA performs better than proposed NBG algorithm, while later one performs better with one antenna at receiver and with large number of users. As generality of both the algorithms can be considered, so the system can be easily extended for

heterogeneous users while considering the equality. Also, the different types of precoding can be used to determine the channel while scheduling. So the results show that, complexity of the system is reduced while the sum rate performance around 96% - 99%, because the system reduces the interference among the users to very low level.

This paper discusses the BER of MU-MIMO system in downlink case with user having single antenna for zero forcing system. The BER is investigated in presence of delayed and imperfect CSI by **Baolong Zhou** *et al.* [19]. In downlink systems, ZF have been the best method to separate the users and thus their data streams for the effective transmission of signal. But, it depends on availability of CSIT. But in practically viable systems, there is always delay and imperfection in the CSI availability, so it leads to deteriorated performance. It is shown that the channel estimation error cause the array gain loss whereas CSI delay causes diversity gain loss. Moreover, CSI delay causes more degradation of the system at high SNR values.

The ergodic channel capacity of a MU-MIMO broadcast system having feedback of CSI is given by **Fan Jin** *et al.* [20]. The capacity is found under both random user selection (RUS) and semi-orthogonal user selection (SUS). Also, the effects of channel estimation errors, CSI quantization errors and CSI feedback-delay are taken into account. Due to excessive inter-user interference caused by imperfect channel state information at both receiver and transmitter under RUS, support of full-rank transmissions should be avoided because it does not provide highest data rates. But, under SUS full rank transmissions may be feasible.

In this paper, variations due to large scale fading over the base station antenna array for the massive multiuser MIMO system has been investigated by **Mohammad Kazemi** *et al.* [21]. They investigated the two scenarios by considering the linear array as well as distributed antenna array at the base station. In both cases, the uplink ergodic capacity for wide range of SNR of -10 dB and 17 dB is evaluated. It is deduced that the closed form expressions are accurate in this wide range of SNR's and it can be further validated for the less number of antennas and for massive number of antennas.

Hao Zhu *et al.* [22] considered MU-MIMO scheduling using the uplink. Here, each scheduled user transmits precoded multistream and also the flexible multiuser scheduling is carried out where multiple users are assigned same time-frequency resource. But, imposing certain practical boundations to maintain minimum signaling overhead is required. The gain

due to multiuser scheduling enables us to improve the quality of system along with enhancement of data rate.

Shahram Zarei *et al.* [23] presented a downlink massive multiuser MIMO giving a low complexity linear precoding and power allocation scheme for maximization of sum rate and maximization of minimum user rate respectively. They gave regularized zero forcing precoding and have said that it is far better than simple conjugate beam forming. Authors conclude that the results with the RZF are much better than the BF which has been used earlier as the sum rate and minimum user rates are maximized using this technique.

A CSI prediction scheme for multi-user MIMO is given by **Toshinori Suzuki** [24]. He addressed that MU-MIMO with linear prediction of CSI have larger capacity than any prediction. So, even low-order linear prediction gives the excellent result which compensates for the loss of capacity for varying CSI. So, the capacity increases by 1.3 to 1.6 order of magnitude when linear prediction of channel state information is applied. This result demonstrates that the linear prediction of CSI improves capacity of MU-MIMO system for moving users.

Maneesha Sharma [25] found the mechanism which allows the minimum channel knowledge of promptly varying channel from receiver. The channel state information allows adapting the transmission of signal according to channel conditions, which helps in achieving high data rates in multi-antenna systems. This feedback mechanism allows optimal usage of bandwidth and energy in MU-MIMO which varies according to channel variations.

This paper based on ZF beam forming proposes a GUSS algorithm which implies for the user selection among set of users for the MU-MIMO downlink channels. The extant algorithms for user selection like ZFS have flaw of “redundant users” and “local optimum”. This decreases achievable data rate. So, ‘delete’ and ‘swap’ operations are introduced in ZFS to evict “redundant users” and “local optimum” flaws respectively. This helps to achieves 99.3 % sum rate performance with only 1.5 to 2.3 times the complexity of ZFS as said by **Shengchun Huang** *et al.* [26].

Qi Wang *et al.* [27] investigated relative performance of MU-MIMO and SU-MIMO. According to the authors, different Doppler spectra and channel prediction methods affects the ergodic sum rate performance of both systems. So, under different conditions of average received SNR and normalized maximum Doppler frequency the sum rate is analyzed. The

author concluded that MU-MIMO systems retain their theoretical advantage over SU-MIMO performance. These all measurements are for the case of downlink sum rate.

Block diagonalization is an easy and helpful technique in MU-MIMO broadcast channels for depicting the capacity of the system. So, **Sang-Rim Lee** *et al.* [28] said that when CSIT is partially available, it is not possible to fully eliminate the interuser interference. This will ruin the performance of the block diagonalization. So, a proficient CSI quantization technique for Block diagonalization precoded systems should be advised which could be able to work in imperfect feedback scenario. Here, the users are dynamically scheduled for the communication with BS. So, the received SINR is articulated when several data streams are transmitted to the user, along with the derivation of the lower bound expression for expected received SINR. Then, each user determines its quantized CSI feedback which maximizes the derived SINR. So, SINR based channel quantization scheme achieves major sum rate gain over conventional method in practical MU-MIMO systems.

In this paper, **Yi Xu** *et al.* [29] considered the grouping and scheduling of users based on some of the grouping algorithm. They proposed the K-mean based clustering algorithm for user grouping in MIMO-FDD system. According to him, this algorithm provides the good amount of sum throughput. The user scheduling scheme is also implemented after the grouping is done and the results show the better performance than the existing grouping algorithms.

According to **Saif Khan Mohammed** *et al.* [30], the user grouping precoder proposes the improvement in the MU-MIMO system having large number of single antenna users. The system considered is the downlink system where the comparison between the sum rate of the ZF precoder as well as the precoder formed after grouping is done. According to the authors, the user groups formed are of equal size and then the beam forming is done to reduce the interference among the users. The precoder formed gives the better performance than the ZF precoder and it further improves when the groups made are large in number.

In this paper, **Tapas Kanungo** *et al.* [31] proposed the grouping algorithm named as K-mean clustering algorithm. It helps to group the number of users according to the initial value of K, which gives the number of groups to be formed. According to them, this algorithm works by minimizing the mean squared distance from each user to its nearest set data value.

Gaps in Study

1. In the previous studies, the sum rate performance is difficult to improve for large number of users while using linear precoding techniques whereas non linear are complex but provide good performance [9].
2. Since the users are randomly distributed, the communication between base station and related users becomes difficult, without using Channel State information (CSI) at the transmitter [11].
3. In the previous techniques, even a small number of data is sensitive to variation in cluster shape, size and density which further leads to noise and outliers while implementing the user grouping algorithms [29].

Thesis Objectives

This research accomplishes following objectives:

1. To study and simulate the sum rate for the uplink and downlink multiuser MIMO system.
2. To implement the precoding technique appended with the K-mean user grouping algorithm for improving the sum rate performance of the multiuser MIMO system.
3. To compare and find out the optimized K-factor of grouping of users for obtaining maximum sum rate performance for the multiuser MIMO system.

CHAPTER 3

PRECODED MULTIUSER MIMO SYSTEMS WITH USER GROUPING

This chapter gives the capacity analysis of the multiuser MIMO system in uplink and the downlink case along with complete mathematical analysis. In uplink, the capacity is calculated in the low as well as high SNR region and in downlink, the improvement in sum rate for the system using user grouping for zero forcing precoder is examined.

3.1 Single User MIMO Systems

Wireless systems which are the integral part of the 21st century consist of the radio channel, a transmitter and a receiver. These have been categorized based on the number of inputs and number of outputs for the system being considered. So the various antenna configurations are as follows:

- Single Input Single Output (SISO)
- Single Input Multiple Output (SIMO)
- Multiple Input Single Output (MISO)
- Multiple Input Multiple Output (MIMO)

1. Single Input Single Output (SISO)

It is the conventional type of communication system which uses single transmit antenna and single receive antenna. In MIMO terminology, it is called Single-Input-Single-Output (SISO) system.



Fig 3.1 SISO System

The capacity of the SISO system is given by **Shannon Hartley Theorem**. According to Shannon, the capacity C of a radio channel is dependent on bandwidth B and the signal-to-noise ratio S/N . The following applies to a SISO system [1]

$$C=B \log_2 (1 + S/N) \tag{3.1}$$

2. Single Input Multiple Output (SIMO)

It is the communication system which uses single antenna at the input and multiple antennas at the receiver. So, it is called receive diversity scheme. The SIMO system is very easy to implement as no special coding is required and only two RF paths are required [32].

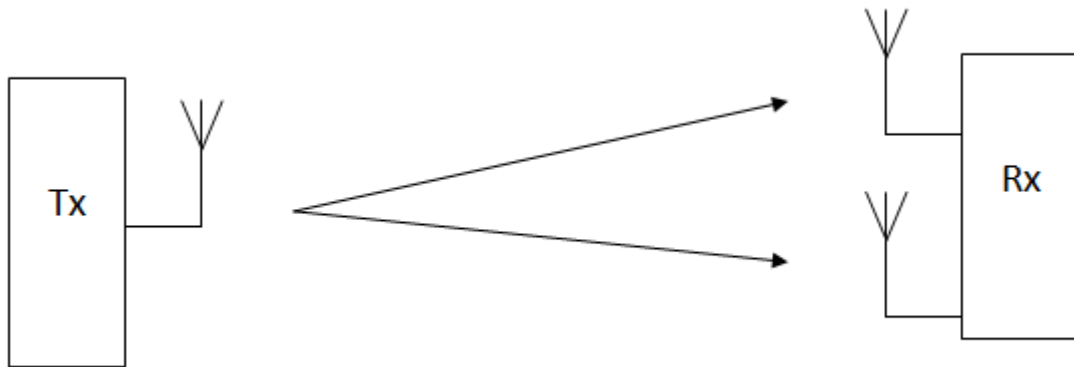


Fig 3.2 SIMO System

3. Multiple Input Single Output (MISO)

In this type of communication system, there are multiple antennas at the transmitter and single antenna at the receiver, so it is called transmit diversity scheme. In simple scenario, use two antennas at the transmitter and one antenna at the receiver.

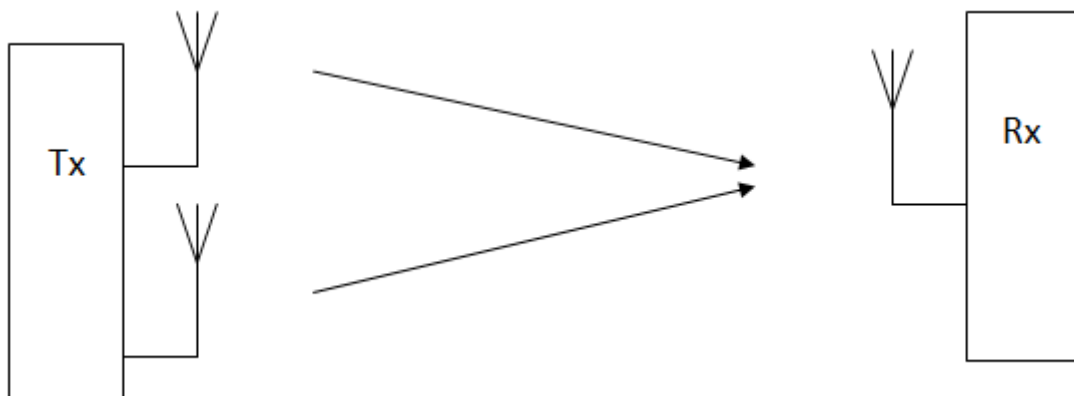


Fig 3.3 MISO System

In MISO systems, same data is transmitted over all the transmit antennas. This method has the advantage that the multiple antennas and redundancy coding has shifted from the mobile user to the base station, so it has become simple and cheaper to implement these technologies [33].

4. Multiple Input Multiple Output (MIMO)

In recent years, the use of multiple antennas both at the transmitter and at the receiver has been trending. This type of communication system is called multiple input multiple output. In this, each antenna receives not only the direct component intended for it but also the indirect components intended for other antennas.

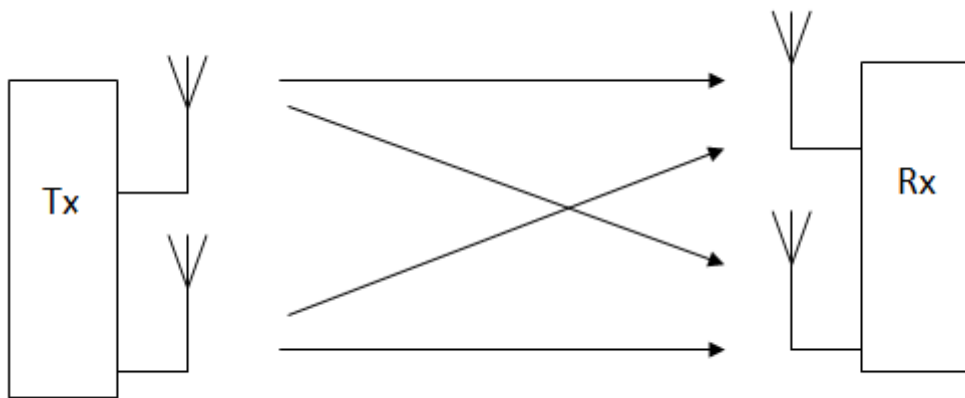


Fig 3.4 MIMO System

The data which is transmitted is divided into independent data streams. The number of transmitted streams is always less than or equal to the number of transmitter antennas M . If the asymmetric ($M \times N$) antenna dimensions are used it is always the smaller or equal to the minimum number of antennas. So, the capacity C increases linearly with the increase in number of antenna streams M and is given by [34]

$$C = M \cdot B \log_2 \left(1 + \frac{S}{N} \right) \quad (3.2)$$

The various benefits of MIMO system are based on some of the parameters which play a crucial role in defining the performance of the MIMO system. These parameters offer the gain in the capacity and the reliability, along with the increase in the cost as well as hardware of the system. These parameters are:

- Spatial Diversity
- Spatial Multiplexing

3.1.1 Diversity and Multiplexing

As compared with the SISO system, the MIMO systems have large number of degrees of freedom for the transmitting signal. So these two techniques come in handy at this point of time.

3.1.1.1 MIMO Diversity

In urban cities, there are large number of buildings and other infrastructure which hinders the propagation of the signal from the transmitter to the receiver. So, such kind of environment causes fading of the signal, which further leads to improper decoding of signal at the receiver. So in order to tackle this problem, a technique known as diversity comes into play. Fundamentally, in this technique the multiple copies of the signal are transmitted from the multiple antennas in the MIMO system, such that the probability of fading of the signal at the receiver is reduced. Therefore the data reception reliability is enhanced and improved [35].

For different antenna configurations, the diversity scheme is applied accordingly i.e. for SIMO systems, the receive diversity is applied. At the different receive antennas, the independent versions of same signal, which are faded according to the environmental condition, are seen. So, these all faded signals are combined such that the received signal exhibits less fading [36]. The diversity order in receive diversity is determined by number of independently fading branches and the maximum diversity order is equal to number of receiving antennas in SIMO system. However in MISO systems, the transmit diversity is applied. Typically, Alamouti scheme is called the transmit diversity [37]. In this case the diversity order is equal to the number of independently faded paths a signal experiences. So, the maximum transmit diversity order is equal to the number of transmit antennas at the transmitter in MISO system.

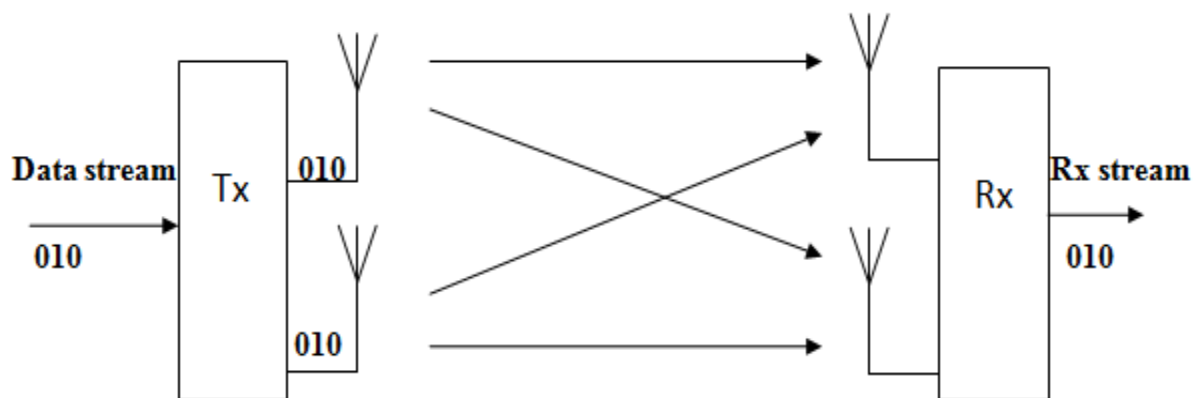


Fig 3.5 MIMO Diversity [36]

So, generally in a MIMO system having ‘T’ transmit antennas and ‘R’ receive antennas, the maximum diversity order can be

$$D = T \times R \quad (3.3)$$

Where, the channel between each pair of antennas fades independently.

3.1.1.2 MIMO Multiplexing

In multiplexing, a signal having very high data rate is split into number of signals with lower data rates streams and these streams are then transmitted from the different transmit antennas from the BS in same frequency channel. It is shown by Foschini [38] that in high SNR regime, the capacity of the i.e. Rayleigh fading channel is given by

$$C = \min\{T \times R\} \log (SNR) \quad (3.4)$$

The main benefit of the spatial multiplexing is that it offers a linear increase in the data rate with an increase in transmit or receive antennas for the same bandwidth and transmit power. The typical model for the spatial multiplexing is the BLAST system. The maximum multiplexing gain of such system is

$$M = T \times R \quad (3.5)$$

Where, M is the multiplexing gain. This can also be applied to multiuser system where the gain would be according to the minimum number between the transmit antennas or the total number of receive antennas of all users.

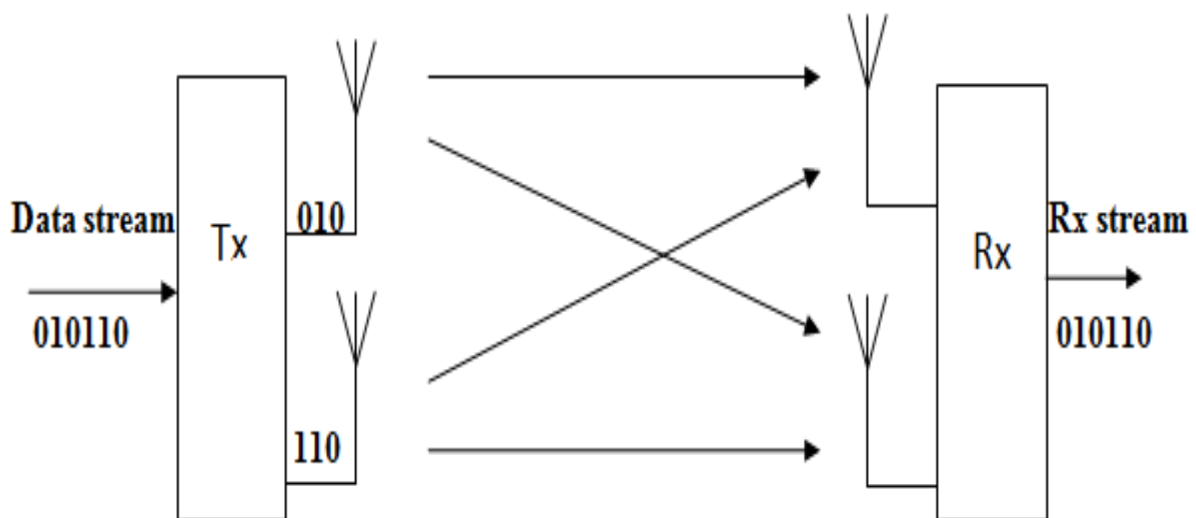


FIG 3.6 MIMO Multiplexing [38]

3.1.2 Single User MIMO System Model

The basic single user MIMO model is as shown below in the figure

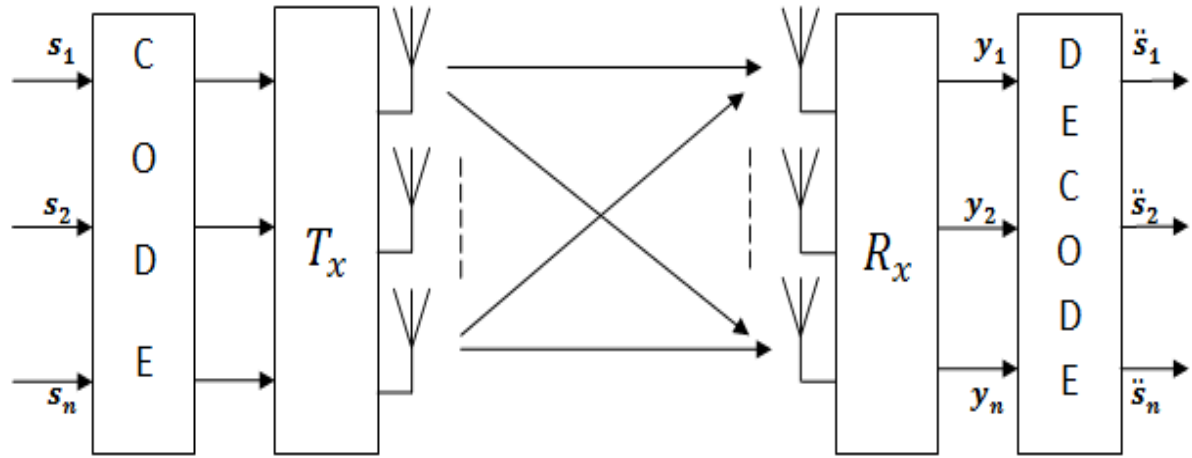


Fig 3.7 Single User MIMO System Model

Here, n is the total number of transmit data streams, and the number of transmit as well as receive antennas are T and R respectively. The symbol ‘ s ’ denotes the transmit data vector, ‘ y ’ denotes the received data vector, and ‘ \hat{s} ’ denotes the estimated data.

Now, the narrowband MIMO model is represented by discrete time model as following [1]:

$$\begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_R \end{bmatrix} = \begin{bmatrix} h_{1,1} & \cdots & h_{1,T} \\ \vdots & \ddots & \vdots \\ h_{R,1} & \cdots & h_{R,T} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_T \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ \vdots \\ n_R \end{bmatrix}$$

Also, this equation can be written as following

$$y = Hx + n \quad (3.6)$$

- y is the receive vector of $R \times 1$ dimension.
- x is the transmit vector of $T \times 1$ dimension.
- n is the noise vector of $R \times 1$ dimension.
- H is the channel matrix having $h_{i,j}$ as the fading coefficient from the i^{th} receive antenna and j^{th} transmit antenna.

For the channel gain matrix H , it gives the various properties of the communication link between transmitter and the receiver. This defines the propagation of the signal from the transmitter to the receiver for various atmospheric effects of fading, scattering and delay etc. Different opinions can be made at the transmitter as well as receiver side about the channel

state. Channel information at the transmitter side, it is called as CSIT and at receiver side, it is called as CSIR.

3.1.2.1 Single User MIMO Capacity

In SU-MIMO system shown in figure 3.7, the channel capacity is expressed as following [39]

$$C = \max_{Tr(R_{xx})} \log_2 \det \left(I_R + \frac{E}{TN_o} HR_{xx}H^H \right) \quad (3.7)$$

Here, N_o is the noise power, E is the total transmits power and R_{xx} is the autocorrelation of transmitted signal.

In this case, the CSI is known at the transmitter side and thus this system is called the closed loop system. Whereas the open loop system are those where no CSIT is available. As in OL systems no CSIT is available, so transmit energy for all antennas are same i.e. $R_{xx} = I_T$. So in this case the capacity for the open loop MIMO systems is

$$C = \log_2 \det \left(I_R + \frac{E}{TN_o} HH^H \right) \quad (3.8)$$

So, now using the Eigen decomposition $HH^H = Q\Lambda Q^H$ the channel capacity is given by

$$C = \log_2 \det \left(I_R + \frac{E}{TN_o} \Lambda \right) \quad (3.9)$$

$$C = \sum_{i=1}^j \log_2 \left(1 + \frac{E}{TN_o} \lambda_i \right) \quad (3.10)$$

Where $j = \min(T, R)$ and it is rank of channel matrix and λ_i denotes the i^{th} eigenvalue of HH^H . The above equation gives the description about how the MIMO channel is converted into j SISO channels with λ_i and $\frac{E}{T}$ as the power gain and transmit power respectively.

Now for the closed loop MIMO, where capacity depends on the CSIT, as the knowledge about various conditions about the channel is known, accordingly different amount of transmit energies can be allocated to different antennas at the BS [39]. So, the auto correlation function R_{xx} will be the diagonal matrix with varying transmitting power γ_i . Now, applying the SVD on $H = U\Sigma V^H$ with U and V being the unitary matrices of $[R \times R]$ and $[T \times T]$ dimensions respectively and Σ being the $[R \times T]$ dimension matrix.

Now the capacity of the system could be given as

$$C = \sum_{i=1}^j \log_2 \left(1 + \frac{E\gamma_i}{TN_o} \lambda_i \right) \quad (3.11)$$

Now, by using the power allocation problem, the capacity can be maximized and is given by

$$C = \max_{\sum_{i=1}^j \gamma_i = T} \sum_{i=1}^j \log_2 \left(1 + \frac{E\gamma}{TN_o} \lambda_i \right) \quad (3.12)$$

Now, the optimal value of the $\gamma_i(opt)$ is given by the water filling formula and that is

$$\gamma_i(opt) = \left(\phi - \frac{TN_o}{E\gamma} \right) \quad (3.13)$$

Here ϕ is the constant. So, the capacity closed loop MIMO system is given by sum of all the SISO channel capacities

$$C_{max} = \sum_{i=1}^j \log_2 \left(1 + \frac{E \gamma_i(opt)}{TN_o} \lambda_i \right) \quad (3.14)$$

So, the capacity gain in SU-MIMO is scaled by the minimum number out of transmit and receive antennas.

$$C_{SU-MIMO} \propto \min(T, R) \quad (3.15)$$

3.1.3 Advantages and Limitations of Single User MIMO Systems

There have always been pros and cons to each and every technology. Each and every day, there has been advancement in the existing technology, which leads to various new technologies. So, some of the advantages of MIMO and multiuser MIMO have been discussed below.

Advantages of Single User MIMO systems:

- Increase the achievable data rates and hence system reliability.
- Increases the system reliability by decreasing the bit error rate.
- Increases the coverage area.
- Decreases the required transmit power.

However, these four desirable attributes usually compete with one another. For example, an increase in data rate will often require an increase in either the error rate or transmit power.

Disadvantages of Single User MIMO system:

- The performance of single user MIMO cannot be fully exploited due to the limited number of receiver antennas used in the user equipment.
- The capacity for perfect CSIR and CDIT is not resolved under combined channel covariance information [40].

- The multiple antennas in single-user MIMO helps to increase the overall diversity order but the large number of pilot symbols required reduces the maximum achievable spectral efficiency of the system.
- The single user transmission has lower link utilization than the multi user which leads to large degree of multi-user diversity.

3.2 Multiuser MIMO Systems

In today's scenario of 21st century, the field of communication has been extended out to such a great level that it has become the need for each and every person to be in contact with others through different form of communication tools. So, it can be said that there is need for systems which can leverage the demands and requirements of the people need to be considered at a priority.

So, the systems which can deal with this current scenario are the multiuser systems, which accommodate large number of user terminals in the network providing all the system resources to each one of the user. Due to the limited bandwidth and time duration, there is need to accommodate all the users based on these resources only.

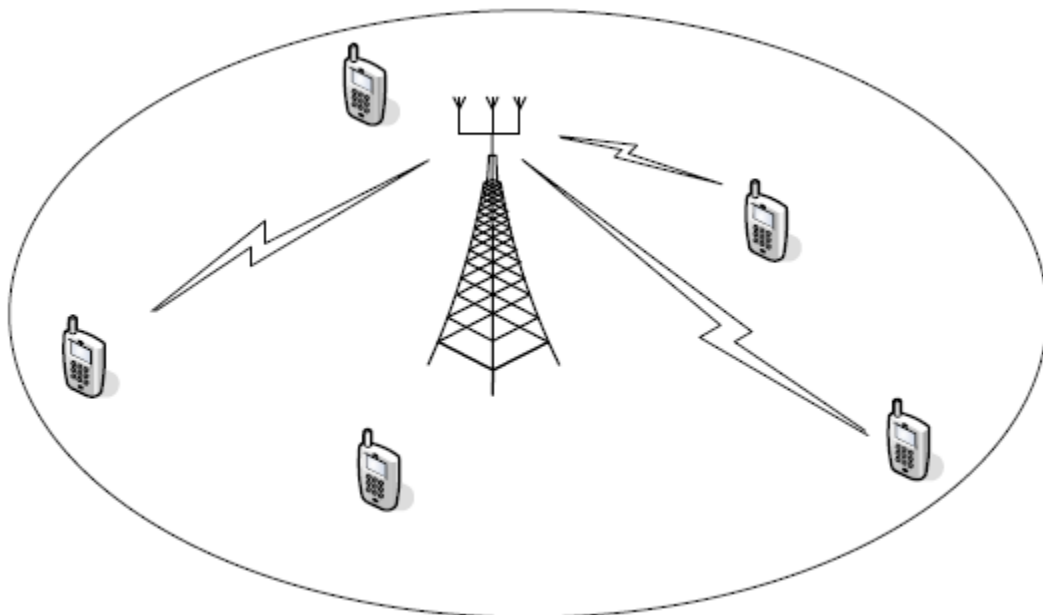


Fig 3.8 Multiuser MIMO System

In these multiuser systems, the transmission of signal has been occurring in the two different ways i.e. from the BS to the users and from the users to the BS. A channel is the medium over

which the transmission of signal occurs and this channel is shared among multiple numbers of users. The two types of multiuser channels are:

- Multiple Access Channel or Uplink Channel
- Broadcast Channel or Downlink Channel

3.2.1 Multiple Access Channel (MAC)

The multiple access channel also called the uplink channel is the one over which a large number of users transmit the signals to a single receiver. Each signal which is sent by the user should be in the limit of the total system bandwidth and the total bandwidth is the sum of bandwidth of all the signals sent by different users. In this, each user has a power constraint according to the strength of the signal sent by the user. Also, the signals sent from different users needs to be coordinated, if the coordination is required at some point. As the users are located at different places in practical scenario, so the received power at the receiver will always be different for each user due to different channel conditions for each transmitter. In order to achieve signal synchronization for good performance, the signals should coordinate with the base station as well with each other. It is crucial at base station to select proper set of users getting manifold transmissions. If CSI is available, then BS can use various algorithms like greedy user selection for downlink multi-user scheduling for elevating the throughput [41]. Also, the base station needs to differentiate between the simultaneously transmitted signals from different users which is done using MMSE. In this scheme, the base station gets the signals from users which are multiplexed by some parameter called weight and then all are summed up. The performance of MMSE improves as number of antennas at base station increases [42]. The other technique called as Successive Interference Cancellation is the extension of the Minimum Mean Square Error (MMSE). The signals with the highest power and minimum interference due to other signals are detected for transmission to the base station [43].

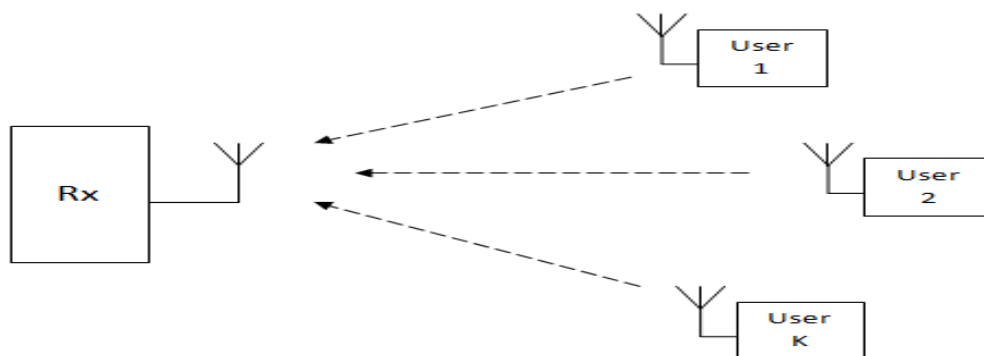


Fig 3.9 Multiple Access Channel

The various multiple access techniques are the following:

1. Time Division Multiple Access (TDMA)

In this multiple access technique, the total system is divided along the time axis for non overlapping channels, where each user is allocated a different time slot. In the uplink case the difficulty incurred to implement this technique is that synchronization among the different users is required. This technique is being used in GSM, PDC etc.

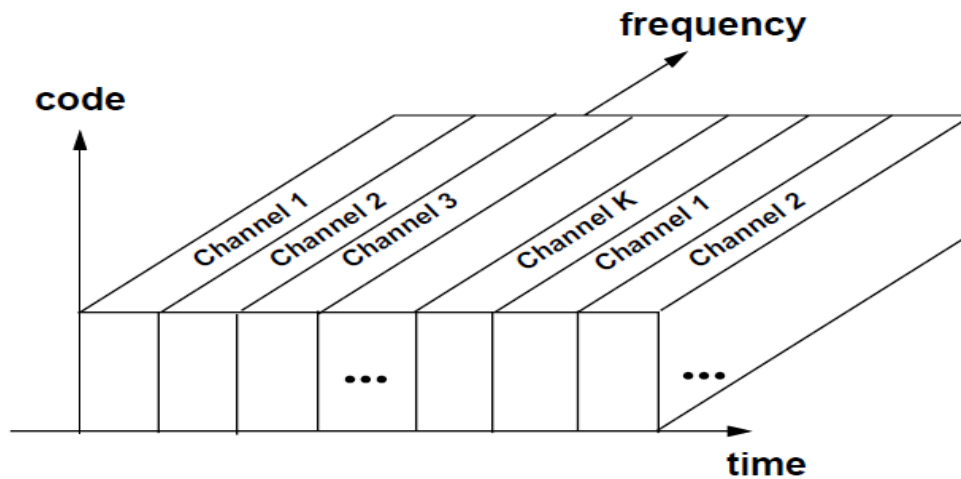


Fig 3.10 Time Division Multiple Access

2. Frequency Division Multiple Access (FDMA)

In this multiple access technique, the total system is divided along the frequency axis for non overlapping channels, where each user is allocated a different frequency channel. There is always a guard band between the usable frequencies due to the imperfect filters, adjacent channel interference etc.

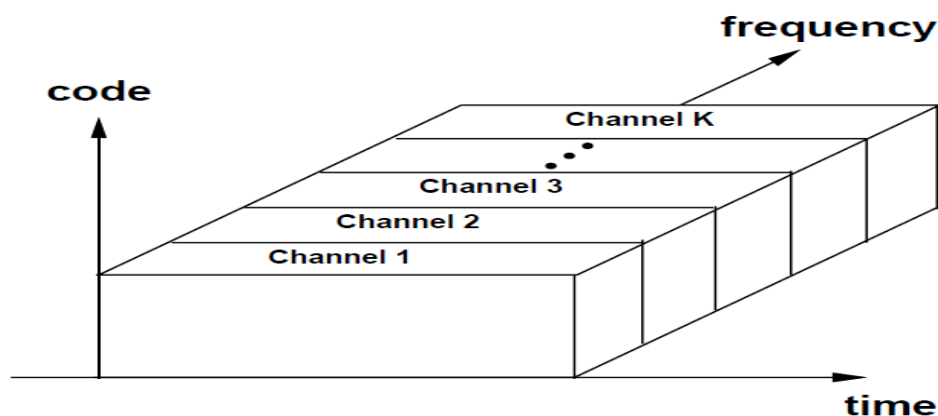


Fig 3.11 Frequency Division Multiple Access

3. Code Division Multiple Access (CDMA)

In this multiple access technique, multiple numbers of transmitters can send their data simultaneously by sharing a single communication channel. In this way, large number of users shares the band of frequencies. The codes being used in downlink CDMA are the orthogonal codes like Walsh-Hadamard codes whereas in uplink the codes used are non orthogonal codes due to difficulty in synchronization of users. It is already being used in the various mobile communication standards like IS-95, IS-2000 etc.

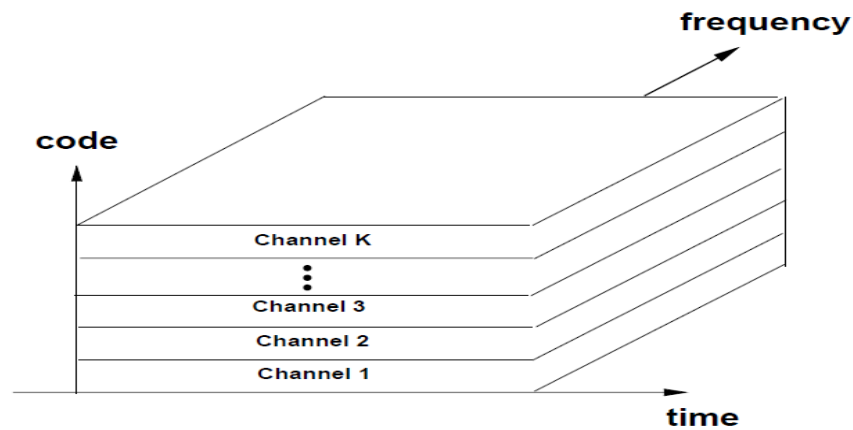


Fig. 3.12 Code Division Multiple Access

4. Space Division Multiple Access (SDMA)

In this multiple access technique, different directions in the space are used for transmitting signals to different users. This is basically done using the directional antennas. In cellular networks, BS does not have any knowledge of user terminals in space, so there is loss of signal as it is transmitted in all directions. So, this technique helps to get the signal in the in the required direction according to the user terminal.

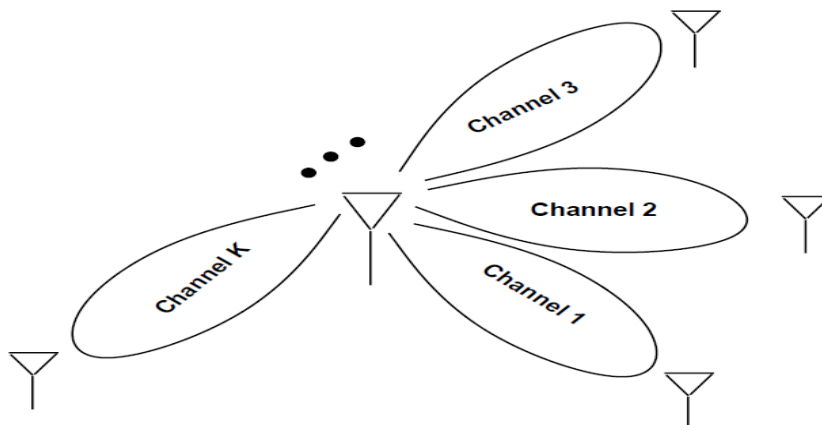


Fig 3.13 Space Division Multiple Access

3.2.2 Broadcast Channel

The broadcast channel which is also called as the downlink channel is the one in which the base station transmits the signal to large number of user terminals since one transmitter is used in this case, the total bandwidth and the total power is the summation for all the users. In this case, the synchronization is easy as all the signals are originating from the same source i.e. from the same base station and travel to different users according to their position. But at some point, this synchronization is corrupted due to the multipath transmission. In broadcast channel there is an increase in the system multiplexing gain via simultaneous transmission of signals. This technique, referred as space division multiple access, scales the throughput as compared to other multiple access techniques like time division multiple access [44].

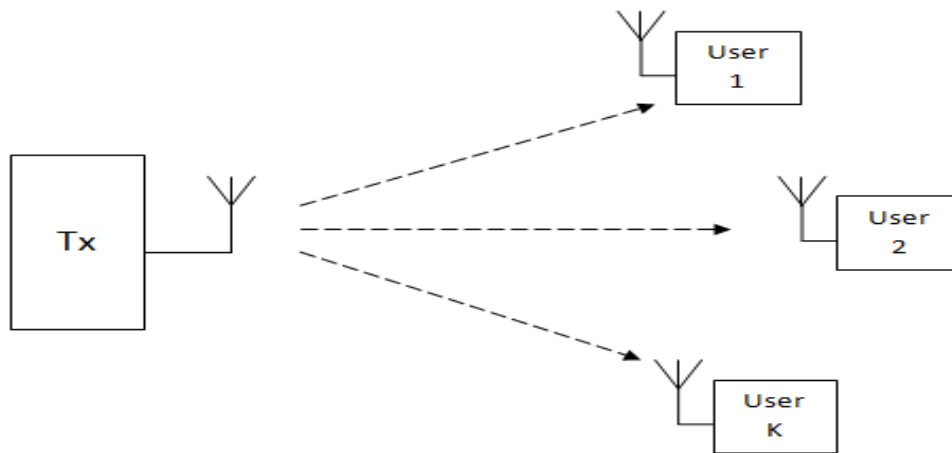


Fig 3.14 Broadcast Channel

In downlink, base station performs its functions in following ways. Firstly, for user scheduling, each user sends its channel state information at the base station. However, it is useless to allocate same number of channel bits to all users as bits allocated to the non selected users will be wasted [45]. Among selected users, channel state information accuracy has different effects. For high-SNR users, inter user interference limits the throughput performance immensely. Thus, channel feedback bits dominate performance at user side. For the low SNR users, noise influences the throughput. Thus, number of channel feedback bits in low SNR region is of less importance than high-SNR users [45].

3.2.3 Multiuser MIMO System Model

The basic multi-user MIMO system model is as shown below in the figure

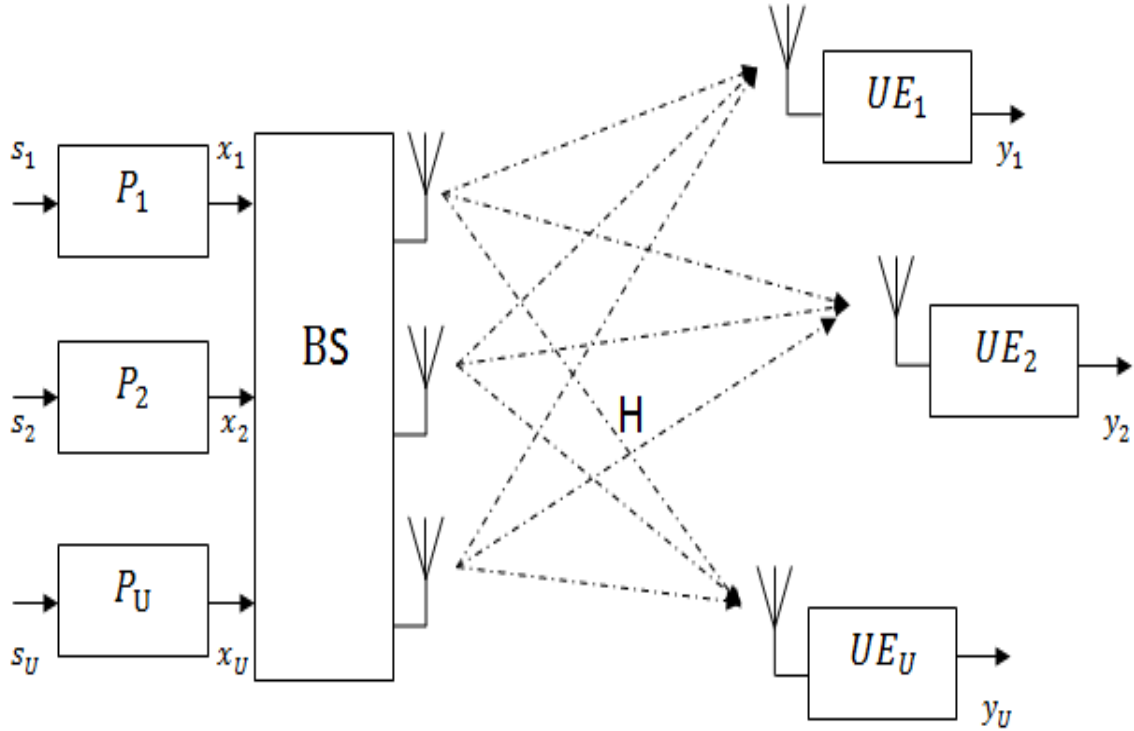


Fig 3.15 Multiuser MIMO System Model

Consider the base station with B_t antennas and single antenna user equipment which are U in number. So, total number of receive antennas is U_r . In the above figure, the vectors, s_u , P_u , x_u and y_u are the transmit data, precoding matrix, precoded data and received data respectively. The channel matrix H and precoding matrix P from the system model can be given as following

$$H = [H_1^T \quad H_2^T \quad \dots \quad H_U^T]^T \quad (3.16)$$

$$P = [P_1^T \quad P_2^T \quad \dots \quad P_U^T]^T \quad (3.17)$$

Here H is $U_r \times B_t$ and P is the $B_t \times U_t$. Also, H_u is $1 \times B_t$ and P_u is the $1 \times B$ dimension channel and precoding matrix respectively for the u^{th} user. For a flat fading MIMO channel, received signal is given by

$$y_u = H_u x_u + H_u \sum_{j=1, j \neq u}^U x_j + n_u \quad (3.18)$$

In this equation the quantity $x_u = P_u s_u$ and is the u 'th user transmitted signal and n_u is the Gaussian noise with i.i.d entries of zero mean and unit variance.

As in practical situations there is large number of users to be served. All these users need to be served with the good performance. So, the MIMO system has been set to the advancement which further leads to the implementation in the practical scenario. For this, MIMO system has to be implemented for the large number of users being considered for communication with each other. So, the system which consists of large number of user terminals is said to be multiuser. Further, it is being implemented in the MIMO system, so it is called multiuser MIMO system. In this network, a large number of user terminals equipped with one or multiple antennas communicate with the BS equipped with many antennas. MU-MIMO being considered the advancement of space division multiple access (SDMA) permits large number of end users on single channel [46]. MU-MIMO provides large number of benefits over SU-MIMO like multi-user diversity enhances channel condition as users having best channel quality are allowed to occupy the channel [1]. MU-MIMO is rigid to the propagation limitations like rank loss or antenna correlation pertaining in single user MIMO [47]. Such MU-MIMO systems achieve a spatial multiplexing gain even if there are single antennas at the user terminal. So, these advantages of MU-MIMO over SU-MIMO led many researches to investigate further improving multi-user MIMO system.

3.2.3.1 Capacity of Multiuser MIMO MAC

MU-MIMO system, consisting of multiple numbers of antennas at transmitter i.e. A_t and multiple numbers of users being U in number at receiver is considered. All these users have a single antenna. So, the data streams of all the U number of users are available with the BS. It is shown in the [48] that sum rate capacity of the MAC is proportional to the $\min(U, A_t)$ which is given by

$$C_{MAC} = \log_2 \det \left(I_U + \frac{P}{U} H H^H \right) \quad (3.19)$$

Where P is the total transmit power and $\frac{P}{U}$ is the power transmitted by each antenna. From above equation, it can be seen that coordination among all the users is not required. Also, it can be said that the A_t fold increase in the capacity can be obtained till the time the number of users are more than the number of BS antennas, which is not in case of SU-MIMO as receive antennas in that case are always less [49].

3.2.3.2 Capacity of Multiuser MIMO BC

The downlink Shannon sum capacity is the aggregate of the sum rate of all the users in the systems. Here, some users get less data rate and some get the good data rate due to various parameters like distance from base station antennas, channel conditions etc. So, in totality, the aggregate data rate of the system is calculated and it is called the sum rate of the system.

For this, consider the system with A_t antennas at the transmitter and U single antenna users. Then, the downlink sum rate for the multiuser system is calculated as following [50]

$$C_{BC} = \log_2 \det(I_{A_t} + PHD_a H^H) \quad (3.20)$$

Here, P is the transmitted power and D_a is the diagonal matrix of dimensions, $M \times 1$. This capacity is calculated at both the ends of the link by knowing the channel condition. Also, the BS has to know the channel conditions of all the users while each user has to know the channel condition for itself. For getting the near capacity performance the technique called dirty paper coding is to be used [51]. But, it is a very complex technique to implement. Also, for using this, very accurate channel conditions are required.

So, comparing both SU-MIMO and MU_MIMO for various parameters, following has been the main features that acquired the attention for the MU-MIMO systems:

- MU-MIMO does not just inherit all the benefits of single user MIMO, but also improves various propagation limitations faced in SU-MIMO like ill conditioned channels.
- The line of sight problem which is a problem in SU-MIMO systems is not a problem in the MU-MIMO systems.
- In MU-MIMO system, spatial multiplexing gain can be allowed at the base station even if there are no multiple antennas at the user equipment.

This is of importance because; user equipments being of small size cannot support many antennas due to physical size and low cost constraint.

However there has been a tradeoff between the pros and cons of such practical systems. So, there is a tradeoff between the performance and the implementation of such systems.

3.2.4 Multiuser MIMO Challenges

- In order to achieve higher spatial multiplexing gain, the BS needs to process the received signal accurately. For this it requires the timely and accurate CSI. This is challenging, especially in high mobility scenario.
- The various user scheduling schemes are required because several users are being served on the same time frequency resources. This leads to increment in the cost of the system.
- The pilot contamination in the multiuser scenario leads to the performance degradation of the system in practical scenario.

3.2.5 Massive Multiuser MIMO systems

In contrast to conventional MU-MIMO systems, very large MU-MIMO systems known as the massive MU-MIMO has been of great interest to the researches these days. Massive MIMO is a technology which uses hundreds of antennas at the base station for serving the tens and hundreds of users in the same time frequency slot [52]. The main advantages of massive MU-MIMO systems are:

- **Improves data rate and system reliability**

These very large MU-MIMO systems inherit all the properties from the conventional MIMO systems. For example, with B antennas at base station and U single antenna users, diversity order of B and multiplexing gain of $\min(B, U)$ could be achieved.

- **Power efficiency**

In the case of uplink, a very high array gain could be achieved due to the coherent combining which ultimately helps in reduction of the transmit power of each user and in the case of the downlink, the base station focuses its power in those directions only in which the user equipment is located. So, with the very large array the transmit power is reduced to a great extent.

- **Simple signal processing**

As the BS antennas keep on increasing, the channel becomes more and more deterministic. So the effect of various atmospheric parities like small scale fading and thermal noise get reduced.

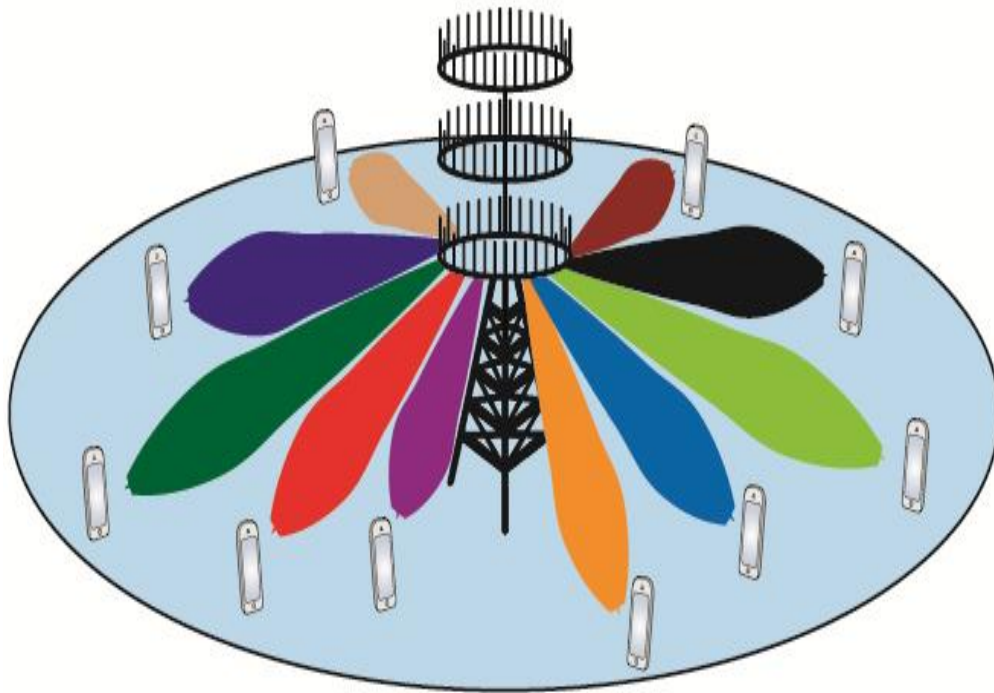


Fig. 3.16 Massive MU-MIMO System [41]

The massive MIMO system has broken the scalability barrier as it has just increased the size and cost of system but yet it is not in position to provide the Shannon capacity. It departs from Shannon theory in following ways. Firstly, just the base station learns the downlink channel. Also the time required for getting the CSI at the transmitter is independent of number of antennas at the BS. Secondly, the number of antennas at the BS increases in large number in contrast to number of users. Thirdly, the linear precoding needs to be applied in case of downlink. As the number of antennas increase the capacity tends towards the Shannon capacity [53]. So, it is to be depicted that the massive MIMO requires the channel information and user mobility imposes the limit on number of active users.

3.3 Precoding

It is a technique which helps in exploiting the channel state information at the transmitter (CSIT) such that it can match with the instantaneous channel conditions which helps to maximize the SINR value. So, precoding works by weighing the information data stream with the proper set of values so that the signal power at the receiver is maximized [54]. The main benefits of precoding could be the following:

- Firstly, as precoding is applied at the start where the source signal is available before transmission, so it reduces the losses caused due to interference and fading.

- Secondly, as the base stations are more robust and have more ability to compute the various functions, along with the fact that they have power supply in plenty. So, shifting some of the processing from receiver side to transmitter side. So, the user equipment is simpler and more power is saved for the betterment in the mobility of the UE.

In single layered systems, it is done at the transmission end to maximize the power at the receiver whereas in multi layered systems i.e. MIMO systems maximization of throughput is done by beam forming of multilayered signals. Basically, the precoding can be classified in two ways. Those are:

- Precoding for single user MIMO
- Precoding for multiuser MIMO

3.3.1 Precoding for Single User MIMO

In single user MIMO systems, communication takes place between transmitter and receiver having multiple antennas and the condition of the channel does not vary for some period of time and so can be shown a single matrix [55]. Thus, these channels are called narrowband and slowly fading channels. In single user MIMO, the CSI plays an important role in determining the channel throughput while using precoding. When CSI is known to receiver and transmitter follows statistical information, it is known to approach the channel capacity. Whereas, when CSI is not known, the precoding technique like SVD helps to achieve the channel capacity.

3.3.2 Precoding for Multiuser MIMO

In multiuser MIMO systems, the transmitter with multiple antennas communicates with large number of user terminals having single or multiple antennas. It works by maximizing the ratio between the signal gain for intended user and interference at other users plus noise. So, accordingly there is need to choose the precoding technique. For this, there are two categories of precoding in MU-MIMO systems i.e. linear and non linear precoding. The linear techniques are the suboptimal techniques which maximizes the weighted sum performance instead of achieving that highest point to capacity. These techniques do not have a closed form solution. Basically, the non linear ones achieve the capacity, but they are more complex to implement whereas, the linear are not much complex and easy to implement and also give good performance. So, usually linear techniques are implemented instead of non linear. Some of the precoding techniques are following:

- **Maximum Ratio Transmission (MRT) precoding**

This techniques uses channel state information for calculations and it only maximizes the signal power at the intended user. It can provide the near optimal solution, when the system is noise limited and the interuser interference is negligible [56].

- **Zero Forcing (ZF) precoding**

Zero Forcing precoding is a technique of signal processing in which the delay of receiving signals at the receiver is compensated. As the channel behavior is different at different places this causes the delay in reaching the signal at the destination. So, in order to make the performance better the weights are attached to the received signal. This can achieve almost the system capacity for available CSIT. The main focus in this is to null the interuser interference, at the loss of some signal [57]. This is used when large numbers of users are available in the system or the system is interference limited.

- **Dirty Paper Coding (DPC)**

This is a non linear precoding technique which is little bit difficult to implement. In this, without hitting the power of the system, it pre cancels the interference. Here, the knowledge of CSI is required on both sides but interference needs to be known at the transmitter only [58].

3.4 User Grouping in Multiuser MIMO Systems

On the transmitter side, there is multiple numbers of antennas, but they are also limited by some number due to practical constraint. But, there is need to accommodate large number of users up to hundred-scale which could lead to degradation of the system. So, it is very important in multi-user MIMO system to select the number of users accordingly, so that the system performance is not compromised along with accommodating maximum number of users in the system [29]. This can be done by dividing the users into groups.

User grouping is a technique which allows to group the number of users based on some criteria, such that each group is similar in a way. User grouping helps to aim for maximizing the system performance while minimizing spatial correlation among the users [59]. There has been number of grouping algorithms which could be used for this purpose.

The various grouping or clustering algorithms are based on some of the criteria being used. So, the mainly defined grouping algorithms are:

- Connectivity based grouping
- Distribution based grouping
- Density based grouping
- Centroid based grouping

3.4.1 Connectivity based grouping

It is a grouping technique which relates to the objects which are closer to them than the farther away objects. So, algorithms based on connectivity mainly use the distance to form groups. At different distances various groups will be formed. These algorithms do not provide the single partitioning of the data, but provides the hierarchy of groups which merge with each other. These methods are generally too complex and thus are too slow while computing the grouping of large number of sets.

3.4.2 Distribution based grouping

It is the grouping technique which basically uses the distribution of the data sets as the main criteria. The data points having same statistical distribution are considered in the same group. The main model of this type is the Gaussian mixture model where the data is grouped based on the fixed number of Gaussian distributions that is initialized randomly. This type of grouping produces the complex models for clusters formed on the basis of dependence and correlation.

3.4.3 Density based grouping

In density based grouping, the more dense areas are confined into groups than the less dense areas. So, these sparse data is considered to be noise in the groups that are formed by the much dense area. The two main models in density based grouping are the DBSCAN and the OPTICS. In DBSCAN, the groups formed satisfy the two conditions. Firstly, all the points in the group are mutually density connected. Secondly, if the random point is in the reach of the density of the point in the group, then it is also considered the part of the cluster. OPTICS is the generalization of the DBSCAN which removes the need of choosing a particular value for the range parameter of the cluster

3.4.4 Centroid based grouping

In this type of clustering, the groups are basically represented by the central vector which is not the member of the data. By pre-fixing the number of clusters to K, the K-mean clustering

algorithm may be defined as given in [31]. In K-mean clustering, first of all specify the total number of groups formed and initialize the value of all K centroids. Secondly, calculate the Euclidian distance between the cluster centroid to each object. The rows corresponds to the distance of each object from the corresponding centroids i.e. first row gives distance from first centroids for all users. Thirdly, according to the position and number of members in the group, form the new centroid of each group based on new memberships. Finally, when the centroid does not move, it gives the final value of the centroid according to the minimum distance.

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CHAPTER 4

METHODOLOGY AND ANALYSIS

In this chapter, discussion about the capacity of multiuser MIMO system is considered. Firstly, the uplink case is considered where the capacity in low as well as in high SNR regime is calculated. Secondly, the case of downlink multiuser MIMO is considered. In this, the sum rate for the Zero Forcing precoding along with the user grouping algorithm has been discussed.

4.1 Capacity Analysis of the MU-MIMO in Uplink case

In this chapter, discussion about the ergodic capacity of the multiuser massive MIMO system is considered. It is studied in the Rayleigh fading uplink channel for low as well as high SNR scenarios.

The system model consists of K users each having one antenna and L antennas at the BS in distributed formation. The channel considered is Rayleigh flat-fading uplink channel with variance profile as for all users, the coefficients for large scale fading from the BS antennas are not equal.

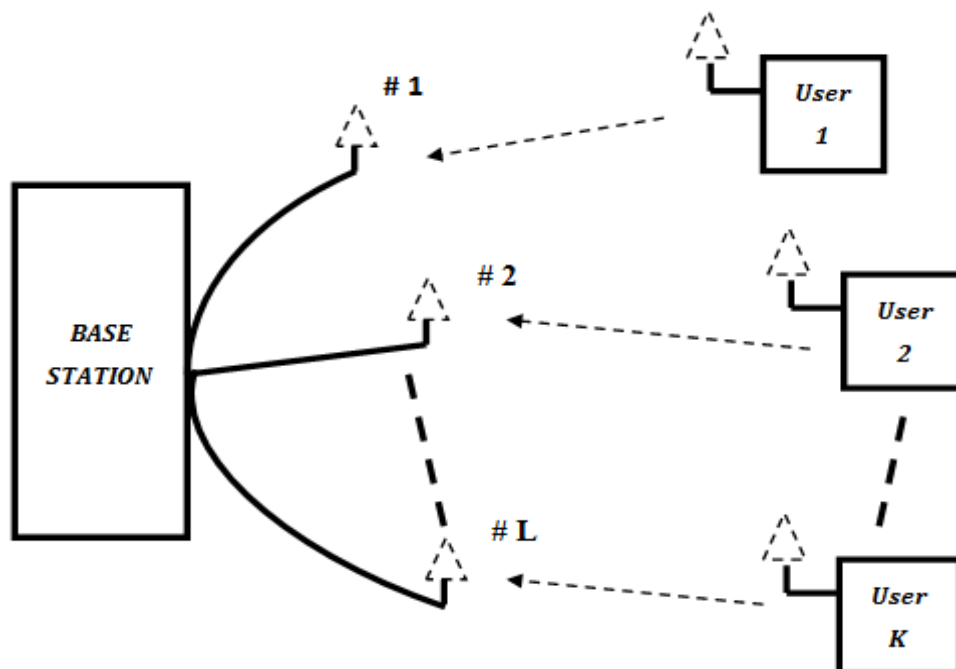


Fig 4.1 Uplink in Multiuser MIMO with Distributed Antennas [21]

So, the received signal y for this multi-user MIMO uplink system is

$$y = H^T x + n \quad (4.1)$$

Where, x and n are the transmitted symbol and additive noise respectively. Noise is zero mean complex Gaussian with variance σ^2 and H is $K \times L$ matrix of channel coefficients. H being the combination of small and large scale fading coefficients as follows

$$H = H_n \oslash A^{\frac{1}{2}} \quad (4.2)$$

Here, \oslash denotes the Hadamard product and H_n and A are the $K \times L$ small and large scale fading coefficient matrix.

Now, the capacity for all users with unit transmit power, normalized ergodic sum capacity $C_{norm-sum}$ for equal number of users and base station antennas i.e. $K=L$ is given as [21]

$$C_{norm-sum} = \frac{1}{K} E \left[\log_2 \det \left(I_K + \frac{1}{\sigma^2} H H^H \right) \right] \quad (4.3)$$

This expression could be further simplified for ergodic sum capacity in Rayleigh fading channel with variance profile [21]

$$C_{norm-sum} = \frac{2}{K} \sum_{k=1}^K \log_2(1 + e_k) - \log_2(e) \frac{1}{\sigma^2 K^2} \sum_{l=1}^K \sum_{k=1}^K \frac{a_{k,l}}{(1 + e_l)(1 + e_k)} \quad (4.4)$$

Here, e is Napier constant and e_1, e_2, \dots, e_k are the solutions for the non linear equations.

$$e_l = \frac{1}{\sigma^2 K} \sum_{k=1}^K \frac{a_{k,l}}{1 + e_k} \quad (4.5)$$

4.1.1 Capacity for Low SNR Regime

In low SNR region which is being considered less than or equal to -10 dB the Napier constants, e_1, e_2, \dots, e_k . Their value is less than one. So, Taylor series expansion would find the linear solution for the non linear equations.

$$e_l \approx \frac{1}{\sigma^2 K} \sum_{k=1}^K a_{k,l} (1 - e_k) \quad (4.6)$$

So, this system of linear equations can be written in the form of matrix by applying the simple calculus which is as follows

$$(\sigma^2 K I_k + A^T)e \approx A^T \mathbf{1}_k \quad (4.7)$$

Here,

$$e = [e_1, e_2, \dots, e_k]_{1 \times K}^T$$

$$\mathbf{1}_k = [1, 1, \dots, 1]_{1 \times K}^T$$

Since $(\sigma^2 K I_k + A^T)$ is a square matrix so the value of e could be written in massive MIMO for $(K \gg 10)$, as following

$$e = \frac{1}{\sigma^2 K} A^T \mathbf{1}_k \quad (4.8)$$

Now, the sum capacity for low SNR regime can be solved as following

$$C_{norm-sum}^{low-SNR} = \frac{2 \log_2(e)}{K} \left[\mathbf{1}_K^T e - \frac{1}{2K\sigma^2} \mathbf{1}_K^T (A + A^T) \left(\frac{1}{2} \mathbf{1}_K - e \right) \right] \quad (4.9)$$

$$C_{norm-sum}^{low-SNR} = \frac{\log_2(e)}{K^2 \sigma^2} \left[\mathbf{1}_K^T A \mathbf{1}_K + \frac{1}{K\sigma^2} \mathbf{1}_K^T A^2 \mathbf{1}_K + \frac{1}{K\sigma^2} \mathbf{1}_K^T A A^T \mathbf{1}_K \right] \quad (4.10)$$

In this equation, ignore the second and third term. So, ergodic sum capacity for the multiuser MIMO system in low-SNR is given by [21]

$$C_{norm-sum}^{low-SNR} \approx \frac{\log_2(e)}{K^2 \sigma^2} \mathbf{1}_K^T A \mathbf{1}_K = \frac{\log_2(e)}{\sigma^2} \bar{a} \quad (4.11)$$

Here, in this equation, the \bar{a} being the average value of all the large scale fading coefficients.

4.1.2 Capacity for High SNR Regime

In high SNR region which is being considered equal to 17 dB or more the Napier constants e_1, e_2, \dots, e_k are greater than one. So, Taylor series expansion gives linear solution for the non linear equations as [21]

$$e_l \approx \frac{1}{\sigma^2 K} \sum_{k=1}^K \frac{a_{k,l}}{e_k} \quad (4.12)$$

In practical scenario, user distance from BS is much larger than diameter of BS antenna array. So, for each user the distance from each antenna at base station is almost equal. Therefore, the large scale fading coefficients are almost constant and are equal to a_k . So, the equation could be written as

$$e_l \approx \frac{1}{\sigma^2 K} \sum_{k=1}^K \frac{a_k}{e_k} \quad (4.13)$$

Due to symmetry of this equation, it can be said that e_1, e_2, \dots, e_k are equal in value. So above equation can be given as

$$e = \sqrt{\frac{1}{\sigma^2 K} \sum_{k=1}^K a_{k,l}} \quad (4.14)$$

This equation could be written in matrix form where the square root is entry-wise and it is given as

$$e = \sqrt{\frac{1}{\sigma^2 K} \mathbf{1}_K^T A} \quad (4.15)$$

Now the sum capacity for high SNR regime can be solved as following

$$C_{norm-sum}^{high-SNR} \approx \frac{2}{K} \sum_{k=1}^K \log_2(e_k) - \log_2(e) \frac{1}{\sigma^2 K^2} \sum_{l=1}^K \sum_{k=1}^K \frac{a_{k,l}}{e_l e_k} \quad (4.16)$$

$$C_{norm-sum}^{high-SNR} = \frac{2}{K} \sum_{k=1}^K \log_2 \left(\sqrt{\frac{1}{\sigma^2 K} \sum_{k=1}^K a_{k,l}} \right) - \log_2(e) \frac{1}{\sigma^2 K^2} \sum_{l=1}^K \frac{1}{e_l} \left(\sum_{k=1}^K \frac{a_{k,l}}{e_k} \right) \quad (4.17)$$

$$C_{norm-sum}^{high-SNR} = \frac{1}{K} \sum_{k=1}^K \log_2 \left(\sum_{k=1}^K a_{k,l} \right) - \log_2(\sigma^2 K e) \quad (4.18)$$

This equation can be written in matrix which gives ergodic sum capacity of multiuser MIMO in Rayleigh fading uplink channel as [21]

$$C_{norm-sum}^{high-SNR} = \frac{1}{K} \sum_{l=1}^K \log_2(\mathbf{1}_K^T A) + \log_2 \left(\frac{1}{\sigma^2} \right) - \log_2(K e) \quad (4.19)$$

Here, logarithm is entry-wise in this equation. Thus it can be concluded from the above equation that sum capacity is proportional to the logarithm of inverse of noise power which is proportional to SNR.

4.2 Capacity Analysis of MU-MIMO system in Downlink Case

Consider the downlink system model having B_t antennas at BS and K_u user terminals each equipped with single antenna. The transmit antennas have geometry such that they are placed along the axis forming uniform linear array.

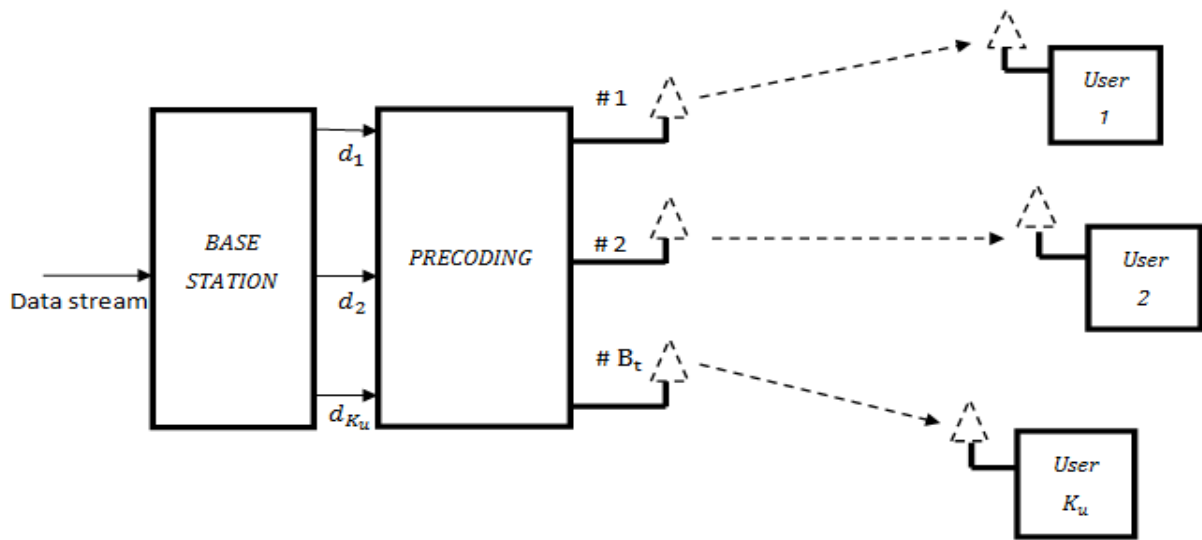


Fig 4.2 Block Diagram for Downlink Multiuser MIMO System

Now, the signal received by all the users is given by the following equation [46]

$$R = H^H X + z \quad (4.20)$$

Where $(.)^H$ denotes the Hermitian of the matrix; H , is the channel matrix between the transmit antennas and the users and have dimension $B_t \times K_u$.

$$H = [h_1, h_2 \dots \dots \dots , h_k] \quad (4.21)$$

The transmit signal vector X is represented as

$$X = \frac{1}{\sqrt{\gamma}} W d \quad (4.22)$$

Here, d represents the transmitted symbol data vectors and W is the precoding matrix. This factor γ helps to limit total transmitted power to some predetermined value p . Thus, it could be given as

$$\|X\|^2 = \frac{1}{P} d^H W^H W d \quad (4.23)$$

Now in zero forcing, precoding matrix is known as Moore Penrose pseudo inverse of H given as [60]

$$W = H^H [H H^H]^{-1} \quad (4.24)$$

In this way, received signal vector as shown in equation 1 is given by

$$R = H^H X + z \quad (4.25)$$

$$R = H^H \frac{1}{\sqrt{\gamma}} W d + z \quad (4.26)$$

$$R = \frac{1}{\sqrt{\gamma}} H^H [H H^H]^{-1} d + z \quad (4.27)$$

4.2.1 User grouping based on K-mean Algorithm

In the realistic cells, the number of users is very large. So, selecting n users from all the N number of users, then there will be C_N^n combinations, which is a complicated process. Therefore adapting user grouping based on some parameter, the computational complexity is reduced [31].

For example, the random set of unlabeled data is provided. The data is divided in two matrices X and Y which are represented by the blue and red color respectively are shown in the figure below. These two matrices are divided on some basis of some parameter. Now, consider the centroids of the two matrices which are shown in green color.

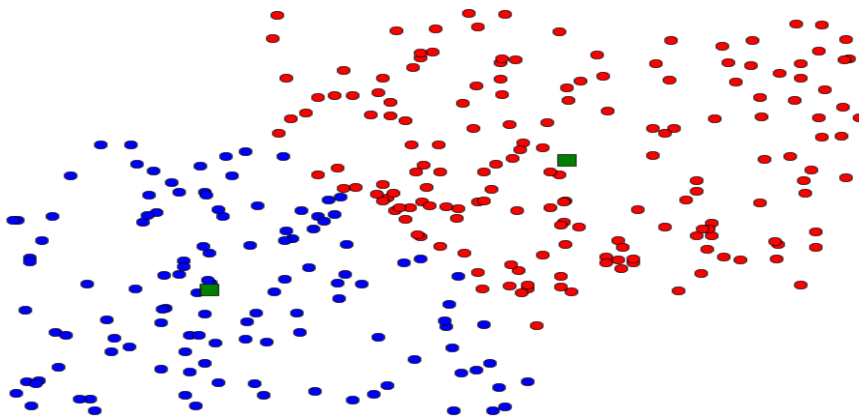


Fig 4.3 Example of K-mean Grouping

Intuitively, make the cluster as it be comprising of the data points whose inter point distance is small as compared to the points which are outside the cluster.

So, if the value of K is given initially, K-mean algorithm works as follows:

- For each random centre take the subset of points which are closer to it than any other centroids.
- The means of the data points in each cluster are computed, and this mean vector becomes the new centre for that cluster.

This algorithm can group users based on various parameters like signal to noise ratio, position, velocity etc as the matrices. K-mean is a very light weight clustering algorithm, which requires an initialization parameter, which determine the number of groups the users are to be divided. So, partitioning K_u users in G groups, each group belong to the nearest mean. The chordal distance between the mean of two groups i.e. centroids of the two groups is considered [18]. So, for given two matrices X and Y the chordal distance is

$$d_c = \|XX^H - YY^H\|^2 \quad (4.28)$$

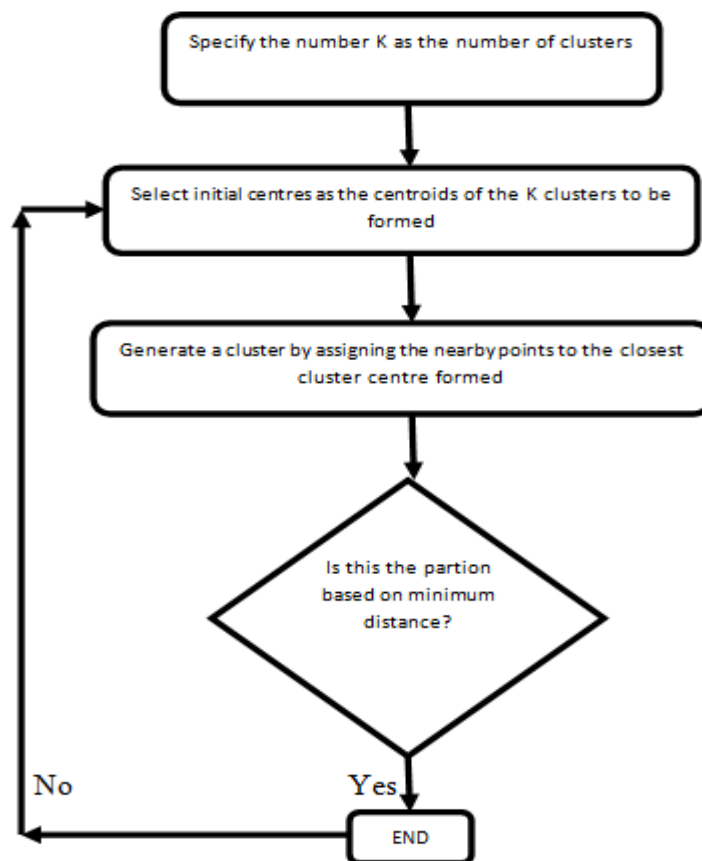


Fig 4.4 Flow chart for K-mean Grouping Algorithm

Accordingly, $\sum_{g=1}^G K_g = K$ and $\sum_{g=1}^G S_g = S$. Here, K_g shows the number of users in the group g and S_g shows the data stream for group g . Now, there are many user groups for which channel matrix is being represented by

$$H_g = [h_{g1}, h_{g2}, \dots \dots \dots, h_{gK_g}] \quad (4.29)$$

In this equation of channel matrix, h_{gK_g} shows the channel matrix for the member of g^{th} group and the channel matrix for the total number of groups would be shown as the following

$$H = [H_1, H_2, \dots \dots \dots H_G] \quad (4.30)$$

As the different user groups are formed, based on their distance from base station antennas, accordingly the different precoding matrix for different user groups are determined. So, for total no. of groups the precoding matrix will be shown as following

$$W = [W_1, W_2, \dots \dots \dots W_G] \quad (4.31)$$

Now, this matrix W is made up of two matrices which help to suppress the interference among the different groups formed and interference among the users of same group. So, this precoding matrix W is shown as the product of the two matrices i.e. pre beam forming matrix B and precoding matrix P of $B_t \times 1$ and $1 \times K_u$ respectively.

Now from equation 1, the following could be given as

$$R = H^H X + z \quad (4.32)$$

$$R = H^H W d + z \quad (4.33)$$

$$R = H^H B . P . d + z \quad (4.34)$$

$$R = \tilde{H}^H . P . d + z \quad (4.35)$$

Where,

$$\tilde{H}^H = \begin{pmatrix} H_1^H B_1 & \dots & H_1^H B_G \\ \vdots & \ddots & \vdots \\ H_G^H B_1 & \dots & H_G^H B_1 \end{pmatrix} \quad (4.36)$$

Now, users of only group 'g' receive the signal given by

$$R_g = \tilde{H}^H_g \cdot P_g \cdot d_g + \left\{ \sum_{g=1}^G \tilde{H}^H_g \cdot P_g \cdot d_g \cdot B_g \right\} + z_g \quad (4.37)$$

Here, the bracketed term shows the intergroup interference. But when using the unitary condition then the inter-group interference disappears. So, the equation becomes

$$R_g = \tilde{H}^H_g \cdot P_g \cdot d_g + z_g \quad \{g = 1, 2, \dots, G\} \quad (4.38)$$

Now, the transmit power is evenly distributed on all the downlink channels. Each user feeds back SINR value to the base station. For K^{th} user in the g^{th} group i.e. g_k , the SINR value is given by [61]

$$SINR_{g_k} = \frac{|h_{g_k}^H W_g|^2}{|h_{g_k}^H W_g|^2 + \sum_{g \neq g'} \|h_{g_k}^H W_{g'}\|^2} \quad (4.39)$$

Accordingly, the base station allocates the users with the maximum SINR value from different groups to communicate. Now to reduce the inter-user interference, increase the SINR i.e.

$$R_g = E [\log\{1 + \max SINR_{g_k}\}] \quad (4.40)$$

So, the sum rate for the user of the g^{th} group is given by

$$R_g = E \left[\log\{1 + \max \left(\frac{|h_{g_k}^H W_g|^2}{|h_{g_k}^H W_g|^2 + \sum_{g \neq g'} \|h_{g_k}^H W_{g'}\|^2} \right)\} \right] \quad (4.41)$$

Now, sum rate for zero forcing precoder for the active users who have good SINR value from all the user groups r after applying the grouping algorithm could be given as following

$$R_{sum} = E \left[\sum_{g=1}^G \sum_{k=1}^K \log_2 \det \left(1 + \frac{P}{K\sigma^2} |h_{g_k} W_g|^2 \right) \right] \quad (4.42)$$

$$R_{sum} = \sum_{g=1}^G \left\{ \log_2 \left(1 + \frac{P}{K\sigma^2} \sum_{g_k=1}^K |h_{g_k} W_g|^2 \right) \right\} \quad (4.43)$$

CHAPTER 5

RESULTS AND DISCUSSION

In this chapter, capacity performance of the multiuser MIMO system in both uplink and downlink case is depicted. The performance of the system has been evaluated using the MATABL simulations.

5.1 Results depicting Capacity for MU-MIMO System in Uplink Case

In this section, the performance of ergodic sum-capacity of the multi-user MIMO system in uplink case has been analyzed for low SNR as well as high SNR of -10dB and 17dB respectively. It is analyzed for the practical scenario of distributed antenna array and channel is Rayleigh flat fading along with AWGN noise with unit variance and zero mean. It is found under the condition of equal number of BS antennas and users.

Figure 5.1 depicts sum-capacity against SNR for a multiuser MIMO scenario with equal number of BS antennas and users. According to figure, the low-SNR approximation is an upper bound on the actual capacity. As the SNR reduces this approximation gets tighter. Also the approximation error in this is less than 10 percent at -10dB.

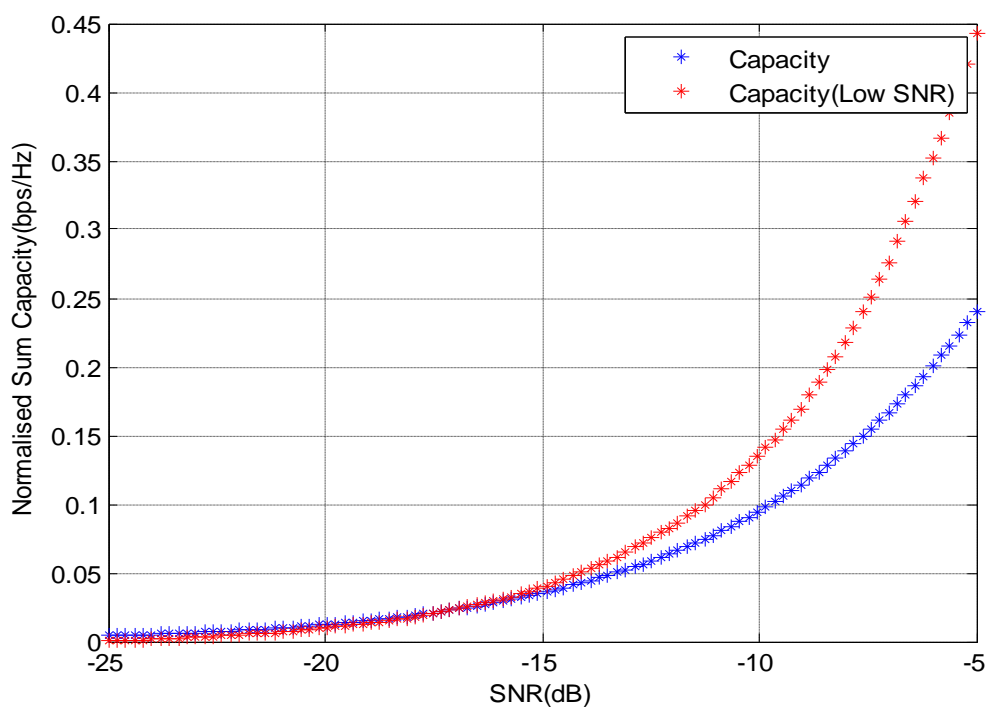


Fig. 5.1 Sum-capacity against SNR in Low SNR Scenario

Figure 5.2 depicts the sum-capacity against SNR for a multiuser MIMO system for high-SNR value of 17dB. It has been found in the practical scenario of distributed antenna array in Rayleigh flat fading environment along with AWGN noise having unit variance and zero mean. The total number of base station antennas and users considered are equal in number.

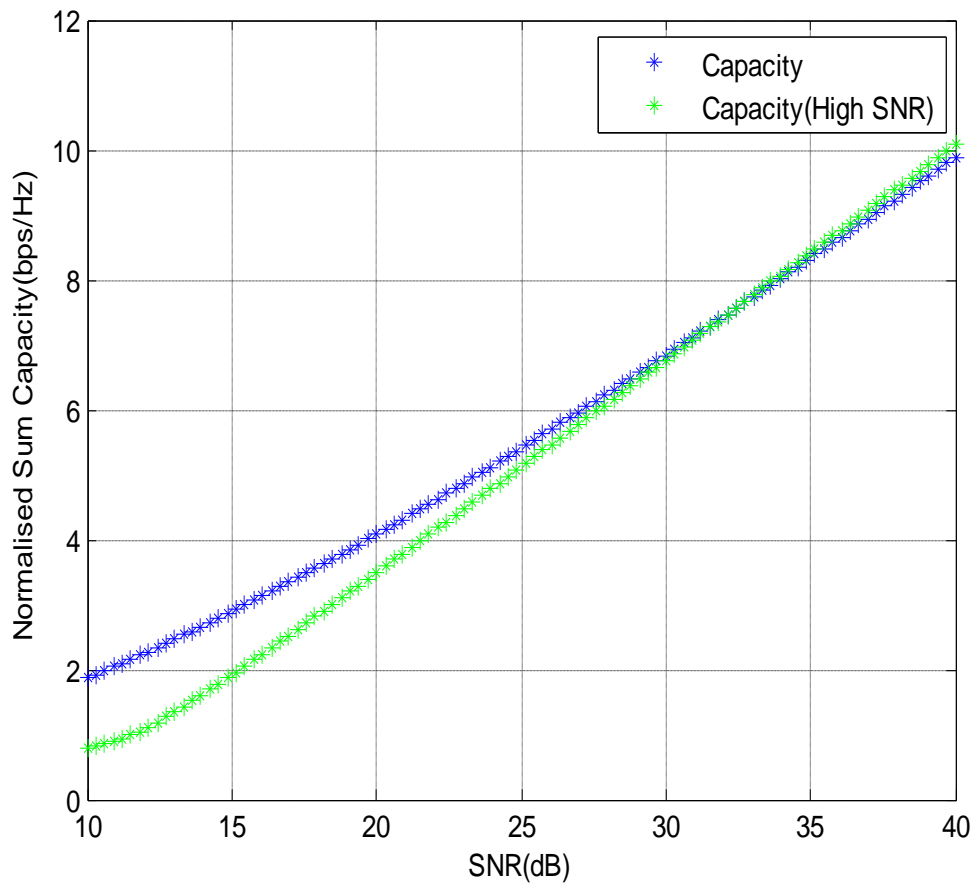


Fig. 5.2 Sum-capacity against SNR for High SNR Scenario

According to figure, high-SNR approximation is the lower bound on the actual capacity and gets tighter as the SNR increases. In this also, the error is below 10 percent at the high SNR value of 17dB.

In figure 5.3, joint analysis of overall comparison of the accuracy for sum capacity approximation is shown. The actual and the proposed low as well as high SNR sum-capacities are plotted in logarithmic scale.

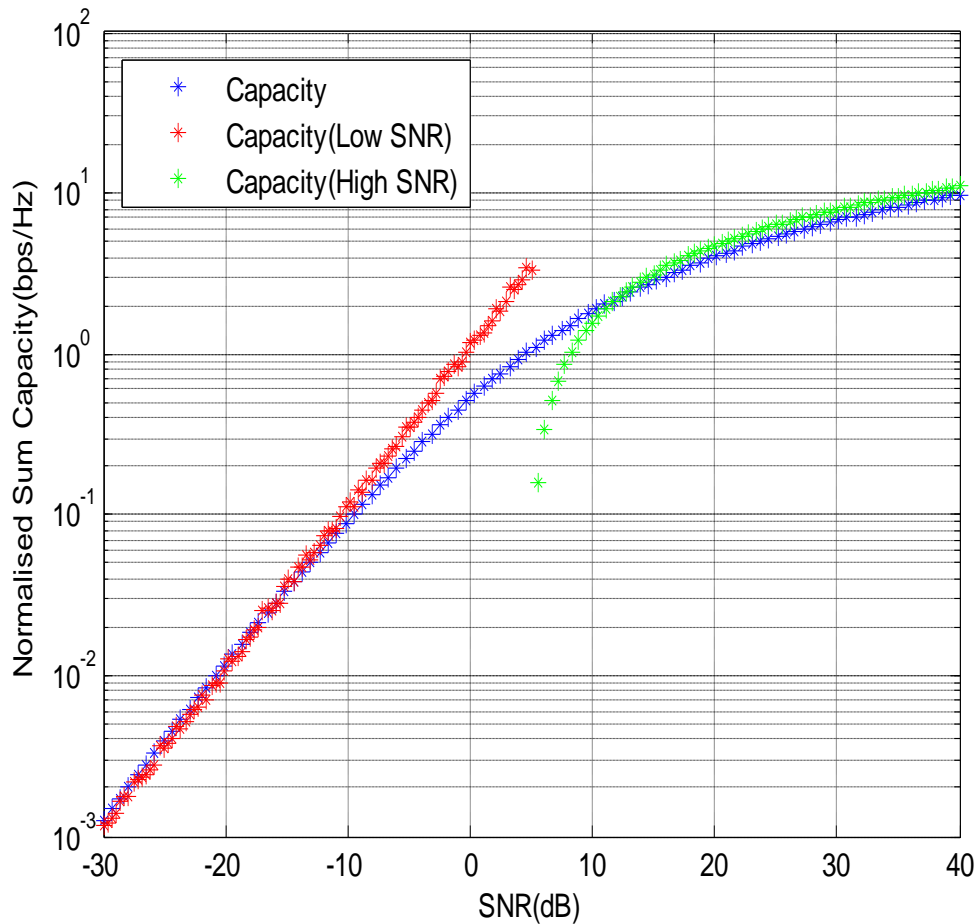


Fig 5.3 Sum-capacity against SNR for K=100 for Low and High SNR

The figure shows that the accuracy of the proposed approximate capacity expressions is acceptable in a wide range of practical SNRs. Also, with the increase in number of base station antennas the error is reduced rapidly till the time number of antennas is reduced to 10. So, this is acceptable for the less number of antennas too.

5.2 Results depicting Capacity for MU-MIMO System in Downlink Case

The simulation results demonstrating performance of grouping algorithm are presented here. For this, consider 100 antennas at the transmitter and 100 users being served by these antennas in the Rayleigh fading environment. For all simulations, use the transmit power P to be 10 dB and the received power $\frac{1}{\sigma^2}$ at the receiver varies according to the minimum distance from the base station while using K-mean clustering. So, it is seen that performance after applying user grouping algorithm is better than just the zero forcing precoding. In this, K-mean clustering is used to make two user groups and it is seen that sum rate improves while making three groups. Firstly, the results for the zero forcing precoding for the sum rate of the system are shown below.

In figure 5.4, the sum rate for zero forcing precoder is shown to vary against the SNR values. It is shown that at SNR of 15dB, the sum rate is 12 bps/Hz and with the increase of the signal to noise ratio value, the sum rate for the system grows exponentially. The desired result is obtained by multiplying the pseudo inverse of channel matrix with transmitted signal.

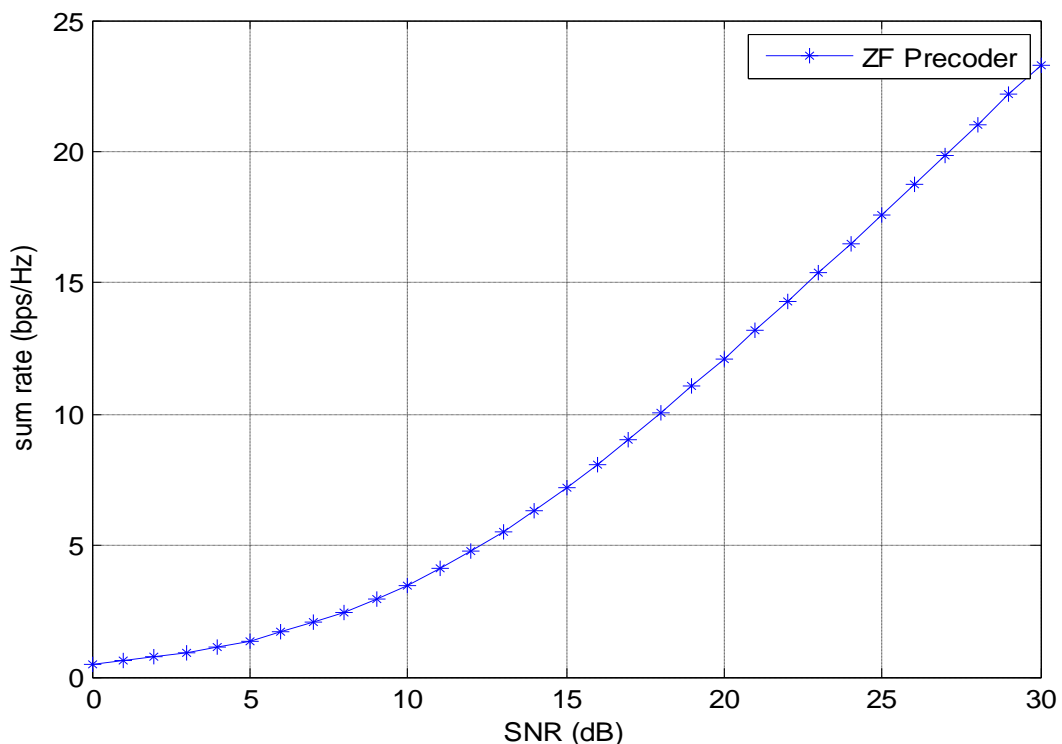


Fig 5.4 Sum rate vs. SNR for Zero Forcing Precoder

In fig 5.5, the sum rate for the zero forcing precoder against the number of users is depicted. In this the total number of users considered is 100 in the Rayleigh fading environment.

According to the graph, as the numbers of users are increasing the sum rate is also increasing as it is aggregate of all users. But after a threshold value the sum rate becomes almost constant by decreasing the value by little and stays constant for further increase of users.

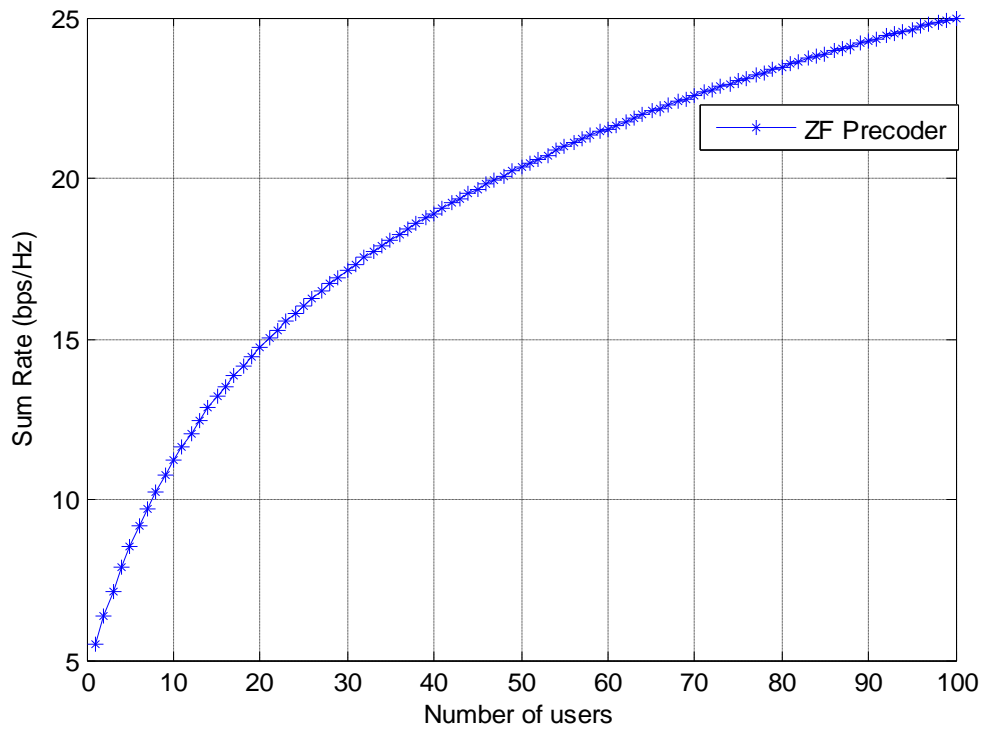


Fig 5.5 Sum rate vs. Number of users for Zero Forcing Precoder

In figure 5.6, we make the clusters of users according to the K-mean clustering algorithm who are spreaded in the vicinity on the basis of the received SNR by the user on the basis of distance. The green color represents the cluster 1 and the yellow color represents the cluster 2. The two clusters formed here are for the total of 100 users who are divided in two groups according to the distance from BS antenna and consecutively the received signal by user terminal.

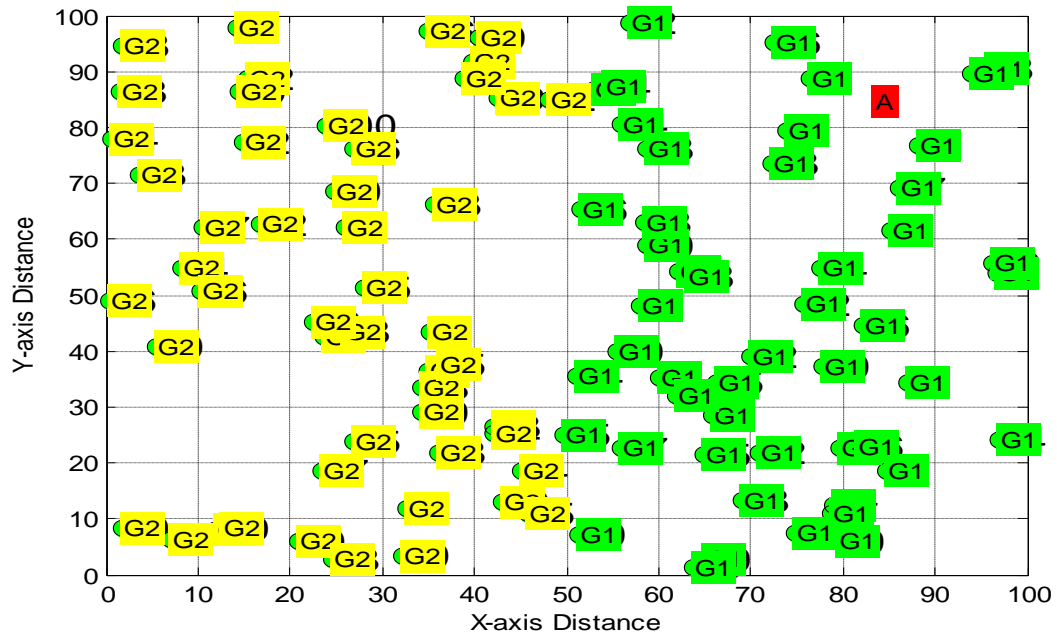


Fig. 5.6 User grouping based on K- mean Grouping Algorithm

In figure 5.7, the information sum rate is given for the zero forcing precoding as well as the precoder formed by user grouping for the function of signal to noise ratio.

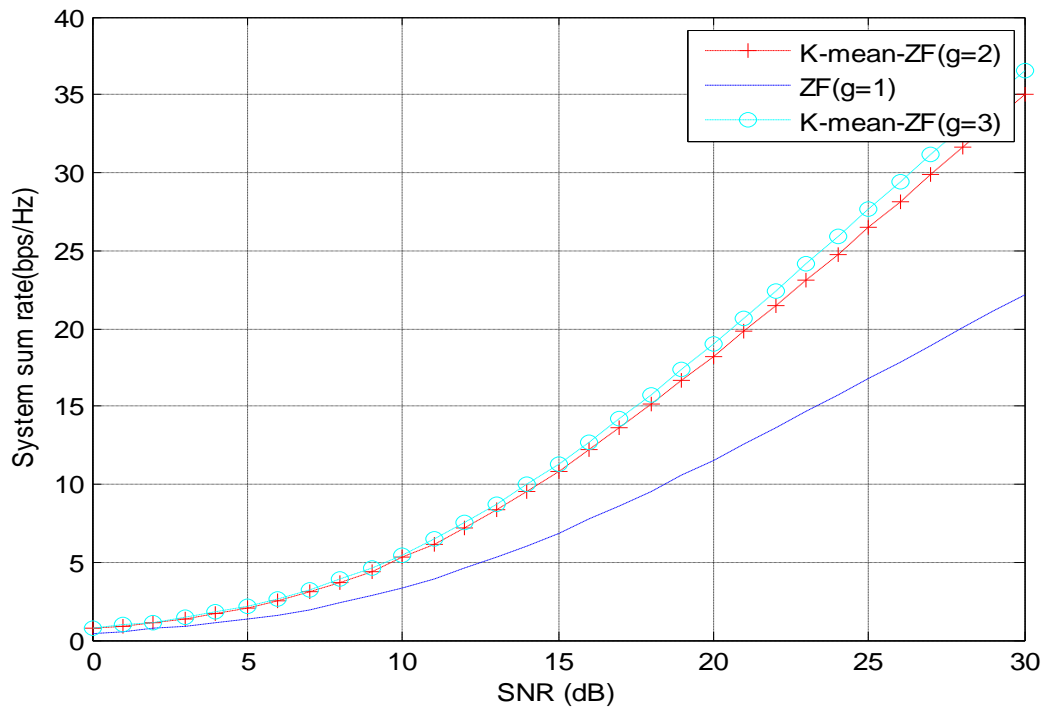


Fig. 5.7 System sum rate vs. SNR using K-mean

It is observed that proposed grouping algorithm achieves better sum rate than the conventional zero forcing at the given transmit power. For SNR of 15 dB, the sum rate for proposed precoder for ($g = 2$) is 11 bits/sec/Hz which is almost 1.7 times more than the conventional zero forcing algorithm.

In figure 5.8, the sum rate vs. the number of users is shown for 100 users in the system. Results for the zero forcing and for the user grouping have been compared.

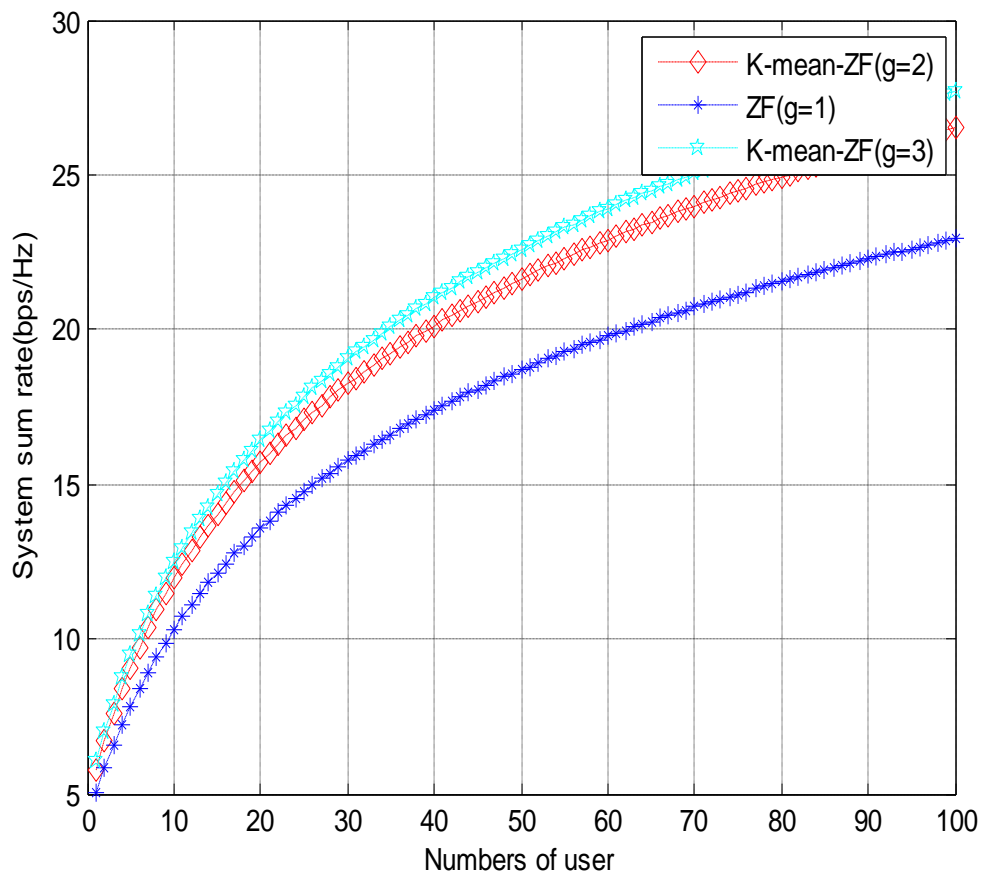


Fig. 5.8 System sum rate vs. Number of users using K-mean

It is seen that the user grouping algorithm performs better than the zero forcing algorithm. By increasing number of users in the system, the sum rate increases for the proposed algorithm. Along with that when we make three clusters instead of two the sum rate increases.

In figure 5.9, sum rate vs. number of users is shown for different number of groupings i.e. for different value of K. It can be seen that when 50 users are divided in groups, the sum rate for two groups (g=2) is 26.5 bps/Hz and it keeps on increasing while the number of groups formed are increased till four i.e. it is 29 bps/Hz and 29.5 bps/Hz respectively for three (g=3) and four (g=4) groups.

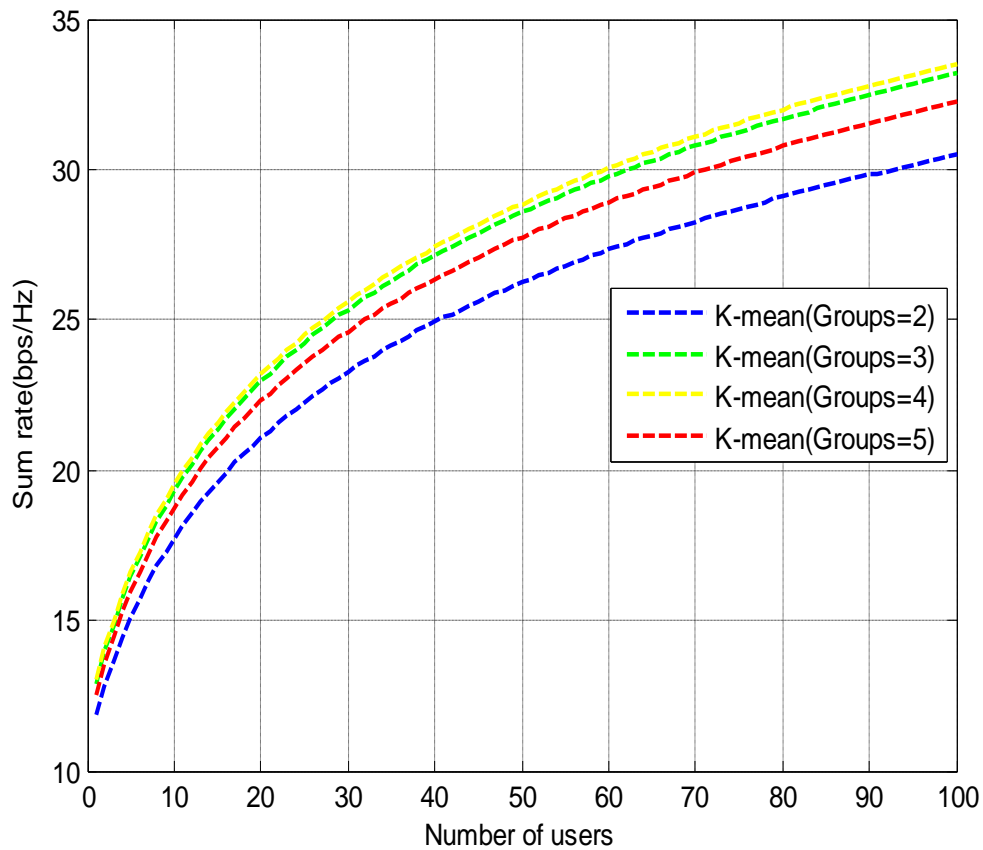


Fig. 5.9 Sum rate vs. Number of users for different values of K

But, when the five (g=5) groups are made for same number of users; it decreases to 28 bps/Hz, which is less than value of two and three grouping. But it is still higher for grouping done into two.

In figure 5.10, sum rate vs. SNR for the K-mean clustering is given for different value of K i.e. different number of groups formed. For two ($g=2$) groups at SNR of 15dB value is 7 bps/Hz and it keeps on increasing when value of K increases till four. For $g=3$, the value is 8.5 bps/Hz and for value of $g=4$, it increase little bit to 9 bps/Hz. But when the value of K is further increased i.e. when $g=5$, the value deteriorates to 7.5 bps/Hz. But this value is still higher than the grouping done into two i.e. for $g=2$.

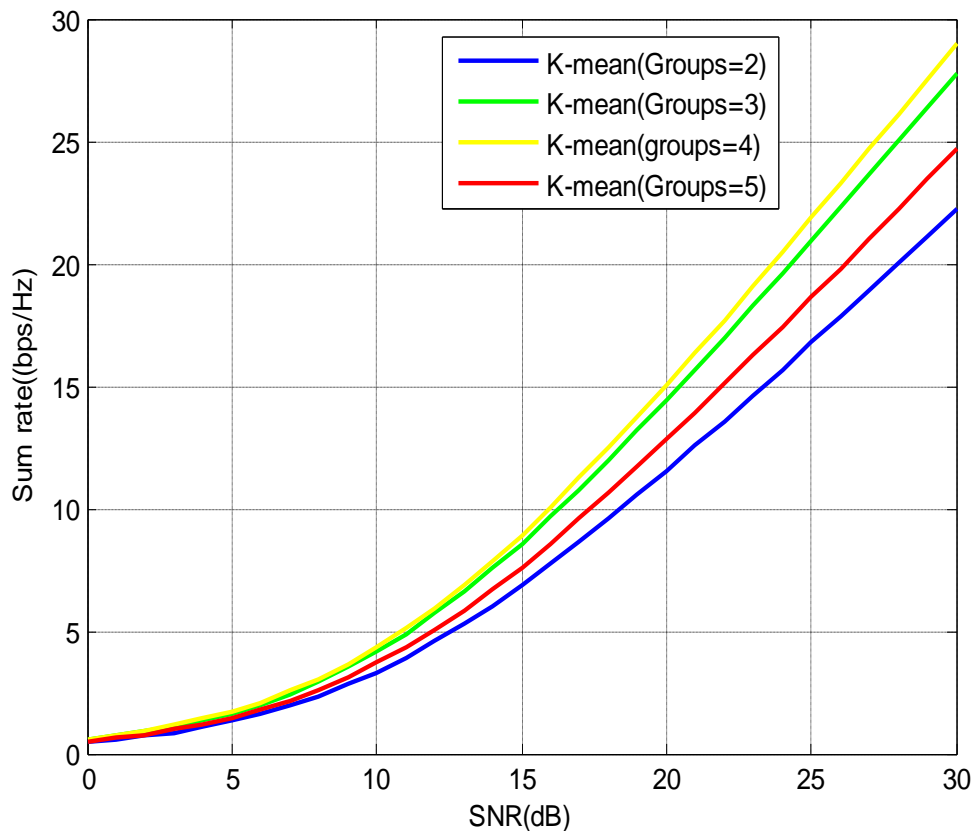


Fig. 5.10 Sum rate vs. SNR for different values of K

CHAPTER 6

CONCLUSION AND FUTURE SCOPE

6.1 Conclusion

Multiuser MIMO systems are the main attraction in today's scenario and they have led to various advancements in the field of wireless communication. Due to increasing number of users day by day, it has led to the various challenges like more congestion, reduced capacity of the system along with increase in the interference. So, the MIMO technology helped to make the system better by overcoming all these shortcomings and implementing it in the multiuser scenario. Further, it becomes difficult to accommodate all the users in the system simultaneously at same instant of time. So, by dividing the users into groups based on their properties, it is possible to reduce the congestion, interference and increase the capacity of the system.

In this dissertation, the multiuser MIMO system along with the use of zero forcing precoding and K-mean user grouping algorithm has helped to overcome the practical implementation issues related to wireless systems. The total of 100 antennas at the base station and 100 single antenna users have been considered in the study. For total set of users; the zero forcing precoding is implemented and also, the users are grouped into the groups of two, three, four etc. It is observed that proposed grouping algorithm achieves better sum rate than the conventional zero forcing at the given transmit power by the use of grouping of users. For SNR of 15 dB, the sum rate for proposed precoder for ($g = 2$) is 11 bits/sec/Hz which is almost 1.7 times more than the conventional zero forcing algorithm. Also, for 50 users in the system, the sum rate using K-mean for ($g=2$) is 22.5 bps/Hz and it increases to 24bps/Hz when three groups are made. So, it can be seen that the performance is better than zero forcing in both the cases

The optimization of user grouping leads to the maximum number of groups that can be formed while maximizing the performance of the system. It has been observed from the results presented in this dissertation proved that till grouping of four the sum rate improves but it deteriorates when five groups are made for the total number of users.

6.2 Future Scope

The multiuser systems have been implemented along with the use of multiple antenna technology and K-mean user grouping algorithm in order to improve the performance of the communication system. But, these systems do suffer from some limitations like fading and co channel interference which reduces the performance of systems. In order to improve the performance of the K-mean user grouping algorithm, it can be implemented using the OFDM in the time and frequency domain for the multi dimensional domain.

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