Chapter 2

Background and Related work: MIMO Wireless

Background and Related work: MIMO Wireless Communication

2.1 Introduction

Wireless communication is one of the great success stories of recent years, offering users levels of mobility and services never available before. The success of future wireless communication systems depends on meeting, or exceeding, the needs, requirements and interests of users and society as a whole . This will require an increase in spectral efficiency to allow high data rates and high user capacities far beyond those of 2G or 3G systems [1]. This goal is particularly challenging for systems that are power, bandwidth, and complexity limited. However, the domain which can be exploited to increase the channel capacity is the use of multiple transmit and receive antennas. Pioneering work by Foschini [2] and Telatar [3] ignited much interest in this area by predicting significant higher bit rates compared to single-antenna systems. The use of multiple antennas for wireless communication systems has gained overwhelming interest during the last decade [4]. MIMO is now being integrated into many wireless standards like 3G and 4G wireless communication systems [5].

Throughout this introductory chapter, an attempt has been made to present MIMO channel capacity analysis, performance gains offered by MIMO architecture and trade-offs in MIMO wireless communication system.

2.1.1 MIMO Wireless System model

The MIMO wireless communication system investigated in this work consists of n_T transmitting and n_R receiving antennas, the descriptor used is (n_T,n_R). The input and output relation of MIMO communication system model is commonly represented by the vector notation as:

$$y = Hx + n \tag{2.1}$$

where **x** is (n_T x 1) transmit symbol vector, **y** is the (n_R x 1) receive vector, **H** is (n_R x n_T) channel matrix, and **n** is (n_R x 1) Additive White Gaussian Noise (AWGN) vector at a given instant of time as shown in Figure 2.1 .

In channel matrix H, h_{ij} represents the complex gain of the channel between the j^{th} transmitter and i^{th} receiver. For a MIMO system represented by Equation 2.1, with n_T transmit antennas and n_R receive antennas, the channel matrix **H** is given by Equation 2.2.

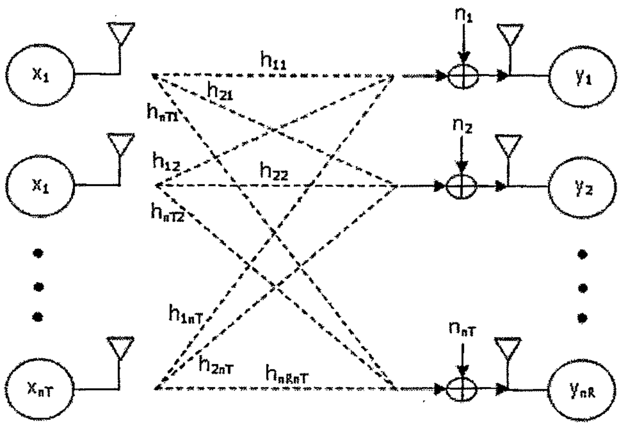

Figure 2.1: MIMO wireless communication model

$$H = \begin{bmatrix} h_{11} & h_{12} & \cdots & h_{1n_T} \\ h_{21} & h_{22} & \cdots & h_{2n_T} \\ \vdots & \vdots & \ddots & \vdots \\ h_{n_R1} & h_{n_R2} & \cdots & h_{n_Rn_T} \end{bmatrix} \tag{2.2}$$

In rich scattering environment with no specular component of the signal i.e Line-Of-Sight (LOS), the channel gains $|h^{ij}|$ are usually Rayleigh distributed [6]. It is assumed that the entries of channel **H** are Independent Identically Distributed (i.i.d) Gaussian, complex and each entry is of zero mean with independent real and imaginary parts. Each entry of **H** has uniformly distributed phase and Rayleigh distributed magnitude with expected magnitude square equal to unity. This is intended to model a Rayleigh fading channel with enough physical separation within the transmitting and the receiving antennas to achieve independence in the entries of H as in Equation 2.3.

$$H_{ij} = Normal(0, 1/\sqrt{2}) + i.Normal(0, 1/\sqrt{2}) \tag{2.3}$$

The Rayleigh channel model considered here is similar to that in Foschini's work [2]. Considering the described MIMO wireless channel model, the capacity analysis for SISO, SIMO, MISO and MIMO system is carried out in following section. The capacity analysis are plotted using Matrix Laboratory (MATLAB).

2.2 MIMO Channel Capacity Analysis

The MIMO systems can be studied from two different perspectives: one concerns performance evaluation in terms of error probability of practical systems, the other concerns the evaluation of the information-theoretic (Shannon) capacity [7]. For the latter, the Shannon capacity of MIMO communication systems in terms of Ergodic capacity and Outage capacity is briefly discussed. The capacity analysis for different types of MIMO channels are discussed in [8–10]. All these analyses showed that MIMO systems in Rayleigh-fading environments can potentially provide enormous channel capacity.

The inspiration for research and applications of wireless MIMO systems was mostly triggered by the initial Shannon capacity results obtained independently by Bell Labs researchers E. Telatar and J. Foschini. In this section we examine the capacity aspects of MIMO wireless communication systems.

2.2.1 Shannon capacity of wireless channels

Information theory is very broad mathematical framework, which has its roots in communication theory, as founded by Shannon in his well known paper [11]. Information theory deals with measurement and transmission of information through a channel. Shannon's law defines the theoretical maximum rate at which error free digits can be transmitted over a bandwidth limited channel in the presence of noise as given in Equation 2.4.

$$C \leq Blog_2(1 + \frac{S}{N}) \tag{2.4}$$

where **C** is the effective channel capacity in bits per second; **B** is the channel bandwidth in hertz and **S/N** is the SNR of the communication signal to the Gaussian noise interference expressed as a straight power ratio.

Single-Input Single-Output

Given a Single-Input Single-Output (SISO) channel corrupted by an AWGN noise, at a level of SNR denoted by ρ, the capacity (rate that can be achieved with no constraint on code or signaling complexity) can be written as in Equation 2.5 [12]:

$$C = log_2(1 + \rho|h|^2) \quad b/s/Hz \tag{2.5}$$

where $|h|^2$ is the normalized complex gain of a fixed wireless channel.

Single-Input Multiple-Output

Single-Input Multi-Output (SIMO) system consists of single transmit antenna and multiple receive antenna. This system is also known as Receive Diversity. It is mainly used to enable receiver to receive signal from number of independent sources to combat the effect of fading. As we deploy more receiver antennas the statistics of capacity improve with n_R receive antennas. The capacity of SIMO system is given by [13]:

$$C = log_2(1 + \rho \sum_{i=1}^{n_R} |h_i|^2) \quad b/s/Hz \tag{2.6}$$

where h_i is the gain of i^{th} receive antenna. As shown in Figure 2.2, by increasing the value of n_R there is logarithmic increase in capacity. This is due to the spatial diversity which reduces fading and due to high SNR of the combined antennas.

The increase in capacity due to SNR improvement is limited because the SNR is increasing inside the log function in Equation 2.6. In summary, SIMO systems are good at improving the channel capacity performance due to the spatial diversity effect, but this effect saturates with increase in the number of antennas. SIMO system is not acceptable in systems where the receiver is located in mobile device such as mobile equipment, as the receiver processing will be limited by size and battery drain.

Multiple-Input Single-Output

Multi-Input Single-Output (MISO) system consists of multiple transmit antennas and single receive antenna, termed as Transmit Diversity. In such systems, the redundant data is transmitted from transmitter and receiver receives the optimum signal to extract the required data. For MISO system, it is assumed that the transmitter does not have the channel knowledge. MISO system with n_T transmit antennas and one receive antenna, the channel capacity is given as in Equation 2.7, where the normalization by n_T ensures a fixed total transmit power.

$$C = log_2(1 + \frac{\rho}{n_T} \sum_{i=1}^{n_T} |h_i|^2) \quad b/s/Hz \tag{2.7}$$

As shown in Figure 2.3, as the number of transmit antenna increases the channel capacity increases and has a logarithmic relationship with n_T. The advantage of using MISO compared to SIMO, is that the number of antennas are on the transmitter side. In systems like Base station as transmitter it is acceptable to have number of transmit antennas due to space for antennas, size and battery life.

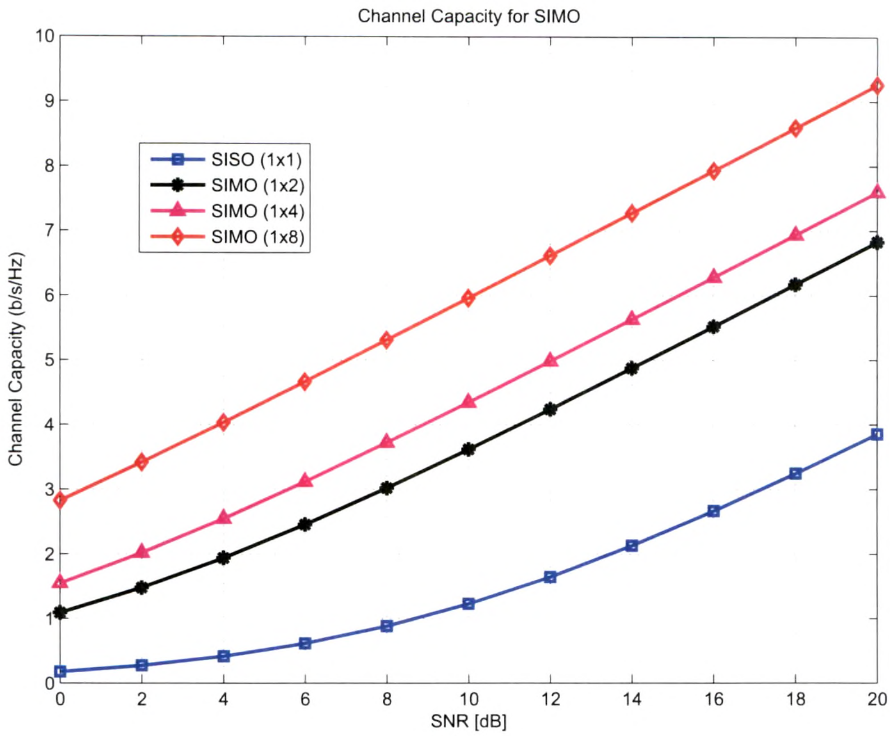

Figure 2.2: SIMO System-Channel Capacity

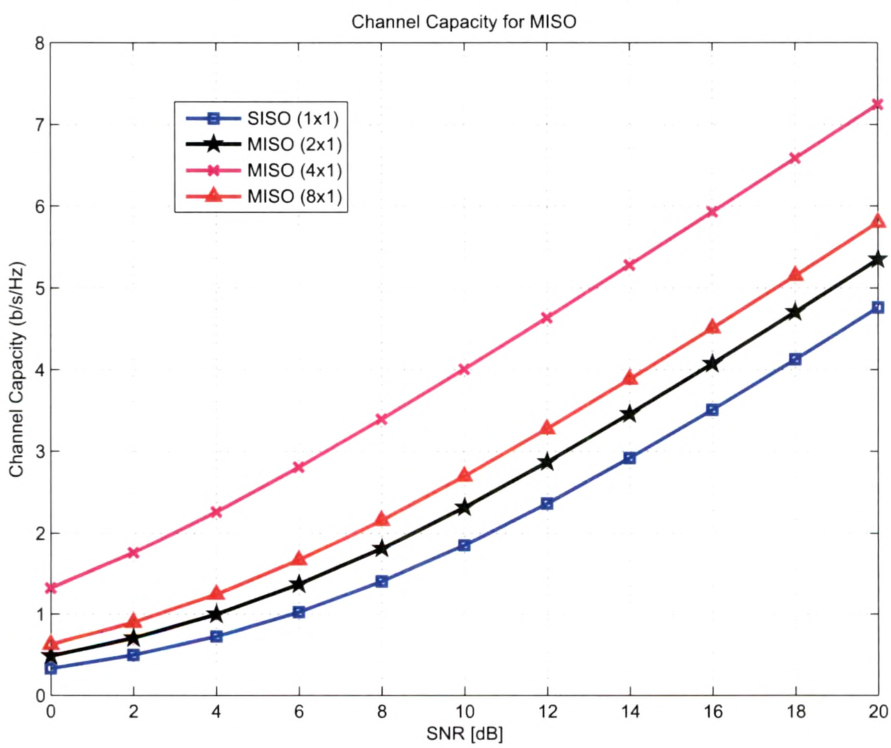

Figure 2.3: MISO System-Channel Capacity

Multiple-Input Multiple-Output

Now, we consider the use of diversity at both transmitter and receiver giving rise to a MIMO system. For n_T transmit antennas and n_R receive antennas, the capacity equation is given by Equation 2.8

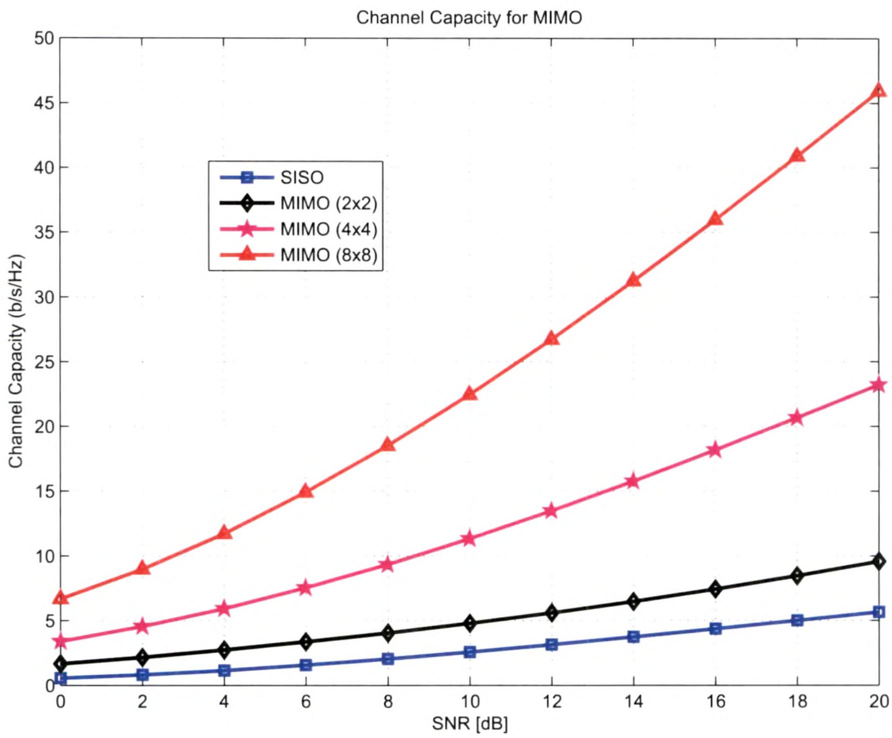

Figure 2.4: MIMO System-Channel Capacity

$$C = log_2[det(I_{n_R} + \frac{\rho}{n_T} HH^*] \quad b/s/Hz \tag{2.8}$$

where (*) means transpose-conjugate. As shown in Figure 2.4, as the number of transmit and receive antenna increases, the channel capacity linearly increases with the term $min(n_T, n_R)$.

To further consider the random variations of the wireless channel, there are two notions of capacity for fading channel [14]. They are as follows:

1) Ergodic Capacity: It is the capacity achieved by encoding each message across multiple channel realizations and

2) Outage Capacity: It is the rate achieved under a constraint on the outage probability. Outage analysis quantifies the level of channel capacity performance that is guaranteed with a certain level of reliability. These capacities for MIMO communication systems are briefly examined.

2.2.2 Ergodic Capacity

For finite number of transmit and receive antennas, E. Telatar [3] derived the analytical expression for the ergodic (or mean) capacity of i.i.d Rayleigh flat-fading MIMO channels by using the eigenvalue distribution of the Wishart matrix **W** in integral form involving the Laguerre polynomials. The calculation of the mean capacity involves the channel H, in terms of the eigenvalues $\lambda_1 ... \lambda_m$ of **W** where

$$W = \begin{cases} HH^*, & n_R < n_T \\ H^*H, & n_R \geq n_T \end{cases} \tag{2.9}$$

An exact calculation of the ergodic capacity with $n_T = t$ transmitters and $n_R = r$ receivers under power constraint P yields [[3],Equation 8]:

$$C = \int_0^\infty log(1 + \frac{P\lambda}{t}) \sum_{k=0}^{m-1} \frac{k!}{(k+n-m)!} [L_k^{n-m}(\lambda)]^2 \lambda^{n-m} e^{-\lambda}\, d\lambda \tag{2.10}$$

where m=min(n_R,n_T) and n=max(n_R,n_T), and L_k^{n-m} is the associated Laguerre polynomial of order k given as:

$$L_k^{n-m}(x) = \frac{1}{k!} e^x x^{m-n} \frac{d^k}{dx^k} (e^{-x} x^{n-m+k}) \tag{2.11}$$

SIMO-Ergodic Capacity

For SIMO system, $n_T = 1$ and $n_R = r$, hence $m = 1$ and $n = r$ in Equation 2.10. The capacity is given as [[3],Equation 9]:

$$C_{SIMO} = \frac{1}{\Gamma(r)} \int_0^\infty log(1 + P\lambda) \lambda^{r-1} e^{-\lambda} du \tag{2.12}$$

Simulation results of the ergodic capacity v/s number of receive antenna is as shown in Figure 2.5. From the graph we can say that as number of receive antenna increases the ergodic capacity increases. For system with large number of receive antennas, the capacity is asymptotic to *log(1+Pr)*.

MISO-Ergodic Capacity

For MISO System the value of r in Equation 2.10 equals to one. The ergodic capacity is given by [[3],Equation 10]:

$$C_{MISO} = \frac{1}{\Gamma(t)} \int_0^\infty log(1 + \frac{P\lambda}{t}) \lambda^{t-1} e^{-\lambda} du \tag{2.13}$$

The MISO Ergodic capacity of given by integral in Equation 2.13 is plotted in Figure 2.6. The

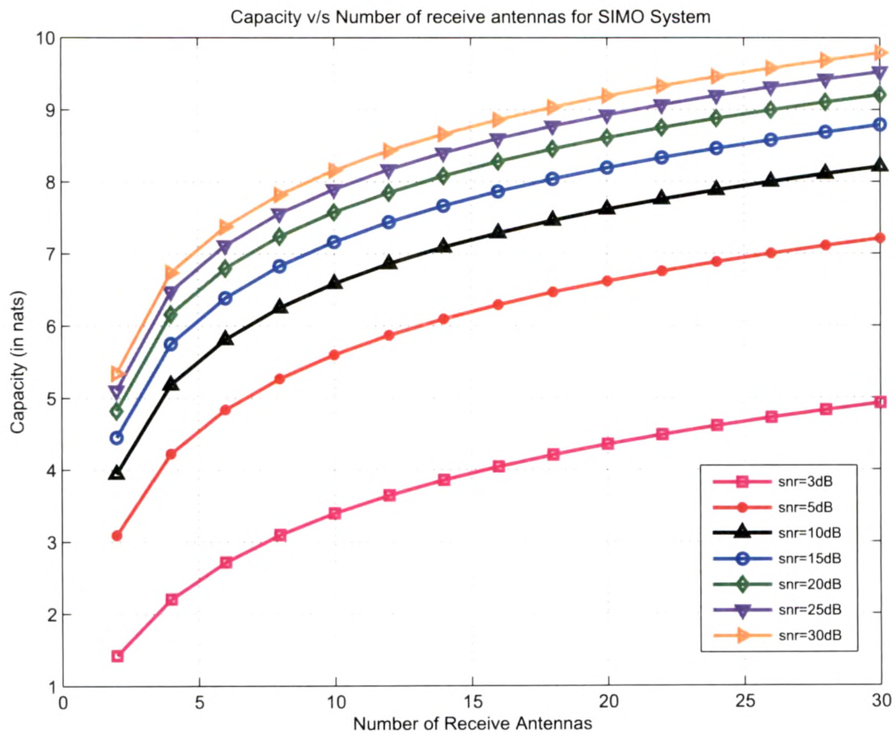

Figure 2.5: Capacity vs Number of receive antenna for SIMO system

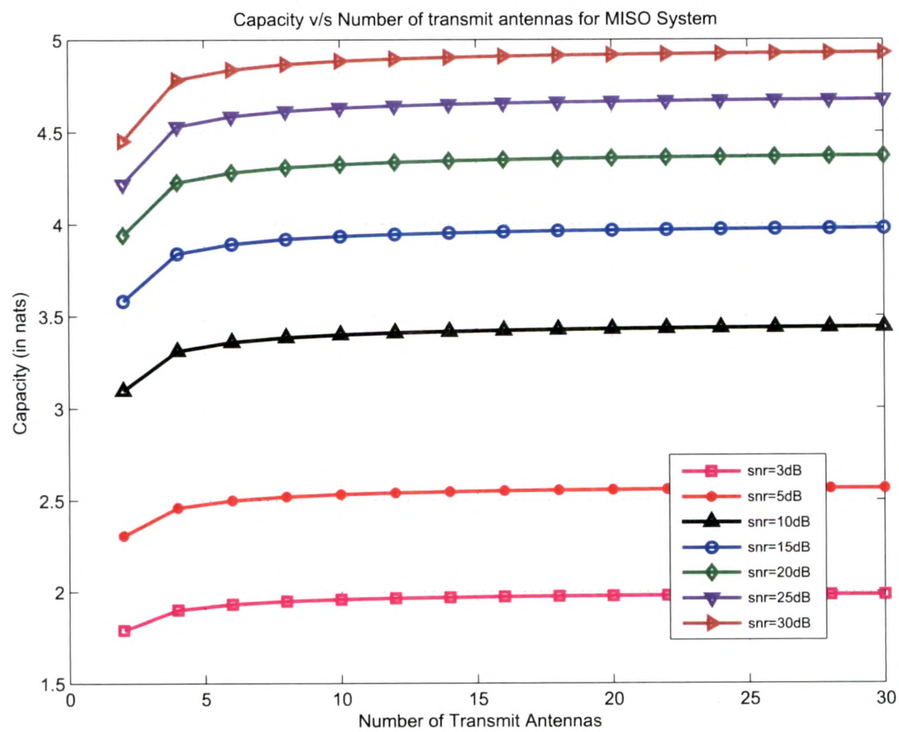

Figure 2.6: Capacity vs Number of transmit antenna for MISO system

plot is for number of transmit antennas v/s Capacity. From the plot we can observe that as the number of transmit antennas increases the capacity approaches to *log(1+P)*.

MIMO-Ergodic Capacity

For MIMO system, with $r = t$, $n = m = r$, the capacity is is given by [[3],Equation 11]:

$$C_{MIMO} = \int_0^\infty log(1 + \frac{P\lambda}{r}) \sum_{k=0}^{r-1} L_k(\lambda)^2 e^{-\lambda}\, d\lambda \tag{2.14}$$

where $L_k = L_k^0$ is the Laguerre polynomial of order k.

Figure 2.7 shows this capacity for number of antenna configurations and SNR. It can be shown that the channel capacity grows proportional with the minimum number of antennas $min(n_R, n_T)$ outside and no longer inside the log function. Hence from theoretical analysis, for idealized random channels, limitless capacities can be obtained if we can afford the cost and space of many antennas and RF chains. In practical applications the capacity is dictated by the transmission algorithms selected and by the physical channel characteristics.

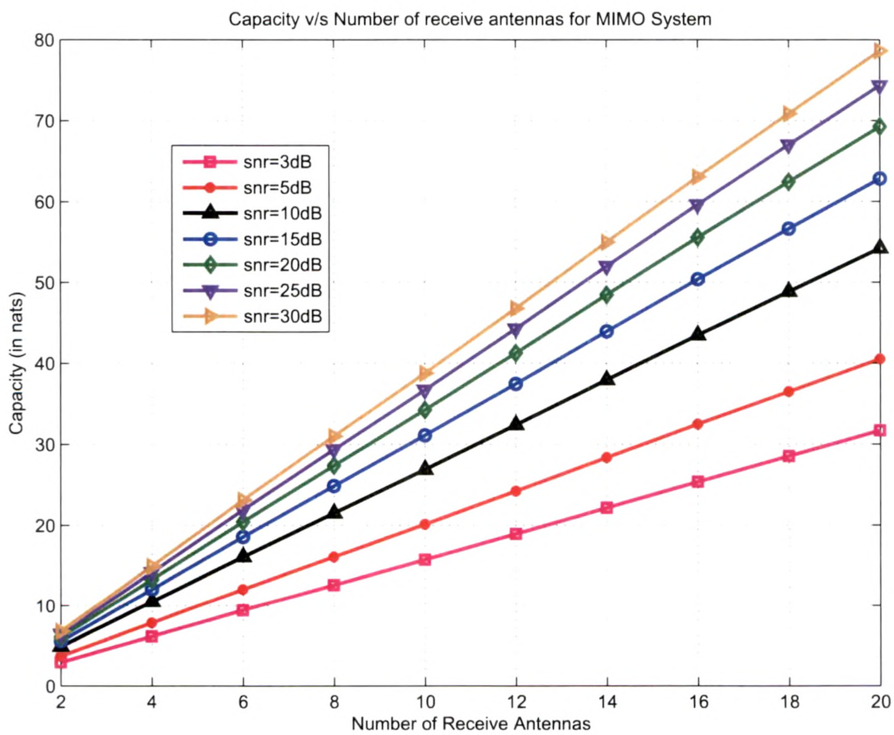

Figure 2.7: Capacity vs Number of receive antenna for MIMO system

2.2.3 Outage Capacity

Since the MIMO channel capacity is a random variable, it is meaningful to consider its statistical distribution. A particularly useful measure of its statistical behavior is the so-called Outage Capacity. With Outage Capacity, the channel capacity is associated to an Outage probability. If the channel capacity falls below the outage capacity, there is no possibility that the transmitted block of information can be decoded with no errors, whichever coding scheme is employed. The probability that the capacity is less than the outage capacity denoted by Cout is q. It is represented as:

$$Pr(C \leq Cout) = q \tag{2.15}$$

Outage Capacity is the information rate that is guaranteed for $(100 - q)$ % of the channel realizations, given by [15]:

$$Pr(C(H) \geq Cout(q)) = q\% \tag{2.16}$$

The outage capacity is more relevant measure than the ergodic channel capacity, because it describes in some way the quality of the channel [16]. For a targeted outage probability p_o, the capacity with outage is the maximal rate for which the outage probability is smaller that p_o [17]. The outage capacity describes the rate at which reliable transmission can be guaranteed with a certain probability.

Denoting ρ is the probability of an outage event, the outage capacity is given as the rate R that satisfies the below equation:

$$\rho = Pr[C(t) < R] = Pr[log_2 det(I_{n_R} + \frac{\rho}{n_T} HH^*) < R] \tag{2.17}$$

The capacity for a fixed outage probability of 10% is as shown in Figure 2.8. And for a fixed outage probability of 90% is shown in Figure 2.9.

Summarizing the results of Ergodic and Outage Capacity for MIMO wireless communication systems, it can be concluded that large channel capacity is obtained using multiple antennas at transmitter and receiver. But the results are based on the assumptions that rich scattering environment provides independent transmission paths from each transmit antenna to each receive antenna i.e. Rayleigh channel is considered and perfect channel knowledge is known at the receiver. Hence, for a single-user system with MIMO architecture can achieve channel capacity which grows linearly with $min(n_T, n_R)$ as compare to SISO system. The channel capacity is highly dependent on the nature of CSI at the transmitter and receiver, the channel SNR and antenna correlations. Channel ca-

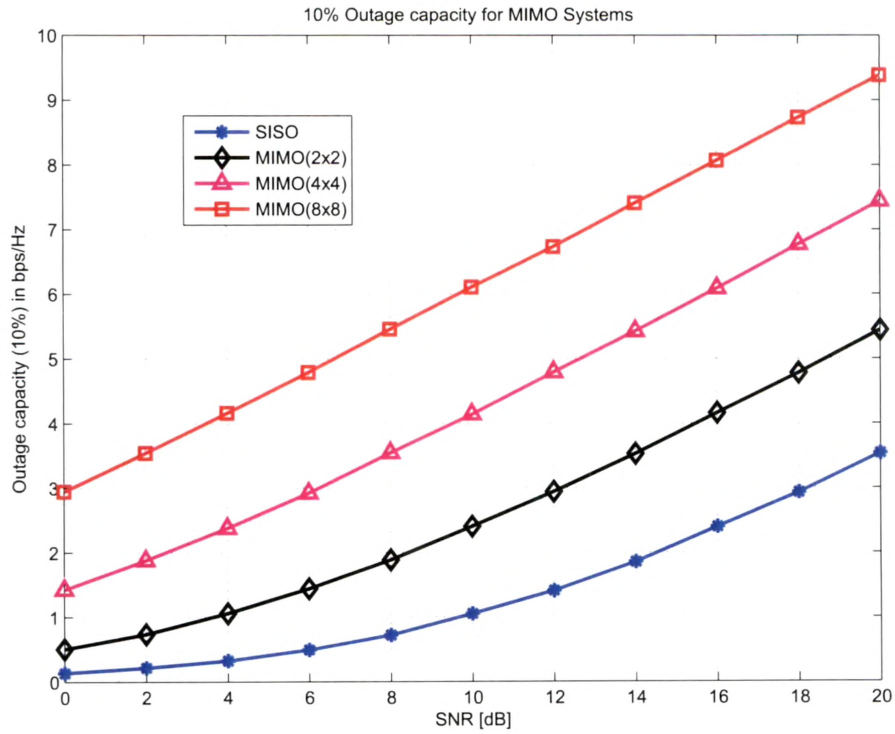

Figure 2.8: 10 percent Outage capacity of MIMO System

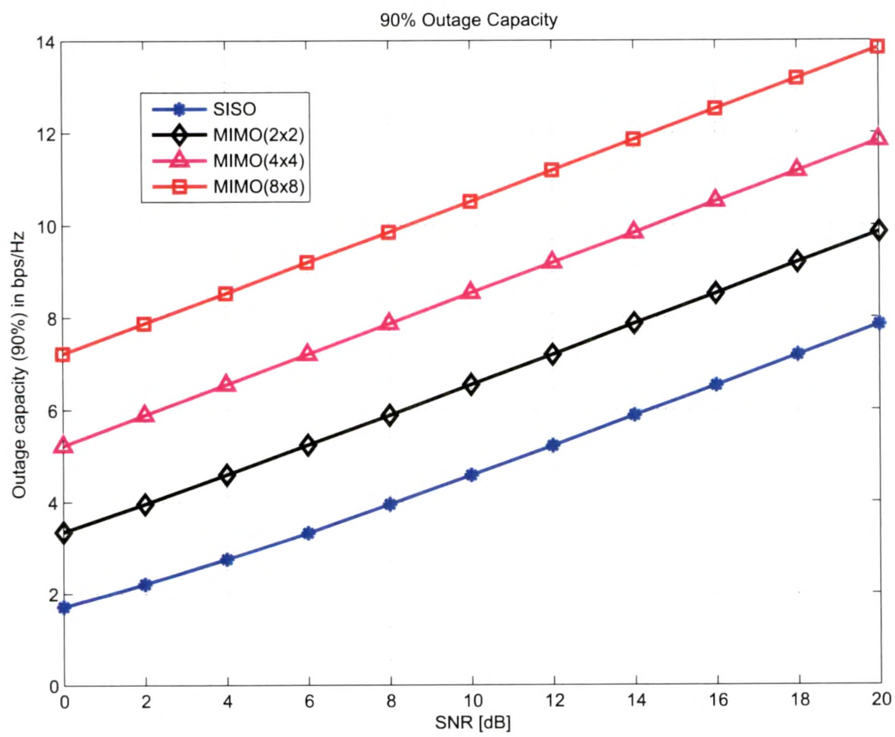

Figure 2.9: 90 percent Outage capacity of MIMO System

pacity limits based on realistic assumptions regarding CSI and time-varying channels are discussed briefly in [18].

2.3 MIMO Performance Gains

In wireless communication, spectral efficiency is of paramount importance due to high data rate demands of multimedia services. Usage of MIMO is considered as a promising way to achieve the necessary demands of spectral efficiency. MIMO system offers new degrees of freedom, which have to be used carefully to get the benefit of a MIMO system [19]. For a system where the channel is unknown at the transmitter and perfectly known at the receiver the MIMO performance gains and their respective effects on system performance are summarized in Table 2.1 [20].

MIMO Performance Gains	**Effects**
Spatial Multiplexing Gain	Increase Spectral Efficiency and capacity
Spatial Diversity Gain	Increase Link Reliability
Array Gain	Increase Coverage and QoS
Interference Cancellation gain	Reduce co-channel Interference and Increase cellular capacity

Table 2.1: MIMO Performance Gains and its effects

The performance improvements resulting from the use of MIMO systems are due to Spatial Multiplexing gain, Spatial Diversity gain, Array gain and Interference Cancellation gain. In this section each of these leverages gains are briefly reviewed. Various MIMO gain trade-offs are also discussed and analyzed.

2.3.1 Spatial Multiplexing Gain

Spatial Multiplexing gain is achieved in MIMO systems by transmitting independent data signals from individual antennas. Under the assumption of channel with rich scattering and independently faded channel paths, the receiver can separate different streams, resulting in increase in channel capacity. This increase in channel capacity is obtained for no additional power or bandwidth expenditure. The spatial multiplexing gain is given by [21]:

$$\lim_{SNR \to \infty} \frac{R(SNR)}{log(SNR)} = r \tag{2.18}$$

where R(SNR) is the data rate at SNR and r is the spatial multiplexing gain.

2.3.2 Spatial Diversity Gain

Diversity in the context of MIMO systems is the ability of system to improve link reliability by providing multiple independent fading parallel signal paths between transmitter and receiver. If multiple antennas are placed sufficiently far apart, the channel path gains between different antenna pairs fade independently, and, thus, independent signal paths are created. Diversity proves to be a powerful technique to mitigate the effects of fading in wireless systems [22].

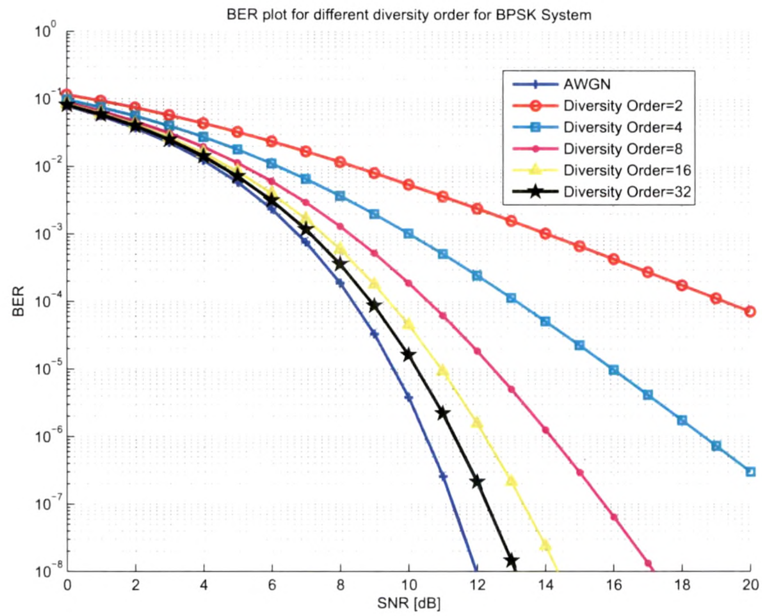

Figure 2.10: BER for different diversity order

Diversity Order: It is the number of independently fading signal paths between transmitter and receiver. Full diversity order for flat-fading spatially white MIMO channel of $n_T X n_R$ is achieved in case of MIMO system with n_T transmit antenna and n_R receive antennas. Capacity of fading channel approaches to an AWGN channel when the diversity order goes to infinity [23]. Figure 2.10 shows the effect of diversity order on the BER for Rayleigh Fading channel for BPSK system. It is seen that as the diversity order increases, the BER decreases and approaches nearer to AWGN channel BER. This plot was plotted using MATLAB based BERTool [24].

Diversity Gain: It is a measure of the decay of the probability of error with respect to the SNR. This quantity is given by [21]:

$$\lim_{SNR \to \infty} \frac{log P_e(SNR)}{log(SNR)} = -d \tag{2.19}$$

where Pe(SNR) is the average probability of error at SNR and d is the diversity gain.

2.3.3 Array Gain

Array gain can be made available through processing at the transmitter and the receiver and results in an increase in average receive SNR due to coherent combining effect. This increase in average receive SNR relative to single-antenna average SNR is termed as Array Gain [25]. Array gain improves coverage by improving the received SNR through coherent combining of the signals arriving at the receive antenna array.

2.3.4 Interference Canceling Gain

Interference canceling gain reduces co-channel interference, thus increases cellular system capacity by nulling out undesired interfering signals. Co-channel interference arises due to frequency reuse in wireless channels. Interference reduction requires knowledge of the desired signal channel. Interference reduction can be achieved by combining the signals in order to suppress the interference signal by using proper multiantenna spatial weighting scheme at the receiver to improve the average SNR at the receiving end [26, 27].

In general it is not possible to exploit all the leverages of MIMO technology simultaneously due to conflicting demands on the spatial degrees of freedom. The degree to which these conflicts are resolved depends upon the transmission techniques and transceiver design.

2.4 Tradeoffs in MIMO Wireless System

In recent developments in wireless communication systems, MIMO has been extensively applied in various wireless standards to increase the system performance dramatically. To date MIMO have been utilized for both spatial multiplexing approaches to increase spectral efficiency [28,29] or for spatial diversity to improve error performance [30]. The pioneering work by Zheng and Tse in the excellent groundbreaking paper [31] showed that both diversity and multiplexing gains can be simultaneously obtained, but there is a tradeoff between how much of each type of gain any MIMO scheme can extract: higher spatial multiplexing comes at the price of sacrificing diversity. The optimal Diversity and Multiplexing tradeoff (DMT) in Rayleigh i.i.d channels was studied. Further in [32], the DMT framework was completed by including array gain to cope with limitations of DMT. The derived Diversity, Multiplexing and Array gain (DMA) analysis gave more insight into the relation between reliability and transmission rate in MIMO Systems.

Based on elegant formulation of DMT, Azarian and El Gamal [33] introduced a new notion called the Throughput-Reliability Tradeoff (TRT), between the throughput, as quantified by the transmission rate, and reliability, as quantified by the so-called outage probability in Block Fading channel for high SNR-regime. Similarly, the Power-Bandwidth tradeoff [34, 35] and Spectral Efficiency (SE) and Energy Efficiency (EE) Tradeoff [36] is also studied for MIMO Systems.

2.4.1 Diversity-Multiplexing Tradeoff

As discussed in previous sections, for i.i.d. Rayleigh fading MIMO channel with n_T transmit and n_R receive antennas has a maximum diversity gain of $n_T X n_R$. On the other hand, the channel capacity scales with $min(n_T, n_R)$, which is the number of spatial degrees of freedom in the channel. This section analyses the DMT between the error probability and the data rate of a system [31].

As in [31,32], for family of codes $C(snr)$ of block length n_S, employs a different code $C(snr)$ with rate $R(snr)$ at each SNR level. A MIMO coding scheme $C(snr)$ is said to achieve a spatial multiplexing gain r, a diversity gain $d(r)$, and an array gain $a(R)$ if the data rate satisfies following equations:

$$\lim_{snr \to \infty} \frac{R(snr)}{log(snr)} = r \tag{2.20}$$

with $0 \leq r \leq \min(n_T, n_R)$

and the outage probability satisfies

$$\lim_{snr \to \infty} \frac{logP_{out}(r, snr)}{log(snr)} = -d(r) \tag{2.21}$$

$$\lim_{snr \to \infty} \frac{P_{out}(r, snr)}{snr^{-d(r)}} = a(r)^{-d(r)} \tag{2.22}$$

Observe that definitions in 2.21 and 2.22 induce the following approximation of the high-SNR behavior of the outage probability when R satisfies 2.20

$$Pout(r, snr) \sim (a(r) \cdot snr)^{-d(r)}(11) \tag{2.23}$$

where $\sim$ denotes asymptotic equivalence as $snr \to \infty$.

The optimal tradeoff curve $d^\star(r)$ between the diversity gain and the spatial multiplexing gain that can be achieved by any scheme in the Rayleigh-fading multiple-antenna channel for the case where block length $l \geq m + n - 1$ is given by piecewise-linear function connecting the points $(k, d^\star(k)), k = 0, 1, .., min(m, n)$, where

$$d^\star(r) = (m - k)(n - k) \tag{2.24}$$

where, $d^\star_{max} = mn$ and $r^\star_{max} = min(m, n)$.

The optimal tradeoff curve for various MIMO antenna configurations is plotted in Figure 2.11.As seen the maximum achievable spatial multiplexing gain is the total number of degrees of freedom

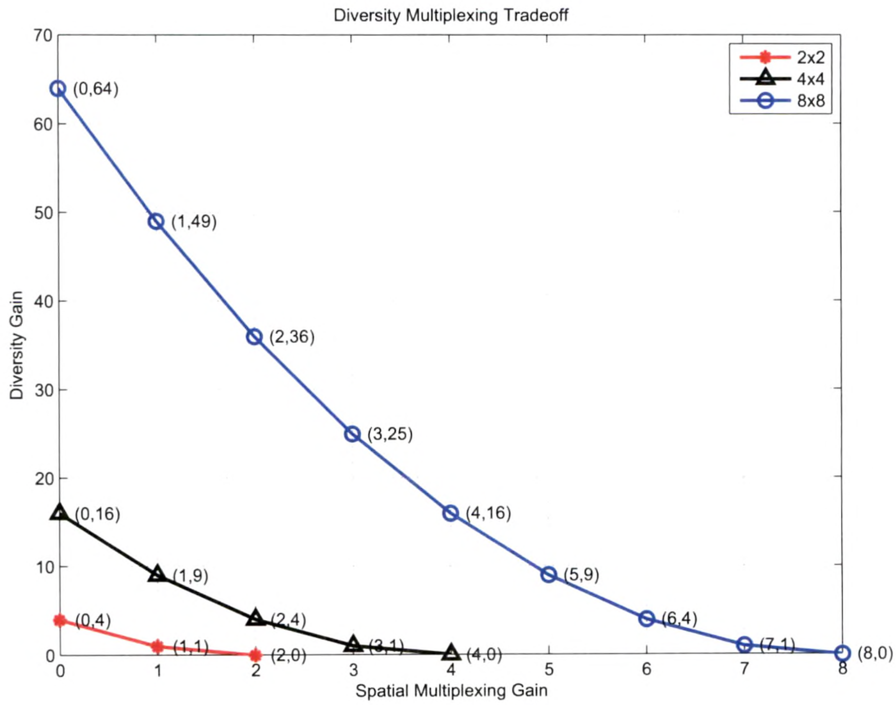

Figure 2.11: Diversity Multiplexing trade-off of MIMO System

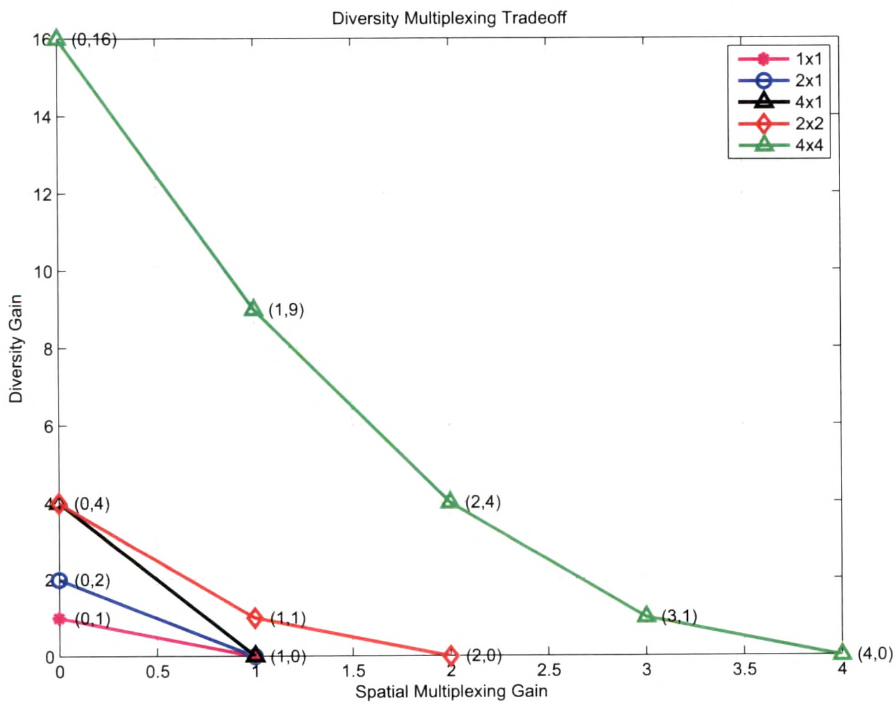

Figure 2.12: Diversity Multiplexing tradeoff of MISO and MIMO system

provided by the channel given by $min(m, n)$. The curve intersects the y axis at the maximal diversity gain given by mn, corresponding to the total number of random fading coefficients that a scheme can average over. It can be concluded that as we increase the diversity gain by increasing the $min(m, n)$ from 2 to 4, the supported spatial multiplexing gain also increases by 2 to 4 i.e. the entire tradeoff curve shifts by a factor of $min(m, n) = 2$.

Similarly comparing the optimal tradeoff for varios MISO and MIMO techniques as shown in Figure 2.12. It can be shown that as we increase the diversity gain by increasing the number of transmit antennas from 2 to 4, the spatial multiplexing gain remains same. But when we compare the results for 4x1 and 2x2 the maximal diversity gain remains similar equal to 4, but the spatial multiplexing gain increase from 1 to 2. Hence there clearly exist tradeoff between spatial multiplexing and diversity gain achieved by MIMO Wireless Communication Systems.

2.5 MIMO Transmission Techniques

MIMO wireless systems have gained overwhelming interest during the last decade which has evolved rapidly. The last ten years of research efforts are recapitulated, with focus on spatial multiplexing and spatial diversity techniques [37]. MIMO techniques can be mainly categorized as: Spatial Multiplexing (SM) MIMO, Spatial Diversity MIMO and Beamforming Techniques. Various MIMO techniques, their respective performance gains and their categorization is as shown in Figure 2.13.

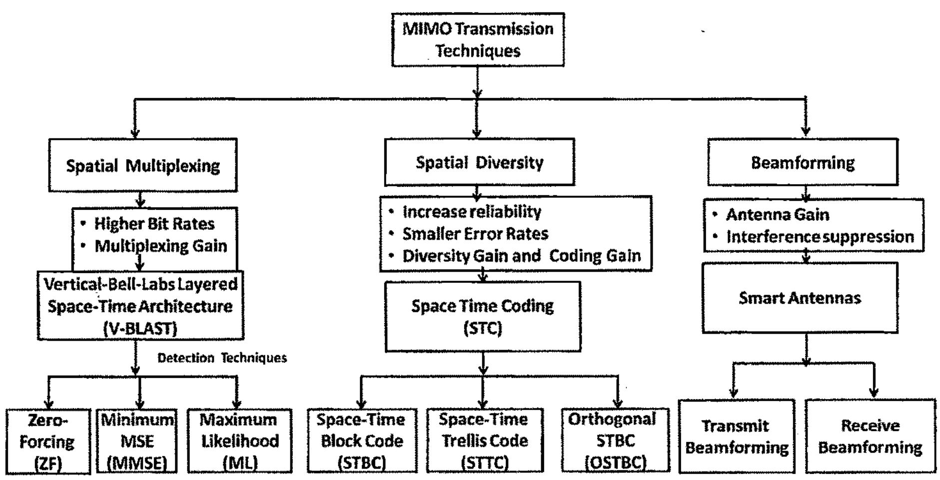

Figure 2.13: MIMO Transmission techniques and their performance gains

A well-known spatial multiplexing scheme is the Vertical Bell-Labs Layered Space-Time Architecture (V-BLAST) [38]. The high spectral efficiency achievement in MIMO SM system is due to the fact that, in rich scattering environment the transmitted signals received at the receiver are highly uncorrelated at each receiving antennas. The receiver exploits this property to separate signals enabling simultaneous reception of multiple spatial streams.

In contrast to SM, Spatial diversity techniques aim at providing higher bit rates [39]. Diversity Techniques exploits the received copies of transmitted data to minimize fading effects. If no channel information is available, the signals can be transmitted from different antenna through Space-Time Coding (STC). It provides both Space and Time diversity. Space-time coding schemes [40,41] that achieve Spatial Diversity are Space-Time Trellis Code (STTC) [42], Alamouti's transmit diversity scheme [30], and Orthogonal Space-Time Block Code (OSTBC) [43,44].

Beamforming is an advanced technology that offers a significantly improved solution to reduce the interference levels and improve the system capacity. They are used to create a certain required antenna directive pattern to give the required performance. Beamforming can be achieved by either transmit beamforming to receive beamforming. Joint transmit and receive beamforming can be implemented to get the advantage of both.

2.6 GUI for Capacity and Performance Analysis

MIMO systems have gain interest due to its performance gains and various transmission techniques. Researchers have studied MIMO Channel capacity and analysis of MIMO transmission techniques. Motivated by various studies based on MIMO Wireless Systems, MATLAB based Multiple-Input Multiple-Output Wireless Simulator (MIMO-WS) is developed to ease the comparative and performance analysis of MIMO Systems. MIMO-WS is able to carry out the Capacity Analysis for various antenna configurations and performance analysis in terms of BER for various MIMO Transmission Techniques. V-BLAST Spatial multiplexing can be analyzed for different receiver techniques: ZF, ML and MMSE. Spatial diversity techniques: Alamouti and STTC is also compared in terms of BER. The snapshot of the developed GUI is as shown in Figure 2.14. The description and operating procedure is explained in detail in Appendix A.

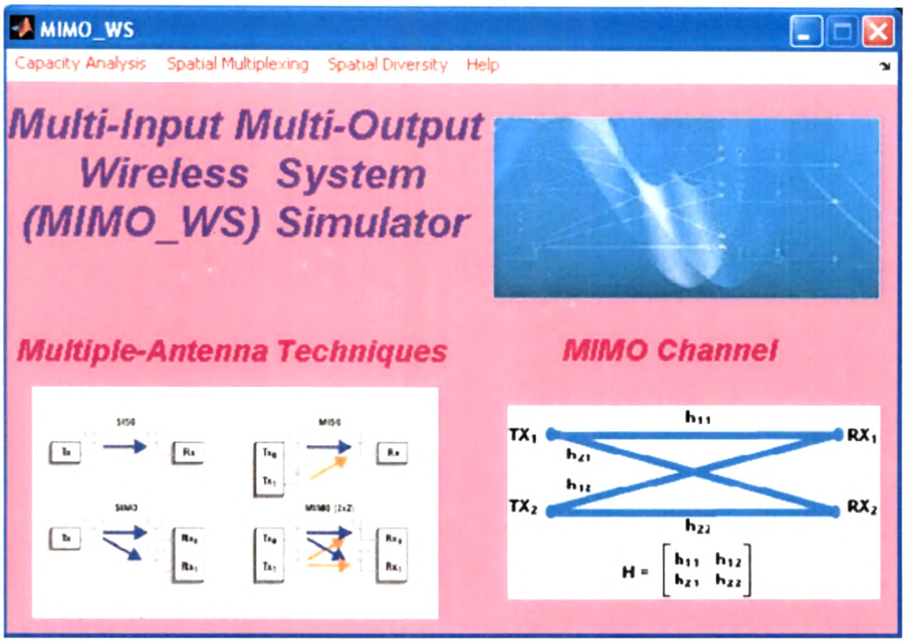

Figure 2.14: GUI for MIMO Wireless Simulator

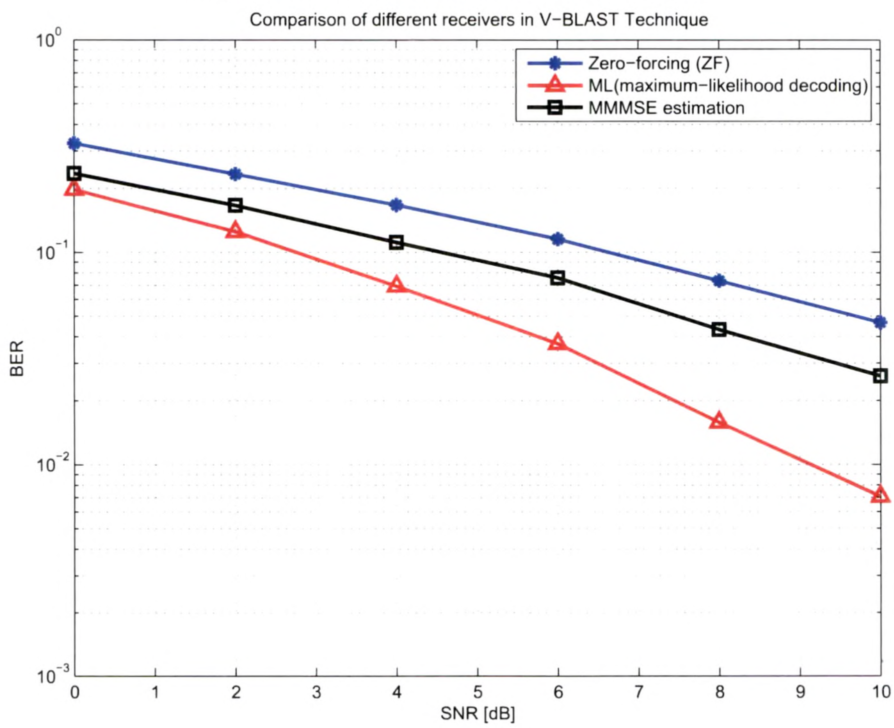

Figure 2.15: Comparison of ZF, ML and MMSE reciver for V-BLAST Technique

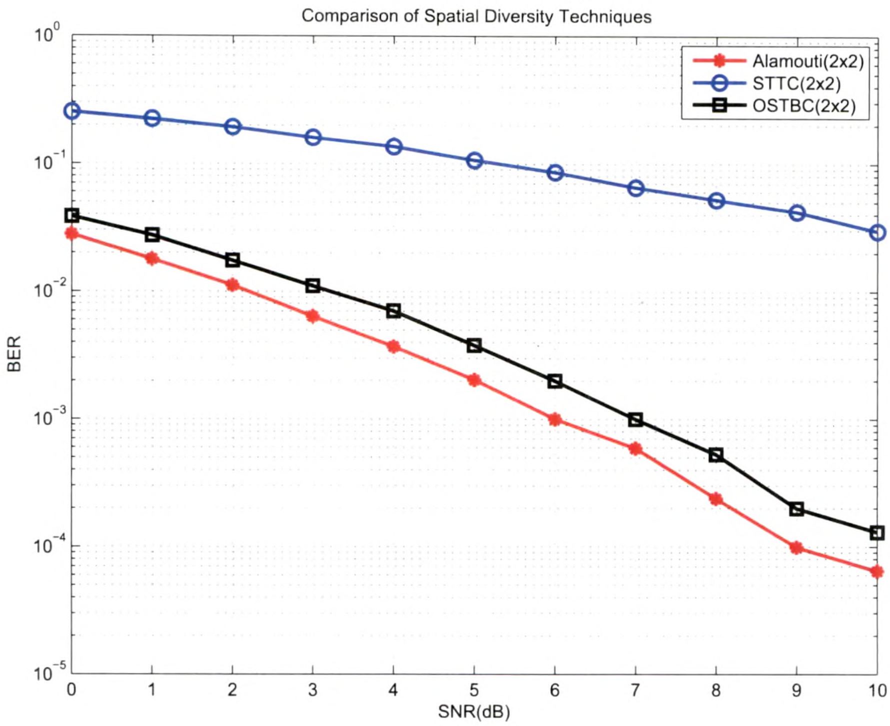

Figure 2.16: Comparison of BER for Diversity Techniques: Alamouti, STBC and STTC

Figure 2.15 shows the comparative performance analysis of 2x2 V-BLAST technique for different receivers. ML detection technique outperforms ZF and MMSE receivers as SNR increases. To achieve target BER of 0.01dB, we need SNR=3dB in V-BLAST system with the ML detector, and SNR=4.5dB in the MMSE and SNR = 7dB with ZF receiver. Figure 2.16 shows comparison of different spatial diversity techniques BER v/s SNR plot. Alamouti code gives minimum BER when compared to OSTBC and STTC. At SNR = 5dB, Alamouti Scheme gives BER of $2.05X10^{-3}$, OSTBC gives $3.8X10^{-3}$ and STTC results in BER of 0.107.

2.7 Concluding Remarks

MIMO technology is an advanced technique which promises high capacity as compared to traditional systems. Capacity analysis of MIMO system is carried out in comparison with SISO systems. Performance gains achieved from MIMO Technology is discussed in detail. Tradeoff between MIMO Transmission Techniques i.e Spatial Multiplexing and Transmit Diversity is analyzed and discussed in brief. MIMO Wireless Simulator GUI is developed to ease the channel capacity and performance analysis of MIMO Wireless System.