

# Channel Capacity Enhancement of Wireless Communication using MIMO Technology

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**Abstract**— In order to have flexibility in transmission system, wireless systems are always considered better as compared to wired channel. Having known the drawbacks of the Single Input Single Output system, and having computed the advantages of Multiple Input Multiple Out, several techniques have been developed to implement space multiplexed codes. In wireless MIMO the transmitting end as well as the receiving end is equipped with multiple antenna elements, MIMO can be viewed as an extension of the very popular 'smart antennas'. In MIMO though the transmit antennas and receive antennas are jointly combined in such a way that fading will decrease and the bit transfer rate will increase so the at receiving end we will get high signal to noise ratio. At the system level, careful design of MIMO signal processing and coding algorithms can help increase dramatically capacity and coverage.

**Index Terms**— Channel, Coding, communication, Diversity, Multi Antenna, Receiver, transmitter, Wireless,.

## 1 Introduction

WIRELESS systems continue to strive for ever higher data rates. This goal is particularly challenging for systems that are power, bandwidth, and complexity limited. However, another domain can be exploited to significantly increase channel capacity: the use of multiple transmit and receive antennas. This report summarizes the segment of the recent work focused on the capacity of MIMO systems for both single-users and multiple users under different assumptions about spatial correlation and channel information available at the transmitter and receiver. The large spectral efficiencies associated with MIMO channels are based on the premise that a rich scattering environment provides independent transmission paths from each transmit antenna to each receive antenna. Therefore, for single-user systems, a transmission and reception strategy that exploits this structure achieves capacity on approximately  $\min(M,N)$  [15] separate channels, where  $M$  is the number of transmit antennas and  $N$  is the number of receive antennas. Thus, capacity scales linearly with  $\min(M,N)$  relative to a system with just one transmit and one receive antenna. This capacity increase requires a scattering environment such that the matrix of channel gains between transmit and receive antenna pairs has full rank and independent entries and that perfect estimates of these gains are available at the receiver. Perfect estimates of these gains at both the transmitter and receiver provide an increase in the constant multiplier associated with the linear scaling. MIMO channel capacity depends heavily on the statistical properties and antenna element correlations of the channel [1]. Antenna correlation varies drastically as a function of the scattering environment, the distance between transmitter and receiver, the antenna configurations, and the Doppler spread [9]. As we shall see, the effect of channel correlation on capacity depends on what is known about the channel at the transmitter and receiver: correlation sometimes increases capacity and sometimes reduces it. Moreover, channels with very low correlation between antennas can still exhibit a "keyhole" effect where the rank of the channel gain matrix is very small, leading to limited capacity gains. Fortunately, this effect is not prevalent in most environments. We focus on

MIMO channel capacity in the Shannon theoretic sense. The Shannon capacity of a single-user time-invariant channel is defined as the maximum mutual information between the channel input and output. This maximum mutual information is shown by Shannon's capacity theorem to be the maximum data rate that can be transmitted over the channel with arbitrarily small error probability. MIMO channels with perfect transmitter and receiver CSI the ergodic and outage capacity calculations are straightforward since the capacity is known for every channel state. In multiuser channels, capacity becomes a  $K$ -dimensional region defining the set of all rate vectors  $(R_1, \dots, R_K)$  simultaneously achievable by all  $K$  users..

## 2 DIVERSITY

Diversity techniques can be used to improve system performance in fading channels. Instead of transmitting and receiving the desired signal through one channel, we obtain  $L$  copies of the desired signal through  $M$  different channels [17]. The idea is that while some copies may undergo deep fades, others may not. We might still be able to obtain enough energy to make the correct decision on the transmitted symbol. There are several different kinds of diversity which are commonly employed in wireless communication systems

### 2.1 Frequency Diversity

One approach to achieve diversity is to modulate the information signal through  $M$  different carriers. Each carrier should be separated from the others by at least the coherence bandwidth  $(\Delta f)_c$  so that different copies of the signal undergo independent fading. At the receiver, the  $L$  independently faded copies are "optimally" combined to give a statistic for decision. Frequency diversity can be used to combat frequency selective fading

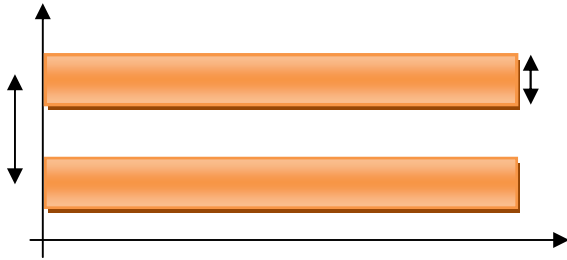


Fig.1 Frequency Diversity

**2.2 Time Diversity**

Another approach to achieve diversity is to transmit the desired signal in M different periods of time, i.e., each symbol is transmitted M times. The intervals between transmissions of the same symbol should be at least the coherence time so that different copies of the same symbol undergo independent fading. We notice that sending the same symbol M times is applying the (M,1) repetition code. Actually, non-trivial coding can also be used. Error control coding, together with interleaving, can be an effective way to combat time selective (fast) fading view Stage

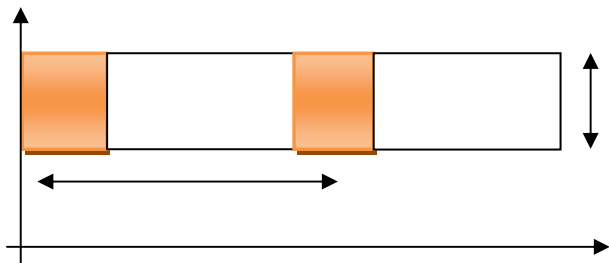


Fig. 2 Time diversity

**2.3 Space Diversity**

Another approach to achieve diversity is to use M antennas to receive M copies of the transmitted signal. The antennae should be spaced far enough apart so that different received copies of the signal undergo independent fading. Different from frequency diversity and temporal diversity, no additional work is required on the transmission end, and no additional bandwidth or transmission time is required. However, physical constraints may limit its applications. Sometimes, several transmission antennae are also employed to send out several copies of the transmitted signal. Spatial diversity can be employed to combat both frequency selective fading and time selective fading.

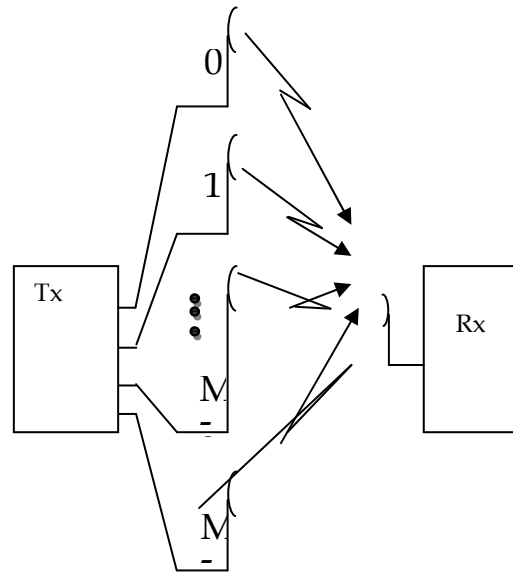


Fig.3. Space diversity

**3. VARIOUS SYSTEM**

Presently four different types (Input and output refers to number of antennas) of systems can be categorized as far as diversity is concerned

**3.1 Single Input Single Output (SISO)—No diversity**

This system has single antenna both side. Due to single transmitter and receiver antenna, it is less complex than multiple input and multiple output (MIMO). SISO is the simplest antenna technology. In some environments, SISO systems are vulnerable to problems caused by multipath effects. When an electromagnetic field (EM field) is met with obstructions such as hills, canyons, buildings, and utility wires, the wave fronts are scattered, and thus they take many paths to reach the destination. The late arrival of scattered portions of the signal causes problems such as fading, cut-out (cliff effect), and intermittent reception (picket fencing). In a digital communications system, it can cause a reduction in data speed and an increase in the number of errors.

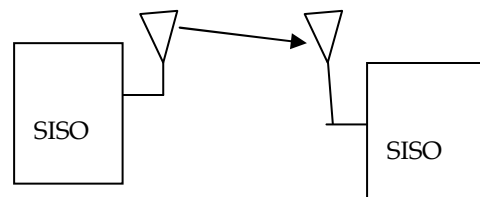


Fig.4 A SISO System

Capacity [10] of a SISO is given by:

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

Where h is the normalized complex gain of a fixed wireless channel and  $\rho$  is the SNR the plot between the C and SNR will be

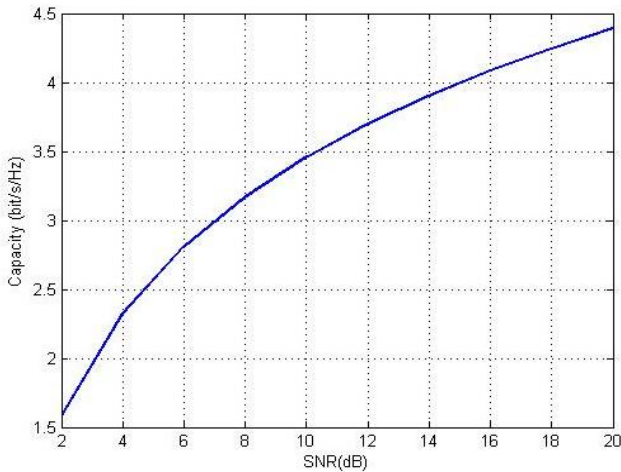


Fig 5 Graph Between Capacity And SNR(SISO)

### 3.2 Multiple Inputs Single Output (MISO)—Transmit diversity

It's a system with Multiple-antenna arrays are known to perform better than their single-antenna counterparts, because they can more effectively counter the effects of multipath fading and interference. However, the enhanced performance depends on the amount of channel information at the transmitter and on whether the transmitter is able to take advantage of this information. [2] We have a multiple input–single-output (MISO) system with N TX antennas and the capacity is given by [9]

$$C = \log_2 \left( 1 + \frac{\rho}{N} \sum |h_i|^2 \right) \text{ b/s/Hz} \quad \dots\dots(2)$$

Where the normalization by N ensures a fixed total transmitter power and show the absence of array gain in that case.

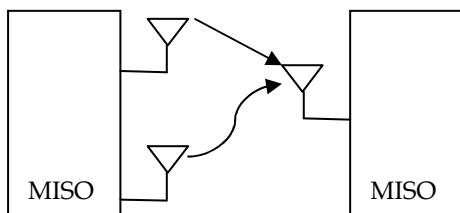


Fig. 6 A MISO System

### 3.4 Multiple Inputs Multiple Outputs (MIMO)—Transmit-receive diversity

Multiple antennas can be used either at the transmitter or receiver or at both. These various configurations are referred to as multiple input single output MISO, Single Input Multiple Output SIMO, or Multiple Input Multiple Output MIMO. The SIMO and MISO architectures are a form of receive and transmit diversity schemes respectively. On the other hand, MIMO architectures can be used for combined transmit and receive diversity, as well as for the parallel transmission of data or spatial multiplexing. When used for spatial multiplexing MIMO technology promises high bit rates in a narrow bandwidth and as such it is of high significance to spectrum[18].

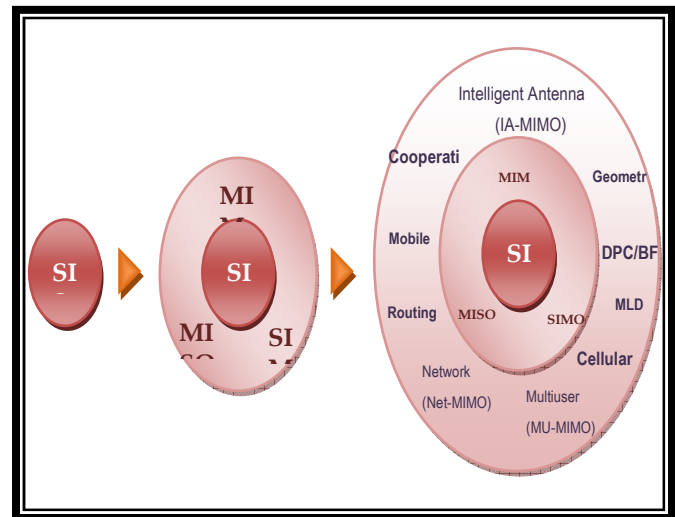


Fig.7 Evolution Of Antenna

## 4 MATHEMATICAL MODEL OF MIMO

Consider a wireless communication system with  $N_t$  transmit (TX) and  $N_r$  receive (RX) antennas. The idea is to transmit different streams of data on the different transmit antennas, but at the same carrier frequency. The stream on the  $p$ -th transmit antenna, as function of the time  $t$ , will be denoted by  $s_p(t)$ . When a transmission occurs, the transmitted signal from the  $p$ -th TX antenna might find different paths to arrive at the  $q$ -th RX antenna, namely, a direct path and indirect paths through a number of reflections[3]. This principle is called multipath. Suppose that the bandwidth  $B$  of the system is chosen such that the time delay between the first and last arriving path at the receiver is considerably smaller than  $1/B$ , then the system is called a narrowband system. For such a system, all the multi-path components between the  $p$ -th TX and  $q$ -th RX antenna can be summed up to one term, say  $h_{qp}(t)$ . Since the signals from all transmit antennas are sent at the same frequency, the  $q$ -th receive antenna will not only receive signals from the  $p$ -th, but from all  $N_t$  transmitters. This can be denoted by the following equation (the additive noise at the receiver is

omitted for clarity).

$$r(t) = \sum h(t) s(t), \dots(3)$$

To capture all  $N_t$  received signals into one equation, the matrix notation can be used:

$$x(t) = H(t)s(t), \dots(4)$$

where,  $s(t)$  is an  $N_t$ -dimensional column vector with  $s_p(t)$  being its  $p$ -th element,  $x(t)$  is  $N_r$ -dimensional with  $x_q(t)$  on its  $q$ -th position and the matrix  $H(t)$  is  $N_r \times N_t$  with  $h_{qp}(t)$  as its  $(q,p)$ -th element, with  $p = 1, \dots, N_t$  and  $q = 1, \dots, N_r$ . A schematic representation of a MIMO communication scheme can be found in Figure 9. Mathematically, a MIMO transmission can be seen as a set of equations (the recordings on each RX antenna) with a number of unknowns (the transmitted signals). If every equation represents a unique combination of the unknown variables and the number of equations is equal to the number of unknowns, then there exists a unique solution to the problem. If the number of equations is larger than the number of unknowns, a solution can be found by performing a projection using the least squares method, also known as the Zero Forcing (ZF) method. For the symmetric case, the ZF solution results in the unique solution.

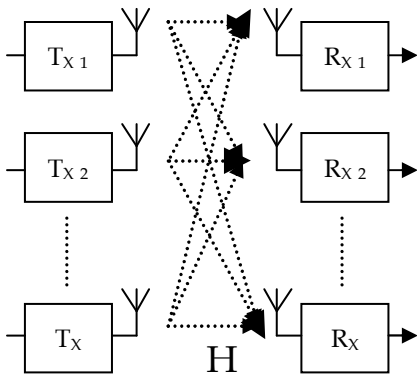


Fig. 8 Schematic Representation Of A MIMO Communication System.

#### 4.1 Information Theoretic MIMO Capacity

Since feedback is an important component of wireless design (although not a necessary one), it is useful to generalize the capacity discussion to cases that can encompass transmitters having some prior knowledge of channel. To this end, we now define some central concepts, beginning with the MIMO signal model.

$$r = Hs+n \dots(5)$$

In (5),  $r$  is the  $M \times 1$  received signal vector,  $s$  is the  $N \times 1$

transmitted signal vector and  $n$  is an  $M \times 1$  vector of additive noise terms, assumed i.i.d. complex Gaussian with each element having a variance equal to  $\sigma^2$ . For convenience we normalize the noise power so that  $\sigma^2 = 1$  in the remainder of this section. Note that the system equation represents a single MIMO user communicating over a fading channel with additive white Gaussian noise (AWGN). The only interference present is self-interference between the input streams to the MIMO system. Some authors have considered more general systems but most information theoretic results can be discussed in this simple context, so we use (figure 5) as the basic system equation. Let  $Q$  denote the covariance matrix, then the capacity of the system described by (5) is given by [10], [11]

$$C = \frac{1}{2} \log_2 [\det (I + HQ^* H^*)] \text{ b/s/Hz} \dots(6)$$

Here,  $Q = E\{s s^H\}$ .

### 5 HOW DOES MIMO DIFFER FROM SMART ANTENNA?

MIMO and “smart antenna” systems may look the same on first examination: Both employ multiple antennas spaced as far apart as practical. But MIMO and smart antenna systems are fundamentally different. Smart antennas enhance conventional, one-dimensional radio systems. The most common smart antenna systems use beam-forming (Fig. 9) or transmit diversity to concentrate the signal energy on the main path and receive combining (Fig. 10) to capture the strongest signal at any given moment.

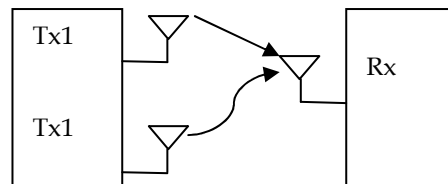


Fig. 9 Beam-forming (beam steering) employs two transmit antennas to deliver the best multipath signal

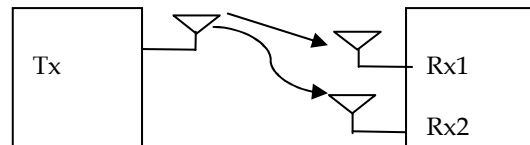


Fig. 10 Diversity (receive combining) uses two receive antennas to capture the best multipath signal

Note that beam-forming and receive combining are only multipath mitigation techniques, and do not multiply data throughput over the wireless channel. Both have demonstrated an ability to improve performance incrementally in point-to-point applications (Fig.12) (e.g., outdoor wireless backhaul applications).

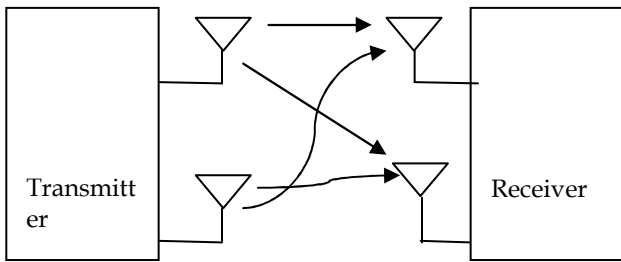


Fig. 11 Physical resemblance between radio systems using a combination of beam steering and diversity and MIMO systems

However, while beam-forming and receive combining are valuable enhancements to conventional radio systems, MIMO (Fig.11) is a paradigm shift, dramatically changing perceptions of and responses to multipath propagation. While receive combining and beam-forming increase spectral efficiency one or two b/s/Hz at a time, MIMO multiplies the b/s/Hz.

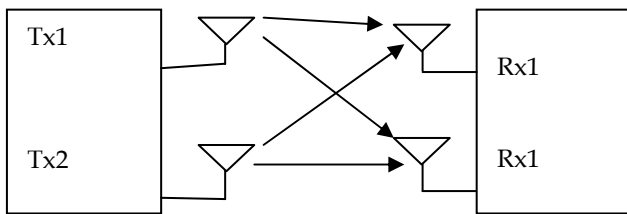


Fig. 12 MIMO uses multiple transmitters, receivers and antennas to send multiple signals over the same channel, multiplying spectral efficiency.

The powerful effect of smart antenna is that, in the presence of random fading caused by multipath propagation, the probability of losing the signal vanishes exponentially with the number of décor-related antenna elements being used. Clearly, in a MIMO link, the benefits of Conventional smart antennas are retained since the optimization of the multi antenna signals is carried out in a larger space, thus providing additional degrees of freedom. In particular, MIMO systems can provide a joint transmit-receive diversity gain, as well as an array gain upon coherent combining of the antenna elements (assuming prior channel estimation). The underlying mathematical nature of MIMO, where data is transmitted over a matrix rather than a vector channel, creates new and enormous opportunities beyond just the added diversity or array gain benefits- the spectrum efficiency.

**6. SPACE TIME BLOCK CODE FOR MAXIMUM DIVERSITY**  
**6.1 Space Time Block Code**

When the number of antennas is fixed, the decoding complexity of space-time trellis coding (measured by the number of trellis states at the decoder) increases exponentially as a function of the diversity level and transmission rate [13]. In addressing the issue of decoding complexity, Alamouti [14] discovered a remarkable space-time block coding scheme for

transmission with two antennas. This scheme supports maximum-likelihood (ML) detection based only on linear processing at the receiver. The very simple structure and linear processing of the Alamouti construction makes it a very attractive scheme that is currently part of both the W-CDMA and CDMA-2000 standards. This scheme was later generalized in [14] to an arbitrary number of antennas. Here, we will briefly review the basics of STBCs. Fig. 6.1.1 shows the baseband representation for Alamouti STBC with two antennas at the transmitter. The input symbols to the space-time block encoder are divided into groups of two symbols each. At a given symbol period, the two symbols in each group  $\{c, c\}$  are transmitted simultaneously from the two antennas. The signal transmitted from antenna 1 is  $c$  and the signal transmitted from antenna 2 is  $c$ . In the next symbol period, the signal  $-c^*$  is transmitted from antenna 1 and the signal  $c$  is transmitted from antenna 2. Let  $h$  and  $h$  be the channels from the first and second TX antennas to the RX antenna, respectively. The major assumption here is that they are scalar and constant over two consecutive symbol periods, that is

$$h(2nT) \approx h(2n+1)T, \quad l = 1, 2$$

We assume a receiver with a single RX antenna. we also denote the received signal over two consecutive symbol periods as  $r$  and  $r$ . The received signals can be expressed as

$$r = h_1 c_1 + h_2 c_2 + n \dots\dots\dots(7)$$

$$r = -h_1^* c_1^* + h_2 c_2 + n \dots\dots\dots(8)$$

Where,  $n$  and  $n$  represent the AWGN and are modeled as i.i.d. complex Gaussian random variables with zero mean and power spectral density  $N/2$  per dimension. We define the received signal vector  $r = [r_1, r_2]^T$ , the code symbol vector and the noise vector  $n = [n_1, n_2]^T$ . Equations (7) and (8) can be rewritten in a matrix form as

$$r = H \cdot c + n \dots\dots\dots(9)$$

Where the channel matrix  $H$  is defined as

$$H = \begin{bmatrix} h_1 & h_2 \\ h_1^* & -h_2^* \end{bmatrix} \dots\dots\dots(10)$$

$H$  is now only a virtual MIMO matrix with space (columns) and time (rows) dimensions, not to be confused with the purely spatial MIMO channel matrix. The vector is a complex Gaussian random vector with zero mean and covariance  $N \cdot I$ . Let us define  $C$  as the set of all possible symbol pairs  $c = \{c_1, c_2\}$ . Assuming that all symbol pairs are equi-probable, and since the noise vector is assumed to be a multivariate AWGN, we can easily see that the optimum ML decoder is

$$\hat{c} = \arg \min_{c \in C} (\|r - H \cdot c\|^2) \dots\dots\dots(11)$$

The ML decoding rule in (11) can be further simplified by realizing that the channel matrix  $H$  is always orthogonal



regardless of the channel coefficients. Hence,  $H^*H = \alpha I$  where  $\alpha = |h_1|^2 + |h_2|^2$ . Consider the modified signal vector given by

$$\tilde{y} = H^* y = H^* (Hx + n) = \alpha x + H^* n \quad \dots\dots(12)$$

Where  $n = H^* n$

In this case, the decoding rule becomes

$$\hat{x} = \arg \min_{x \in \mathcal{S}} (\|\tilde{y} - \alpha x\|) \quad \dots\dots(13)$$

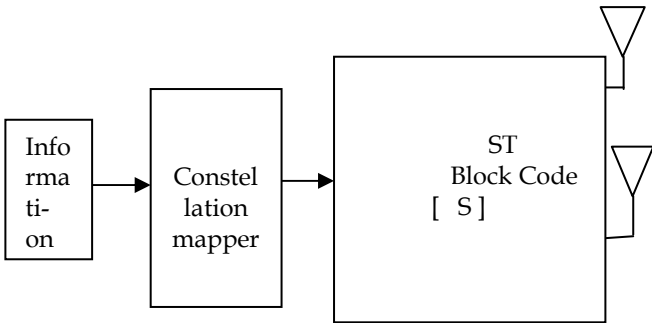


Fig.13 Transmit diversity with space time block coding

**6.2 Spatial multiplexing**

Spatial multiplexing (seen abbreviated SM or SMX) is a transmission technique in MIMO wireless communication to transmit independent and separately encoded data signals, so-called streams, from each of the multiple transmits antennas. Therefore, the space dimension is reused, or multiplexed, more than one time.

If the transmitter is equipped with  $N_t$  antennas and the receiver has  $N_r$  antennas, the maximum spatial multiplexing order (the number of streams) is

$$= \min(N_t, N_r)$$

If a linear receiver is used. This means that  $N_s$  streams can be transmitted in parallel, ideally leading to an  $N_s$  increase of the spectral efficiency (the number of bits per second and per Hz that can be transmitted over the wireless channel). The practical multiplexing gain can be limited by spatial correlation, which means that some of the parallel streams may have very weak channel gains. The spatial multiplexing(SM) delivers parallel streams of data by exploiting multipath. It can double (2x2) or quadruple (4x4) capacity and throughput. It gives higher capacity where RF conditions are favorable and the users are closer to the BTS. In spatial multiplexing, different information is transmitted simultaneously over  $N$  transmit antennas increasing the data rate at short distance and providing high spectral efficiency similar to increasing the constellation size, but without suffering from a power penalty. The spatial multiplexing is sometime also referred as direct

transmission or simply MIMO. The receiver has to decouple the  $N$  spatial streams to recover the transmitted information. Optimal detection tends to be complex and several suboptimal low-complexity detectors have been devised, ranging from the simple zero forcing to complex soft a posteriori probability detection. An example of spatial multiplexing is shown in a figure 14, which improves the average capacity behavior by sending as many independent signals as we have antennas for a specific error rate. In the uplink scenario, a base station employs multiple receive antennas and beam forming to separate transmissions from the different mobiles. More recently, transmit beam forming/pre-coding for multi user downlink transmission is drawing increasing attention.

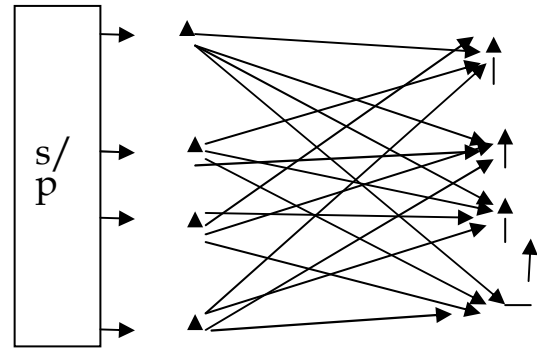


Fig.14 Example of Spatial Multiplexing

Layered space-time architectures exploit the spatial multiplexing gain by sending independently encoded data streams in diagonal layers(D-BLAST) as originally proposed or in horizontal layers, which is the so-called vertical layered space-time(V-BLAST) scheme, depicted in fig 16, originally invented by Bell labs.[15].the receiver must de-multiplex the spatial channels in order to detect the transmitted symbols. Various estimation and zero-forcing, which use simple matrix inversion but give poor results when the channel matrix is ill conditioned, minimum mean square error(MMSE), more robust in that sense but provides limited enhancement if knowledge of the noise/interference is not used, and maximum likelihood(ML), which is optimal in the sense that it compares all possible combinations of symbols but can be too complex, especially for high-order modulation.

**6.2.1 D-Blast**

In wireless systems, radio waves do not propagate simply from transmit antenna to receive antenna, but bounce and scatter randomly off objects in environment. This scattering is known as multipath as it result in multiple copies of the transmitted signals arriving at the receiver via different scattered paths. Multipath has always been regarded as impairment, because the images arrive at the receiver at slightly different times and thus can interfere destructively, canceling each other out. However recent advances in information theory have shown that, with simulations use of antenna arrays at both base station and terminal, multipath interference can be not only mitigated, but actually exploited to establish multiple parallel

channels that operate simultaneously and in the same frequency band. Based on this fundamental idea, a class of layered space-time architecture was proposed and labeled BLAST. Using BLAST the scattering characteristics of the propagation environment is used to enhance the transmission accuracy by treating the multiplicity of the propagation environment is used to enhance the transmission accuracy by treating the multiplicity of scattering paths as separate parallel sub channels. The original scheme D-BLAST was a wireless set up that used a multi element antenna array at both the transmitter and receiver, as well as diagonally layered coding sequence. The coding sequence was to be dispersed across diagonals in space-time. In an independent Rayleigh scattering environment, this processing structure leads to theoretical rates that grow linearly with the number of antennas these rates approaching 90% of Shanon capacity. Rayleigh scattering of light off the molecules of air, and can be extended to scattering from particles up to about a tenth of the wavelength of light. Rayleigh scattering can be considered to be elastic scattering because the energies of scattered photons do not change.

Antenna index

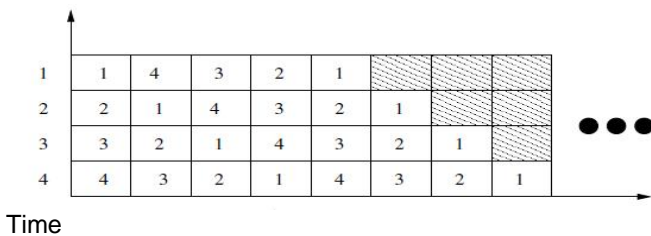


Fig.15 D-BLAST

6.2.2 V-Blast

The Vertical BLAST or V-BLAST architecture [3] is a simplified version of D-BLAST that tries to reduce its computational complexity. We use space time block code in V-BLAST and it can be decoded by ML.

A	A	A	A		demodulated	demodulated
1	1	1	1	.....		
				.....		
A	A	A	A	.....	demodul	demodul

2	2	2	2	.....	ated	ated
A	A	A	A	.....	demodulated	demodulated
3	3	4	3	.....		
A	A	A	A	.....	demodulated	demodulated
4	3	4	4	.....		

Fig.16 V-Blast Architecture

7 CAPACITY ENHANCEMENT OF MIMO AND COMPARISON

The capacity of a wireless link is generally measured in bits per second per Hertz (b/s/Hz). The methods available to increase this capacity in a traditional Single Input, Single Output (SISO) wireless system are fairly limited: increase the bandwidth, allowing a corresponding increase in the bits per second, or increase the transmit power, allowing a higher level modulation scheme to be utilized for a given bit error rate, effectively increasing the bits per second within the same bandwidth. The problem with both of these techniques is that any increase in power or bandwidth can negatively impact other communications systems operating in adjacent spectral channels or within a given geographic area. As such, bandwidth and power for a given communications system are generally well regulated, limiting the ability of the system to support any increase in capacity or performance. MIMO technologies overcome the deficiencies of these traditional methods through the use of spatial diversity. Data in a MIMO system is transmitted over T transmit antennas through what is referred to as a "MIMO channel" to R receive antennas supported by the receiver terminal. If the antennas within the transmit array and the antennas within the receive array are spaced sufficiently far apart, the signals travelling between the various transmit and receive antennas through the MIMO channel will fluctuate or fade in an independent manner. The transmitted data can therefore be encoded, using a so-called space-time code, to make use of this spatial diversity and allow processing at the receiver to extract the underlying data. The specific coding scheme utilized in the MIMO system is selected based on the target performance, the acceptable level of computational complexity in the receiver's signal processing subsystem, and the level of a prior knowledge of the transmission channel. Some schemes, referred to as space-time diversity codes, optimize for "diversity order", which defines the performance gain that can be obtained through the number of decor related spatial branches that can be achieved through the MIMO channel. Other schemes, referred to as Spatial Multiplexing, optimize for channel capacity. Both of these types of schemes are discussed with additional detail below. These schemes can be used in combination to obtain the benefits accrued by both. Ultimately, the space-time coding scheme operating in conjunction with the MIMO channel allows the MIMO based system to support a significant increase in both performance and capacity over

an equivalent SISO system while maintaining the same bandwidth and power.

**7.1. Capacity Enhancement Using MIMO**

For a memory less 1x1 (SISO) system the capacity is given by:

$$C = (1 + |h|^2) \log_2(1 + |h|^2 \rho) \text{ b/s/Hz} \quad \dots(14)$$

Where h is the normalized complex gain of a fixed wireless channel or that of a particular realization of a random channel.

As we deploy more RX antennas the statistics of capacity will improve and with M RX antennas, we have a SIMO system with capacity given by

$$C = (1 + \sum |h_i|^2) \log_2(1 + \sum |h_i|^2 \rho) \text{ b/s/Hz} \quad \dots(15)$$

Where h is the gain of RX antenna. Note that the crucial feature of (15) is that increasing the value of M only result in a logarithmic increase in average capacity. Similarly, if we opt for transmit diversity, in the common case, where the transmitter does not have channel knowledge, we have a multiple input-single-output (MISO) system with N TX antennas and the capacity is given by [9]

$$C = (1 + \sum |h_i|^2) \log_2(1 + \sum |h_i|^2 \rho) \text{ b/s/Hz} \quad \dots(16)$$

Where the normalization by N ensures a fixed total transmitter power and shows the absence of array gain in that case (compared to the case in (15), where the channel energy can be combined coherently). Again, note that capacity has a logarithmic relationship with N. Now, we consider the use of diversity at both transmitter and receiver giving rise to a MIMO system. For N TX and M RX antennas, we have the now famous capacity equation [9], [10], [11]

$$C = \sum_{i=1}^m \log_2(1 + \rho \lambda_i) \quad \dots(17)$$

Where ( \* ) means transpose-conjugate and H is the MxN channel matrix. Note that both (16) and (17) are based on equal power (EP) uncorrelated sources, hence, the subscript in (4). Foschini [9] and Telatar [10] both demonstrated that the capacity in (17) grows linearly with m=min(M,N) rather than logarithmically [as in (17)]. This result can be intuited as follows: the determinant operator yields a product of m=min(M,N) nonzero Eigen values of its (channel-dependent) matrix argument, each Eigen value characterizing the SNR over a so-called channel Eigen mode. An Eigen mode corresponds to the transmission using a pair of right and left singular vectors of the channel matrix as transmit antenna and receive antenna weights, respectively. Thanks to the properties of the MIMO, the overall capacity is the sum of

capacities of each of these modes, hence the effect is capacity multiplication. Clearly, this growth is dependent on properties of the Eigen values. If they decayed away rapidly then linear growth would not occur. However (for simple channels), the Eigen values have a known limiting distribution [12] and tend to be spaced out along the range of this distribution. Hence, it is unlikely that most Eigen values are very small and the linear growth is indeed achieved. For the i.i.d. Rayleigh fading case we have the impressive linear capacity growth discussed above. For a wider range of channel models including, for example, correlated fading and specular components, we must ask whether this behavior still holds. Below we report a variety of work on the effects of feedback and different channel models. It is important to note that (17) can be rewritten as [10].

$$C = \sum_{i=1}^m \log_2(1 + (\rho/N) \lambda_i) \quad \dots(18)$$

Where  $\lambda_i$  (i=1.....m) are the nonzero eigenvalues of W, m=min(M,N), and

$$W = \begin{cases} HH^*, & M \leq N \\ H^*H, & N < M \end{cases} \quad \dots(19)$$

This formulation can be easily obtained from the direct use of Eigen value properties. Alternatively, we can decompose the MIMO channel into m equivalent parallel SISO channels by performing singular value decomposition (SVD) of [3], [21].

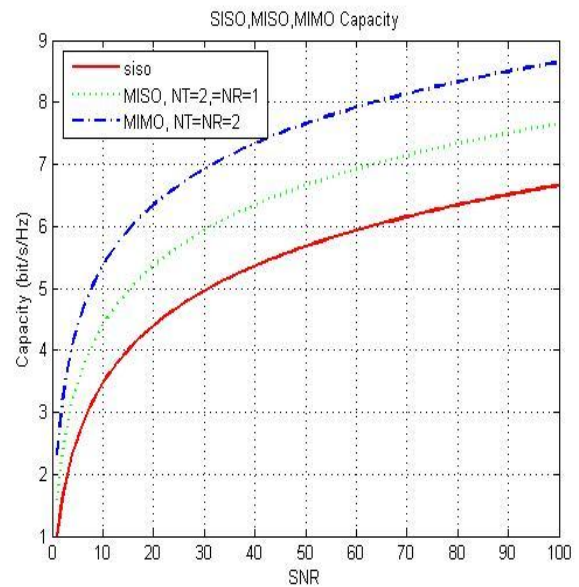


Fig.17 Comparison between SISO, MISO and MIMO



## 7.2 Capacity of MIMO

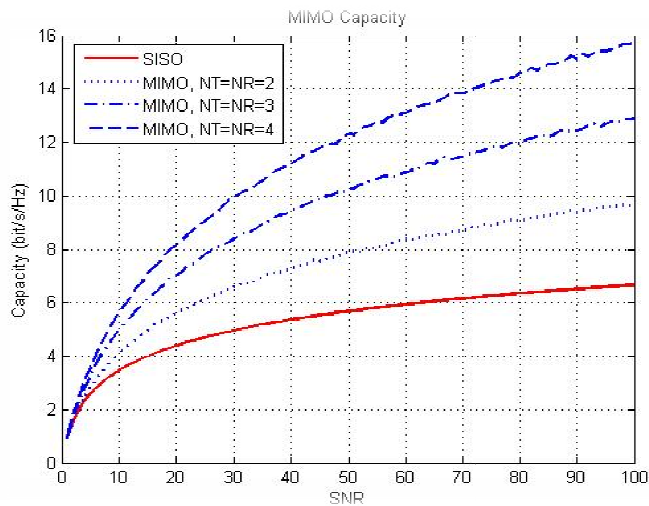


Fig. 18 Capacity Enhancement in MIMO

## 8. CONCLUSION AND FUTURE TRENDS

This report reviews the major features of MIMO links for use in future wireless networks. Information theory reveals the great capacity gains which can be realized from MIMO. Whether we achieve this fully or at least partially in practice depends on a sensible design of transmit and receive signal processing algorithms. It is clear that the success of MIMO algorithm integration into commercial standards such as 3G, WLAN, and beyond will rely on a fine compromise between rate maximization (BLAST type) and diversity (space-time coding) solutions, also including the ability to adapt to the time changing nature of the wireless channel using some form of (at least partial) feedback. To this end more progress in modelling, not only the MIMO channel but its specific dynamics, will be required. As new and more specific channel models are being proposed it will be useful to see how those can affect the performance tradeoffs between existing transmission algorithms and whether new algorithms, tailored to specific models, can be developed. Finally, upcoming trials and performance measurements in specific deployment conditions will be key to evaluate precisely the overall benefits of MIMO systems in real-world wireless scenarios such as UMTS.

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