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Antenna Diversity techniques effect on various channels and their comparison

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ABSTRACT

The rapidly growing demand for wireless communication requires systems to make full use of radio resources and provide reliable services. This dissertation describes the characteristics of the signal propagation and performance degradation issues in wireless communication channels. There are many impairment factors and fading is the major factor amongst them which degrades the performance of wireless communication system severally. Several types of antenna diversity techniques are described which can be used to mitigate fading problem in the channels. Antenna Diversity is used to supply the receiver with several replicas of the same signal. Diversity combining techniques are used to improve the channels' performance without transmitting any additional power. If high received signal are de-correlated, the gain of diversity is also high. The performance of diversity system is expressed by its ability to reduce the value of Signal to noise ratio (SNR) and Bit Error ratio (CIR) at a specified probability of error. The performance evaluated in terms of statistical reduction of the fading dynamic range of the average SNR and BER. Several Antenna Diversity Techniques are discussed out of which the Space Time trellis coding technique comes out to be the best technique for antenna diversity.

Keywords: STBC, STTC, MRC, API

1. INTRODUCTION

Guglielmo Marconi started wireless communication over 100 years ago. Today wireless technology is a vital part of human civilization. This industry is growing very rapidly with a significant increase in the number of subscribers. As a result, the industry is constantly in need of research and development of new technology to produce better system performance of the system. There are lots of challenges a wireless system faces to provide higher data-rates, better quality of service (QoS), fewer dropped calls and higher network capacity. A wireless system designer often faces two major challenges. The first is limited availability of the radio frequency spectrum and the second a complex time-varying wireless environment i.e., multipath fading. This thesis is concerned with multipath fading and methods to get better performance in this hostile environment.

Multipath fading, which widely changes the signal amplitude, often disturbs wireless communication systems. Better reception can be obtained with more transmit power, but for mobile systems power consumption is a major issue. If a handheld device needs less power than the physical dimensions and weight can be reduced which may provide the user with more mobility. The mobile wireless industry is also looking for new technologies to provide more services to an increasing number of subscribers. With the number of customer increasing the industry will look to new technologies to provide better service at a cheaper price.

In the case of severe attenuation of the transmitted signal due to multipath (or fading channels), it becomes impossible for the receiver to determine the transmitted signal unless additional independent replicas of the transmitted signal can be supplied to the receiver. This redundancy is called diversity. This is considered as single most important mechanism for reliable wireless communications. There are several techniques for achieving diversity i.e., frequency diversity, spatial (antenna) diversity and temporal diversity.

Frequency Diversity: Signals transmitted on different frequencies induce different multipath structures. In frequency diversity the information signal is transmitted on more than one carrier frequency. In this way replicas of the transmitted signals are supplied to the receiver in the form of redundancy in the frequency domain.

Temporal Diversity: In temporal (or time) diversity, replicas of the information signal are transmitted in different time slots so that multiple, uncorrelated versions of the signal will be received.

Spatial Diversity (Antenna Diversity): Spatial diversity is one of the most popular forms of diversity used in wireless communication systems. Multiple and spatially separated antennas are employed to transmit or receive uncorrelated signals. Antenna separation should be at least half of the carrier wavelength to ensure sufficiently uncorrelated signals at the receiver.

II CHARACTERISTIC OF WIRELESS COMMUNICATION CHANNEL:

In radio communications, wireless communication channel works as transmission medium. Characteristics of wireless communication depend on transmitting signal or information riding on radio. Radio means electromagnetic wave here. Hence, the information suffers attenuation effects by several reasons which are called fading of radio waves. These attenuation effects can vary with time. This variation depends on user mobility, which makes wireless a challenging medium of communication. Uncertainty or randomness is the main characteristic of wireless communication. Types of randomness are two: randomness in users' transmission channels and randomness in users' geographical locations. These factors of user in the wireless network systems lead a signal to random signal attenuation independently through users.

Modulation of electromagnetic (radio) waves is utilized by wireless communication with a carrier frequency. The frequencies vary from a few hundred MHz to several GHz but it depends on the system. As a result, the behavior of the wireless communication channel is a function of the radio (electromagnetic waves) propagation effects in an environment.

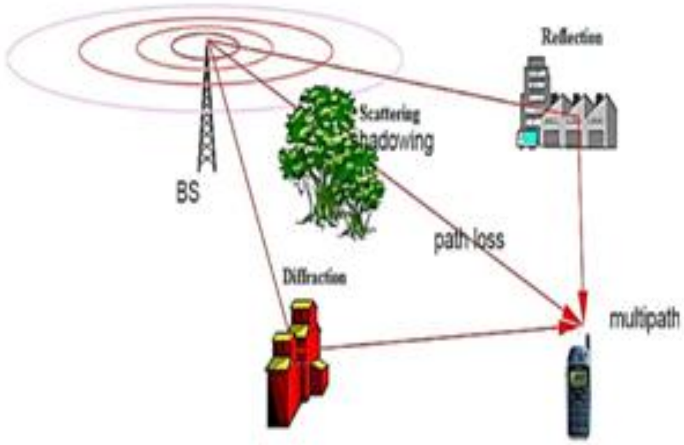
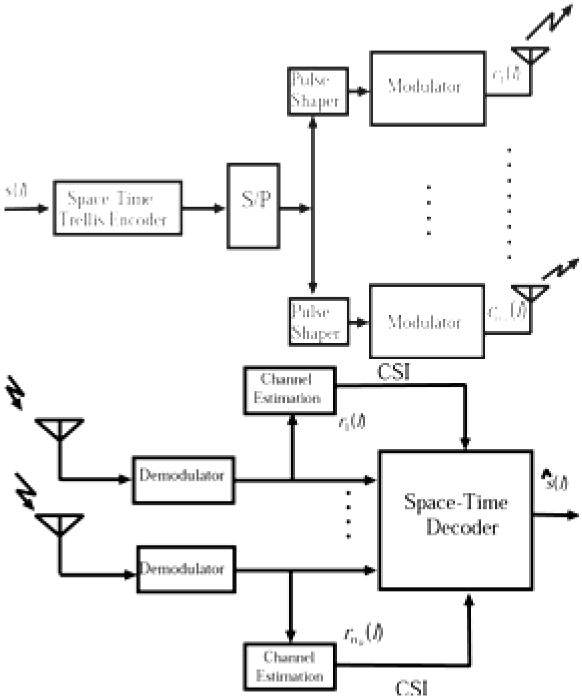


Fig 1: Wireless propagation model

A typical wireless propagation environment at outdoor is seen in figure 3.1, where the mobile wireless node is communicating with base station or a wireless access point. The transmitted signal from the mobile may travel two ways. The signal may reach the access point directly which is called line of sight (LOS) [16] or it may reach the access point through multiple reflections on local scatters (buildings, mountains, bridges, trees etc.). As a result the received signal has multiple random attenuation and of course with some delays. Moreover, the mobility or movement of either the nodes or the scattering objects may cause these random fluctuations to vary with time. Time variation results in random increasing or decreasing of the transmitted signal strength over time period. In conclusion, an undesired interference may be occurred by a shared wireless propagation because of simultaneous transmissions to the transmitted signal. The combined effects of these discussed factors put wireless in a challenging communication environment. Space-time trellis codes (STTCs) provide both diversity gain and coding gain.

A typical STTC based wireless system has an encoder, pulse shaper, modulator and multiple transmit antennas at the transmitter, and the receiver has one or more receive antennas, demodulator, channel estimator and STTC decoder. We consider a mobile communication system with transmit antennas and receive antennas as shown in Figures 2-1 (a) and (b). The space-time trellis encoder encodes the data coming from the information source and the encoded data is divided into streams of data . Each of these streams of data passes through a pulse shaper before being modulated. The output of modulator i at time slot t is the signal , which transmitted through is transmit antenna i. Here 1. The transmitted symbols have energy TnRn()stTn12,,Tntttccc…itcTin≤≤sE. We assume that the signals are transmitted simultaneously from the antennas. The signals have transmission period T. In the receiver, each antenna receives a superposition of transmitted signals corrupted by noise and multipath fading. Let the complex channel coefficient between transmit antenna iand receive antenna TnTnj have a value of at time.



A block diagram of the (a) transmitter and (b) receiver of a STTC based system.

The received signal at antenna j, $j = 1, 2, \ldots, n_R$ [1] is then

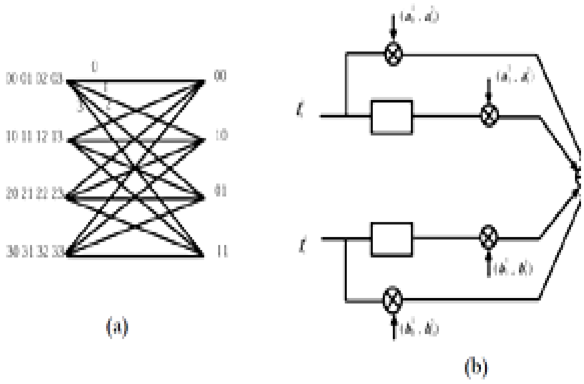
$$r_t^j = \sqrt{E_s} \sum_{i=1}^{n} h_{i,j}(t) c_t^i(t) + \eta_t^j ,$$

where $jt\eta$is the additive white Gaussian noise (AWGN) at receive antenna *j*, which has zero mean and power spectral density . We assume the channel coefficients are modeled as samples of independent complex Gaussian random variables variance 0.5 per dimension [20]

III CODE CONSTRUCTION:

STTCs are represented in a number of ways, such as the trellis form or generator matrix form as illustrated in Figure 3 for a simple STTC. In [5], most codes are presented in trellis form. But for a systematic code search, the generator matrix form is preferable. The generator matrix representation is also used for convolutional codes [61], [62] and [63]. However the generator matrix notation as shown in Figure 3(b) is a little different than that used for convolutional codes [10]. In Figure 3(b) two input bits enter the encoder every symbol period. The input streams are multiplied by the branch coefficients, which can be put into a matrix form (generator matrix) as shown below

$$G = \begin{bmatrix} a_0^1 & b_0^1 & a_1^1 & b_1^1 \\ a_0^2 & b_0^2 & a_1^2 & b_1^2 \end{bmatrix}$$

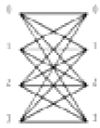


(a) Trellis diagram and (b) generator matrix description of a STTC.

The following example illustrates STTC encoding. In Figure 2.3 we provide a trellis diagram and a table of output symbols related to the input bits and current state. This trellis is for 4- PSK constellations. Let the input symbol stream to the encoder is [2 3 2 1 0 1….]. Initially the encoder is in state "0". Thus "0" will be transmitted from the first antenna, the second antenna transmits "2" and the encoder goes into state "2" [55]. In this way for this input symbol stream the output for the 4-PSK STTC is as follows.

$$c = \begin{bmatrix} 0 & 2 & 3 & 1 & 0 & 1 \\ 2 & 3 & 1 & 0 & 1 & \ldots \end{bmatrix}.$$

State	Output Symbols			
	Input 0	Input 1	Input 2	Input 3
0	00	01	02	03
1	10	11	12	13
2	20	21	22	23
3	30	31	32	33



Code Construction of 4-state 4-PSK STTC

A signal constellation diagram for 4-PSK is shown in Figure 3.4. With PSK information is contained in the signal phase. For 4-PSK, the phase takes one of four equally spaced values, such as 0, 2/4π, 4/4π and 6/4π. These are typically represented by a Gray code [59] and [61], as shown on the right side of Figure 3.4. These signal points are also labeled as 0,1,2 and 3. We can also express these in complex notation.

The encoder structure of a 4-state 4-PSK STTC is shown in Figure 3.5 (b), with bits input to the upper and lower branches. The memory order of the upper and lower branches are 1υ and 2υ, respectively. These are basically shift registers. The main purpose of the shift registers in the encoder is to store the previous transmitted bits. The length of the shift register is the memory of the encoder. The branch coefficients are arranged alternatively in the generator matrix, with representing the most significant bit (MSB). The input bit.

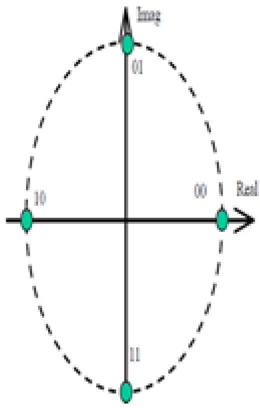
streams I_t^1 and I_t^2 are fed into the branches of the encoder with I_t^1 being the MSB. The output of the encoder is [12] [1]

$$x_t^k = \left(\sum_{p=0}^{v1} I_{t-p}^1 . a_p^k + \sum_{q=0}^{v2} I_{t-q}^2 . b_{t-q}^k \right) \quad \bmod 4 \quad k = 1,2,$$

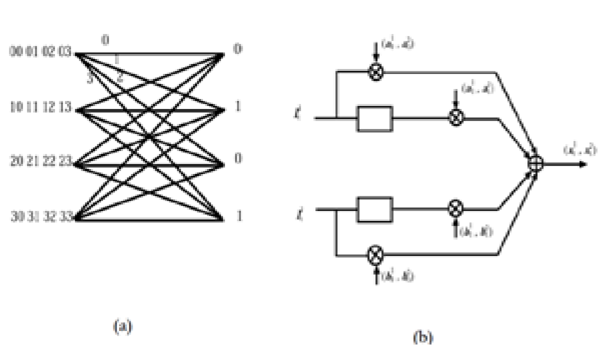
where $\upsilon_1 + \upsilon_2 = \upsilon$ and the number of states is 2^{υ}. υ_i is calculated as

$$\upsilon_1 = \left\lfloor \frac{(\upsilon + i - 1)}{2} \right\rfloor, \quad i = 1,2$$

Here $\lfloor x \rfloor$ denotes the largest integer smaller than or equal to x. For each branch, the output is the sum of the current input scaled by a coefficient and the previous input scaled by another coefficient. The two streams of input bits are passed through their respective shift register branches and multiplied by the coefficient pairs (a_p^1, a_p^2) and (b_q^1, b_q^2). Here



$0 \rightarrow 00 \Leftrightarrow 1+0j$
$1 \rightarrow 01 \Leftrightarrow 0+1j$
$2 \rightarrow 10 \Leftrightarrow -1+0j$
$3 \rightarrow 11 \Leftrightarrow 0-1j$



4 PSK 4-state STTC (a) Trellis diagram (b) Encoder Structure

Then 1*tx* and 2*tx* are transmitted simultaneous through the first and second transmit antennas, respectively. Figures 3.6 (a) and (b) shows 8-state and 16 -state trellis diagrams respectively, for a rate of 2 b/s/Hz.

IV DIVERSITY CONCEPT

The reception of a signal in a channel transmitted through any type of fading channel degrades in quality if the signal level attenuation is below the expected operation region of the receiver. In this situation, the received signal power is not expectedly enough comparing with signal noise and interference power for reliable reception. The solution to overcome the channel attenuation because of fading problem in channel is to increase the transmitted power adjusted to the attenuation which is called power control (PC) [4]. On the other hand, there are two primary problems with this power control (PC) system.

One of these problems is that the dynamic range of the transmitter and the required transmitting power is extremely high if it's intended to fully compensate the fading. This is impossible because of the radiation power limitations, the cost and the size of the amplifiers, and the limited battery power in the portable unit. Moreover, excess transmitted power increases the interference level at the other channels and users in the system unit. Another problem in power control (PC) approach that a feedback link is needed for the channel unless the operation of the radio channel is in time division duplex (TDD) mode. In a TDD system, the same frequency band is used for the downlink transmission from the base station to mobile unit and for the uplink transmission from the mobile unit to the base station. As a result, the transmitted signal undergoes the fading channel as the received signal due to its reciprocal characteristic of the channel, the transmitted power of transmitter is adjusted according to the received signal power. The feedback information usage decreases throughout the channel and increases the complexity in the system [4]. Even an appropriate feedback link may not available in some application.

Using PC the fading can't be overcome completely but the attenuation may compensate considerably. It can mention that large-scale fading can be compensated as well in the uplink of a system, for example CDMA. But stringent power control is required in prevention near-far problem in the system. The rate of large-scale fading is simply slow, as a result it can be tracked well and the delay in the feedback of the power control commands can be neglected comparing with the rapid fading. On the other hand, small-scale fading can result in such rapid variations in the signal power that even the power control can't follow them. Another approach to minimize fading effect in a system is to supply multiple replicas of the transmitted signal to the receiver which already have passed through different fading channels. The result of this approach is that the probability that all replicas of the signal will fade simultaneously is reduced [1]. This is called diversity and it is effectively and commonly used to overcome degradation in performance due to interference and fading. If there is D number of fading channels and the probability of any one channel may fade under some threshold is P, then the probability of all D signals which fade below the threshold is P^D . The number of diversity channel D is called diversity order in the system.

Diversity Branches:

Diversity in wireless radio communication is originated at various sources and this diversity can be achieved by several techniques. Moreover, several methods can be combined to obtain higher diversity and its advantage. A diversity technique needs a number of transmitted signal paths which are called diversity braches. These diversity branches carry the same information with uncorrelated multi-path fading. A circuit also needed to combine the received signals or need to select one of them. There are a number of methods to construct a diversity branches depending on the land mobile radio propagation characteristics.

Diversity Techniques:

Diversity technique is used to decreased the fading effect and improve system performance in fading channels. In this method, we obtain L copies of desired signal through M different channels instead of transmitting and receiving the desired signal through one channel. The main idea here is that some the signal may undergo fading channel but some other signal may not. While some signal might undergo deep fade, we may still be able to obtain enough energy to make right decision on the transmitted symbol from other signals. There is a number of different diversity which is commonly employed in wireless communication systems. Some of them are following:

Multipath/frequency diversity
Spatial/space diversity Temporal/time diversity Polarization diversity
Angle diversity Antenna diversity.

V ANTENNA DIVERSITY

Antenna diversity is a popular and extensively used technique to improve performance in wireless communication systems. The technique reduces fast fading and inter-channel interference effects in the wireless network system. In an antenna diversity system, two or more antennas are used and fixed in positions which will provide uncorrelated signals with the same power level. Then the signals are combined and created an improved signal. The basic method of antenna diversity is that the antennas experiences different kind of signals because of individual channel conditions and the signals are correlated partially. Then we can expect that if one signal from one antenna is highly faded, other signals from other antennas are not faded such way and these signals are our expected quality signals. In a multipath propagation environment, each receiving signal experiences individual fading characteristic.

3.6.1 Why we use Transmit Diversity:

Sometimes, a base station has to serve for hundreds of thousands remote units. Therefore, it is cost saving to add the necessary equipment's to the base stations instead of the remote units. This is the main reason that transmit diversity is very attractive to the wireless service operators. For example, for covering service area of a base station, one antenna and one transmit chain can be added to that base station to improve the reception quality of all the remote units under the base station. Transmit diversity is more effective than receive diversity for increasing the forwarding link that is the bottleneck in broadband asymmetric applications such as browsing internet and downloading files.

Antenna Diversity types: There are various ways of realizing diversity gain, including the following ones:
Space diversity: sufficiently separated (more than 10λ) multiple antennas are used to implement independent wireless channels.
Polarization diversity: independent channels are implemented using the fact that vertically and horizontally polarized paths are independent.
Time diversity: same information is repeatedly transmitted at sufficiently separated (more than coherence time) time instances.
Frequency diversity: same information is repeatedly transmitted at sufficiently separated (more than coherence bandwidth) frequency bands.

Angle diversity: multiple receive antennas with different directivity are used to receive the same information-bearing signal at different angles.Time, frequency and spatial diversity techniques are illustrated in Figure 5.1. In time diversity, data is transmitted over multiple time slots. In frequency diversity, the same data is transmitted at multiple spectral bands to achieve diversity gain. As shown in Figure 5.1(a) and (b), time diversity and frequency diversity techniques require additional time resource and frequency resource, respectively. However, antenna or space diversity techniques do not require any additional time or frequency resource.

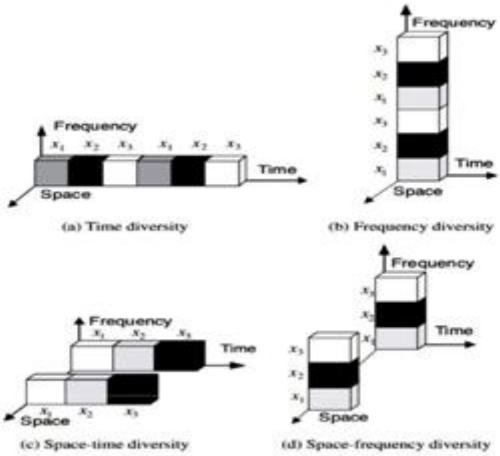


Fig 5.1 Illustration of time, frequency, and space diversity techniques

Figure 5.1(c) illustrates a concept of the space-time diversity that employs multiple transmit antennas, not requiring additional time resource as opposed to one in Figure 5.1(a). Similarly, Figure 5.1(d) illustrates a concept of the space-frequency diversity that employs multiple transmit antennas, which do not require additional frequency resource as opposed to the one in Figure 5.1(b). Although two transmit antennas are illustrated for the antenna diversity in Figure 5.1, the concept can be extended to various antenna configurations. Some examples of single input multiple output (SIMO), multiple input single output (MISO), and multiple input multiple output (MIMO) antenna configurations are illustrated in Figure 5.2

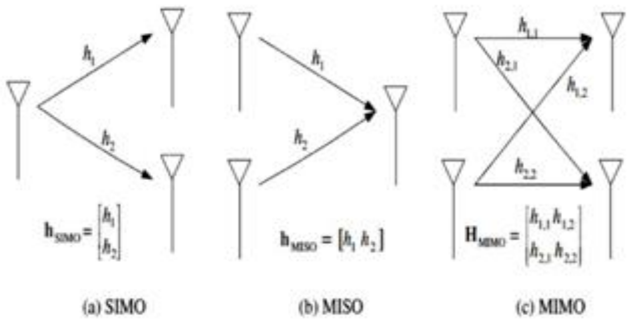


Fig 5.1.2 Examples of various antenna configurations

Receive Diversity:

Consider a receive diversity system with NR receiver antennas. Assuming a single transmit antenna as in the single input multiple output (SIMO) channel of Figure 5.1.2, the channel is expressed as

$$\mathbf{h} = [h_1 h_2 \cdots h_{N_R}]^T$$

for NR independent Rayleigh fading channels. Let x denote the transmitted signal with the unit variance in the SIMO channel. The received signal y € C^{Nx1} is expressed as

$$\mathbf{y} = \sqrt{\frac{E_x}{N_0}}\mathbf{h}x + \mathbf{z}$$

Transmit Diversity:

A critical drawback of receive diversity is that most of computational burden is on the receiver side, which may incur high power consumption for mobile units in the case of downlink. Diversity gain can also be achieved by space-time coding (STC) at the transmit side, which requires only simple linear processing in the receiver side for decoding. In order to further reduce the computational complexity in mobile units, differential space-time codes can be used, which do not require CSI estimation at the receiver side.

Space-Time Coding (STC):

A space-time code design criterion is described by using a pairwise error probability.

Figure 5.2.1 illustrates space-time-coded MIMO systems with NT transmit antennas and NR receive antennas. In the space-time coded MIMO systems, bit stream is mapped into symbol stream f~xigN i¼1. As depicted in Figure 5.2.2, a symbol stream of size N is space-time-encoded into fxðtÞ i gNT i¼1, t ¼ 1; 2; . . . ; T, where i is the antenna index and t is the symbol time index. Note that the number of symbols in a space-time codeword is NT _ T (i.e., N ¼ NT _ TÞ. In other words, fxðtÞ i gNT i¼1, t ¼ 1; 2; . . . ; T, forms a space-time codeword. As N symbols are transmitted by a codeword over T symbol times, the symbol rate of the space-time-coded system example in Figure 3.6 is given as

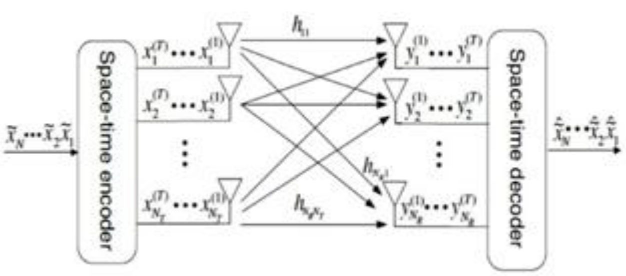


Fig 5.2.1 Space-time coded MIMO systems

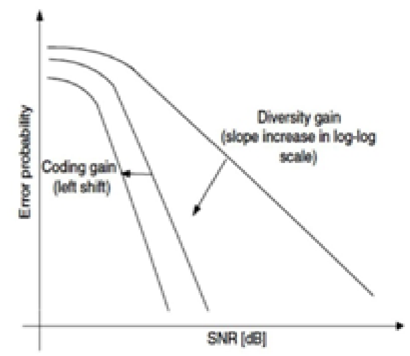


Fig. 5.2.2 Diversity gain vs. coding gain

Space-Time Block Code (STBC)

The very first and well-known STBC is the Alamouti code, which is a complex orthogonal space-time code specialized for the case of two transmit antennas. Alamouti Space-Time Code is complex orthogonal space-time block code for two transmit antennas was developed by Alamouti. In the Alamouti encoder, two consecutive symbols x1 and x2 are encoded with the following space-time codeword matrix:

$$\mathbf{X} = \begin{bmatrix} x_1 & -x_2^* \\ x_2 & x_1^* \end{bmatrix}$$

As depicted in Figure 5.3, Alamouti encoded signal is transmitted from the two transmit antennas over two symbol periods. During the first symbol period, two symbols x1 and x2 are simultaneously transmitted from the two transmit antennas. During the second symbol period, these symbols are transmitted again, where -x*2 is transmitted from the first transmit antenna and x*1 transmitted from the second transmit antenna.

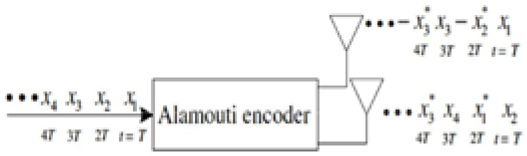


Fig 5.3 Alamouti encoder

VI. SIMULATION RESULT:

Fig 6.1 shows the performance of MRC for Rayleigh Fading Channel. The weight factor of each branch in Equation

$$y_{MRC} = \underbrace{\left[w_1^{(MRC)} w_2^{(MRC)} \cdots w_{N_R}^{(MRC)}\right]}_{\mathbf{w}_{MRC}^T} \mathbf{y} = \sum_{i=1}^{N_R} w_i^{(MRC)} y_i$$

must be matched to the corresponding channel for maximal ratio combining (MRC). Equal gain combining (EGC) is a special case of MRC in the sense that all signals from multiple branches are combined with equal weights. In fact, MRC achieves the best performance, maximizing the post-combining SNR. Fig 5.1 shows that the performance improves with the number of receiving antennas.

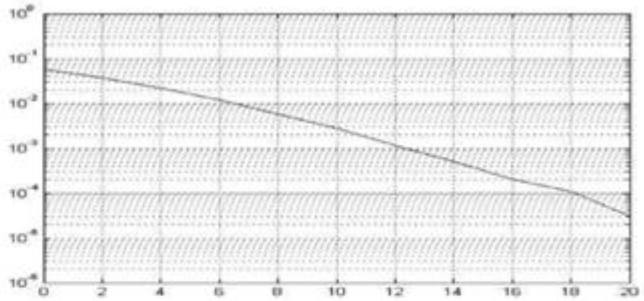


Fig 6.1 the performance of MRC for Rayleigh fading channels

Figure 6.2 compares the Alamouti coding and MRC in terms of BER performance that is obtained by using Program. Here, we assume the independent Rayleigh fading channels and perfect channel estimation at the receiver. Note that the Alamouti coding achieves the same diversity order as 1x2 MRC technique (implied by the same slope of the BER curves). Due to a total transmit power constraint (i.e., total transmit power split into each antenna by one half in the Alamouti coding), however, MRC technique outperforms Alamouti technique in providing a power combining gain in the receiver. Also shown is the 1x2 Alamouti technique which achieves the same diversity order as 2x1 MRC technique.

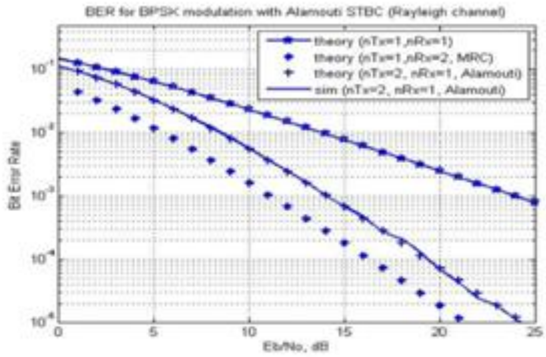


Fig 6.2 Error performance of Alamouti encoding scheme

Figure 6.3 and Fig 6.4shows the BER performance of STBC codes. As expected a higher-order diversity is obtained with a larger number of transmit antennas, that is, steepening the slope of BER curves as the number of transmit antenna increases. In fact, it confirms that all space-time block codes achieve the maximum diversity order of NT .

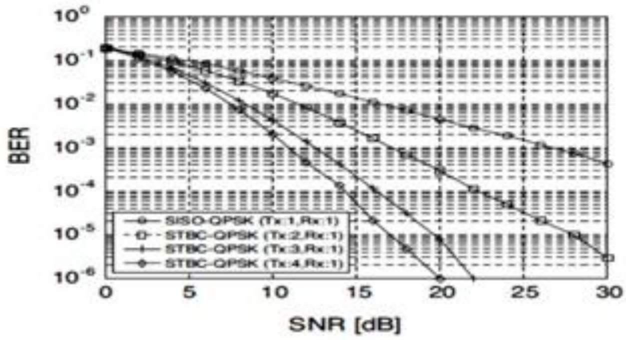


Fig 6.3 BER performance of various space-time block codes using QPSK

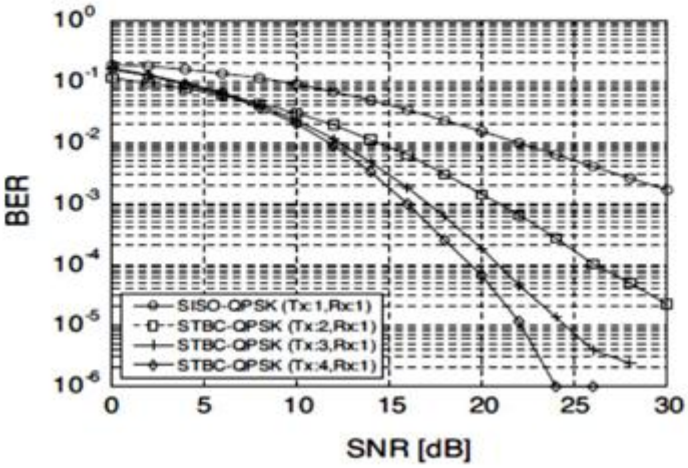


Fig 6.4 BER performance of various space-time block codes using 16 QAM

Figure 6.5 shows the error performance of the space-time trellis codes with various numbers of states and antenna configurations under the quasi-static fading channels.Figure 6.6 shows the BER performance for 2x2 antenna configuration. We observe that all the curves have the same slope, which implies that they have the same diversity gain, and that the performance improves with the number of these states. Figure 6.7 shows the BER vs SNr in lograthmic for

2x2 antenna systems. It is obvious that 2x2 antenna systems outperforms. Fig 6.9 shows the singular values for the mimo channel.

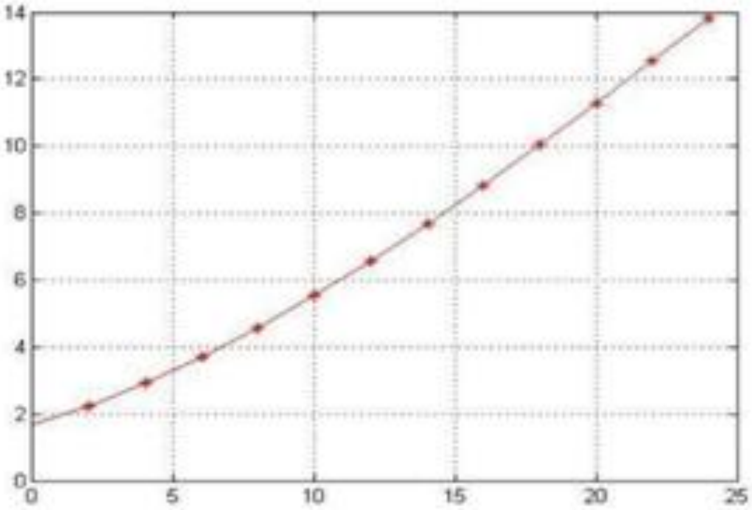


Fig 6.5 MIMO channel capacity

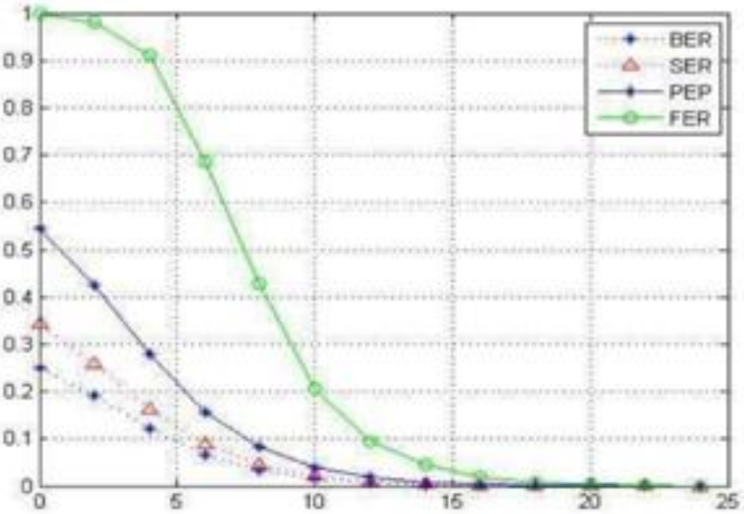


Fig 6.6 BER vs SNR in linear value

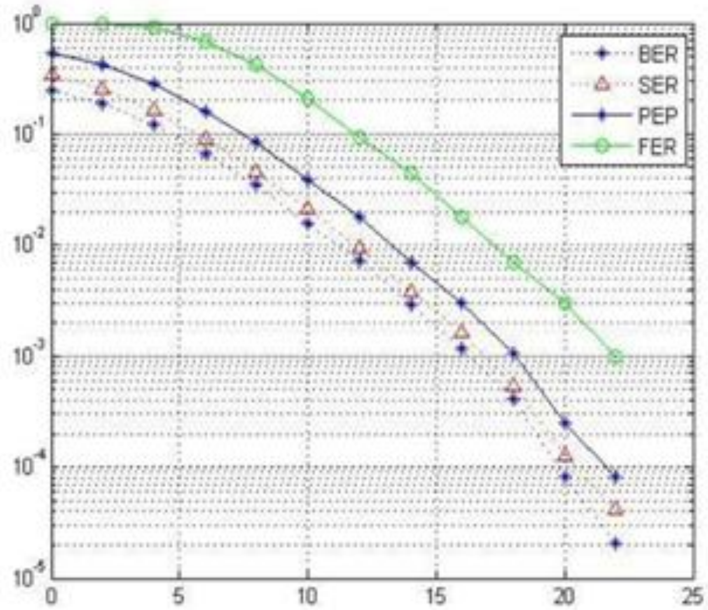


Fig 6.7 BER vs SNR in logaritmic value

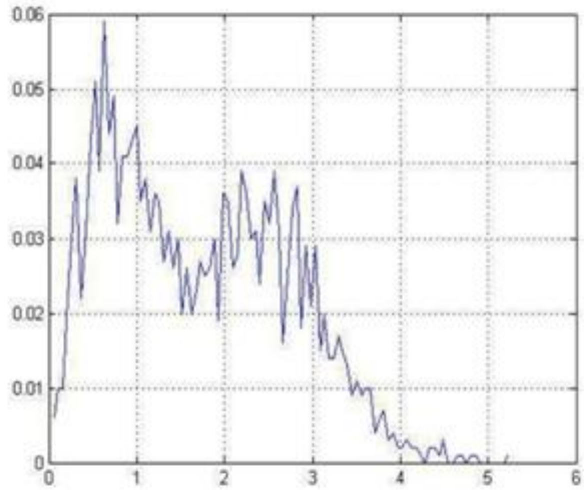


Fig 6.8 Singular value of mimo system

CONCLUSION

This dissertation describes the characteristics of the signal propagation and performance degradation issues in wireless communication channels. There are many impairment factors and fading is the major factor amongst them which degrades the performance of wireless communication system severally. Several types of antenna diversity techniques are described which can be used to mitigate fading problem in the channels. Antenna Diversity is used to supply the receiver with several replicas of the same signal. Diversity combining techniques are used to improve the channels' performance without transmitting any additional power. If high received signal are de-correlated, the gain of diversity is also high. The performance of diversity system is expressed by its ability to reduce the value of Signal to noise ratio (SNR) and Bit Error ratio (CIR) at a specified probability of error. The performance evaluated in terms of statistical reduction of the fading dynamic range of the average SNR and BER. Several Antenna Diversity Techniques are discussed out of which the Space Time trellis Coding technique comes out to be the best technique for antenna diversity.

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