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PERFORMANCE ANALYSIS OF MULTIPLE ANTENNA TECHNIQUES IN WiMAX

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Abstract

The modern wireless systems are required to have high voice quality and data rate. Since our concern is most with scattering environment, antenna diversity is a practically effective and widely applied technique to reduce the effect of multipath fading. In this regard, Multiple Input Multiple Output (MIMO) techniques are an essential part of the IEEE 802.16e - 2005 specifications, which form the basis of mobile WiMAX systems. Mobile WiMAX systems define the physical (PHY) layer and Medium Access Control (MAC) layer for mobile and portable Broadband Wireless Access (BWA) systems. The IEEE 802.16e-2005 specifications actually define three different PHY layers: Single-carrier transmission, Orthogonal Frequency Division Multiplexing (OFDM), and Scalable Orthogonal Frequency Division Multiple Access (SOFDMA). Considering the importance of WiMAX systems based on IEEE 802.16e-2005 specifications, my focus is on the MIMO techniques in the domain of WiMAX technology.

This thesis work describes the cellular networks in the context of different Generations of cellular communication and brief overview of the WiMAX technology. Moreover it describes the multiple antenna techniques in order to discuss the throughput and Bit Error Rate (BER) performance. In addition it describes the simplest Space Time Block Code (STBC) known as Alamouti STBC. Furthermore the capacity of MIMO systems has been analyzed. Matlab Simulation has been performed and results are presented, which shows the good contribution in the classical research of WiMAX Wireless Broadband Access (WBA) technology.

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At the end, I would like to dedicate my thesis to all those who love me and who prayed for me.

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List of Acronyms

1G	1^{st} Generation
2G	2^{nd}Generation
3G	3^{rd}Generation
4G	4^{th}Generation
AAS	Adaptive Antenna System
AMPS	Advance Mobile Phone System
ARQ	Automatic Repeat request
ASK	Amplitude Shift Keying
BWA	Broadband Wireless Access
BS	Base Station
BPSK	Binary Phase Shift Keying
CDMA	Code Division Multiple Access
CS	Convergence Sub layer
CPS	Common Part Sub layer
CRC	Cyclic Redundancy Check
DSL	Direct Subscriber Link
FDD	Frequency Division Duplexing
FFT	Fast Fourier Transform
FSK	Frequency Shift Keying
GSM	Global System for Mobile Communication
HARQ	Hybrid Automatic Repeat request
ISI	Inter Symbol Interference
IFFT	Inverse Fourier Transform
LOS	Line Of Sight
MAC	Medium Access Control
MIMO	Multiple Input Multiple Output
MRC	Maximum Ratio Combining
MRRC	Maximum Ratio Receive Combining Scheme
NMT	Nordic Mobile Telephone
NLOS	Non Line Of Sight
OFDM	Orthogonal Frequency Division Multiplexing
OSI	Open System Interconnection
PCS	Personal Communication Services
PHY	Physical Layer
PMP	Point-to-Multipoint
PSK	Phase Shift Keying
QOS	Quality of Services
RS	Relay Station

RMS	Root Mean Square
SISO	Single Input Single Output
SNR	Signal-to-Noise Ratio
SS	Subscriber Station
STBC	Space Time Block Code
SINR	Signal to Interference Noise Ratio
SOFDMA	Scalable Orthogonal Frequency Division Multiple Access
TDM	Time Division Multiplexing
TDMA	Time Division Multiple Access
TDD	Time Division Duplex
UMTS	Universal Mobile Telecommunication System

CHAPTER 1: INTRODUCTION

Wireless communication is the transfer of information from one place to another without using cables. In earlier time the smoke signal, semaphore and drums were used, but nowadays telecommunication make use of electronic devices such as telephone, television, radio or computer. Radio and TV are used for one way communication and mobile phones are used for two way communication.

In wireless networks there is almost unlimited mobility, we can access the network almost anywhere or anytime. In wired networks we have the restriction of using the services in fixed area services. The demand of the wireless is increasing very fast; everybody wants broadband services anywhere anytime. The IEEE has developed 802.11 as a standard for wireless LAN. The standards of wireless communication are developed all over the world. These technologies are classified into four individual categories, based on specific rang, shown in figure 1.1.

1.1 Cellular Networks:

Cellular network are divided into different generations, currently 4 Gs.

1.1.1 1st Generation:

The First Generation (1G) cellular network was introduced in around 1980s. First Generation phone were analog, used for voice calls and Line of Sight (LOS) system. In case of Advance Mobile Phone System (AMPS), the 1G system started in USA. The first cellular network was built Scandinavia in 1981. The Nordic Mobile Telephone (NMT) uses the frequency 450 MHz.

1.1.2 2nd Generation:

The Second Generation (2G) cellular networks started in 1990s. The first system was introduced in Europe to provide facilities of roaming between different countries. One system in the second generation is the Global System for Mobile communication (GSM). The GSM standard uses Time Division Multiple Access (TDMA) combined with slow frequency hopping. The Personal Communication Services (PCS) use IS-136 and IS-95 standards. The IS-136 standard uses TDMA, while IS-95 uses Code Division Multiple Access (CDMA). The GSM and PCS IS-136 uses data rate 9.6 Kbps. The 2G systems are Non Line of Sight (NLOS).

1.1.3 3rd Generation:

In Third Generation (3G) the Universal Mobile Telecommunication Systems (UMTS) was introduced. The 3G has higher bandwidth. The 3G network have the transfer speed of up to

3 Mbps and enable more services of broadband application, video conferencing, receiving video from the web, downloading e-mail message.

1.1.4 4th Generation:

The Fourth Generation (4G) cellular system upgrade existing communication networks and it will be providing, the secure Internet Protocol (IP) based solution to facilities voice, data and streamed multimedia to the users at anywhere and anytime.

In wireless communication, when signals are transmitted from transmitter to receiver many obstacles may exist. The transmitted signal may take multiple paths to the receiver. To eliminate the multipath or to improve the performance of the wireless link Multiple Input Multiple Output (MIMO) technique is used. In MIMO technique the array of antennas is used for both transmitting and receiving the signals. The ground to ground links are not LOS. To improve the signals performance, the diversity technique is used.

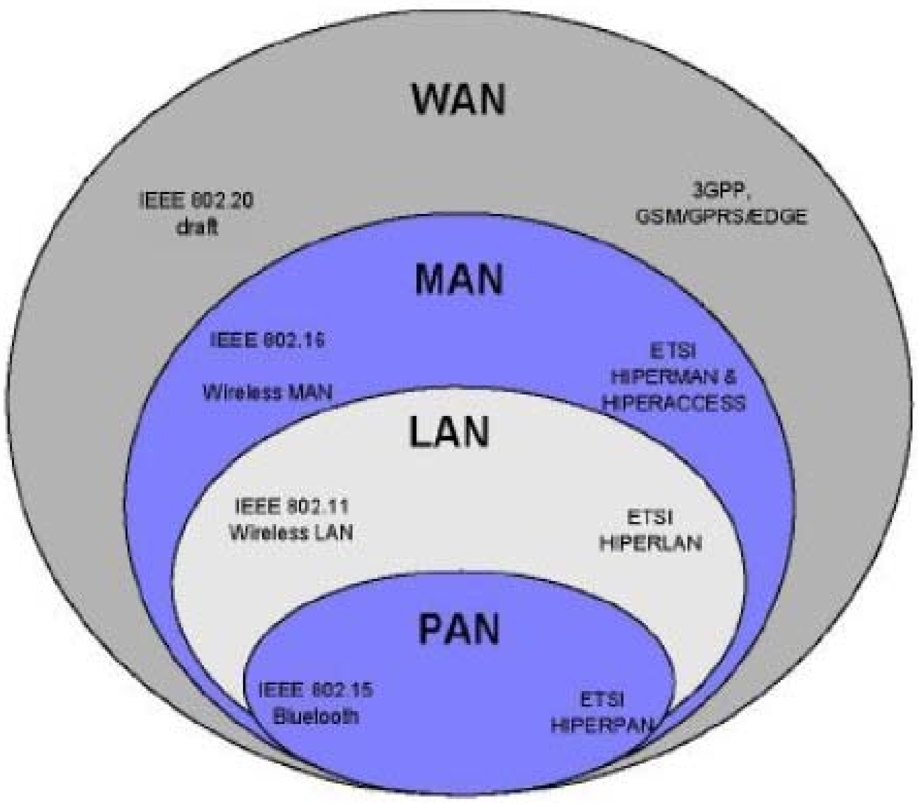

Figure 1.1 Overview of Wireless Network [1]

CHAPTER 2: Introduction to WIMAX

2.1 WiMAX

WiMAX is a Broadband Wireless Access (BWA) technology. The WiMAX is a standard based technology that provides the BWA services as an alternative to the cable and Digital Subscriber Line (DSL). The WiMAX System is used to convey the message between residential buildings and commercial places by economical ways. There are some standards of WiMAX that are used for communication. The Fixed WiMAX (IEEE 802.16d) and Mobile WiMAX (IEEE 802.16e) are commonly used.

2.2 WIMAX Standards

2.2.1 IEEE 802.16-2001

The IEEE 802.16-2001 was published in September 2001. It has the frequency range of 10-66 GHz to provide fixed broadband wireless connectivity. The single carrier modulation techniques are used in physical layer and Time Division Multiplexed (TDM) technique in MAC layer. The standard supports different Quality of Service (QoS) techniques to improve the LOS conditions.

2.2.2 IEEE 802.16a-2003

This standard is the amendment of basic IEEE 802.16. The frequency range is 2-11 GHz, includes both licensed and license free bands. The NLOS communication is possible, when frequency is below then 11 GHz. Orthogonal Frequency Division Multiplexing (OFDM) is used as modulation technique.

2.2.3 IEEE 802.16c

The standard IEEE 802.16c was published in January 2003 as an amendment to IEEE 802.16a. It uses the frequency range of 10-66 GHz.

2.2.4 IEEE 802.16d-2004

The IEEE 802.16d-2004 is also called fixed WIMAX. The IEEE 802.16d has no support for mobility and used to provide fixed BWA to nomadic and portable users. The IEEE 802.16d-2004 was designed for fixed bandwidth allocation (BWA) system to support multiple services and uses frequency band 10-66 GHz. The bandwidth of IEEE 802.16-2004 is 1.25 MHz

2.2.5 IEEE 802.16e-2005

The IEEE 802.16e is also called Mobile BWA System. This standard is standardized for two layers, the physical layer (PHY Layer) and Medium Access Control (MAC) layer. The 802.16e uses Scalable Orthogonal Frequency Division Multiple Access (SOFDMA). It provides the higher speed internet access and can be used as a Voice over IP (VoIP) service. VoIP technologies may provide new services, such as voice chatting and multimedia chatting.

The IEEE 802.16e provides support for MIMO antenna to provide good NLOS characteristics and Hybrid Automatic Request (HARQ) for good correction performance.

Table 2.1: WiMAX Standard [1].

WIMAX Standard	IEEE 802.16	IEEE 802.16a	IEEE 802.16e
Spectrum	10 to 66 GHz	Less than11GHz	Less than 6 GHz
Conditions for Channel Acquiring	LOS	NLOS	NLOS
Bit rate	32 to 134 Mbps at 28 MHz	Less than 75 Mbps at 20 MHz	Less than 15 Mbps at 5 MHz
Modulation	QPSK, 16 QAM and 64 QAM	OFDM 256,OFDM 64 QAM,16 QAM, QPSK,BPSK	OFDM 256,OFDM 64 QAM,16 QAM, QPSK,BPSK
Mobility	Fixed	Both Fixed and portable	Mobility with roaming
Channel bandwidth	20, or 25 or 28 MHz	Between 1.25 and 20 MHz, 16 logical channel	Between 1.25 and 20 MHz, 16 logical channel
Cell radius	1.6 – 5 Km	5 to 8 Km, Maximum range 50 Km based on tower height	1.6 – 5 Km

802.16 Protocol Stack: The 802.16 standard covers the MAC and PHY layer of Open System Interconnection (OSI) reference model. The MAC layer is responsible to determine which Subscriber Station (SS) can access the network. The MAC layer is subdivided into three layers. The three layers are service specific convergence sub layer (CS), MAC Common Part Sub layer

(CPS), and security sub layer. The CS transforms the incoming data into MAC data packets and maps the external network information into IEEE 802.16 MAC information.

The CPS provides support for access control functionality, bandwidth allocation and connection establishment. The PHY Layer control, data and management information are exchanged between MAC CPS and PHY layer. The security sub layer control authentication, key exchange and encryption. The PHY Layer is responsible for data transmission and reception by using 10-66 GHz frequency.

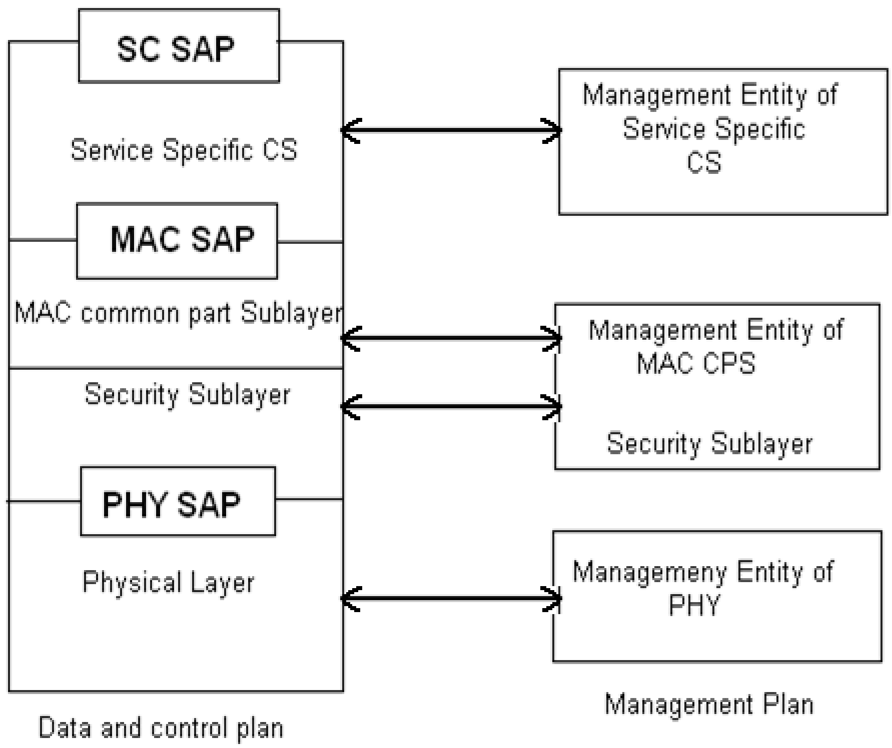

Figure 2.1: WiMAX MAC Layer [2]

2.3 WiMAX Network Architectures

The MAC layer supports two modes, mesh and PMP (Point to Multi point). The BS (Base Station) communicates with several SSs using PMP mode and share uplink and down link channel information. All the SSs need to have a clear LOS to the BS in PMP mode.

In mesh mode BS consist of net, Relay Stations (RSs), Subscriber Station and Mobile Station (MS). The mesh mode support of multi hop BS access the internet and RSs forward traffic to other RSs.

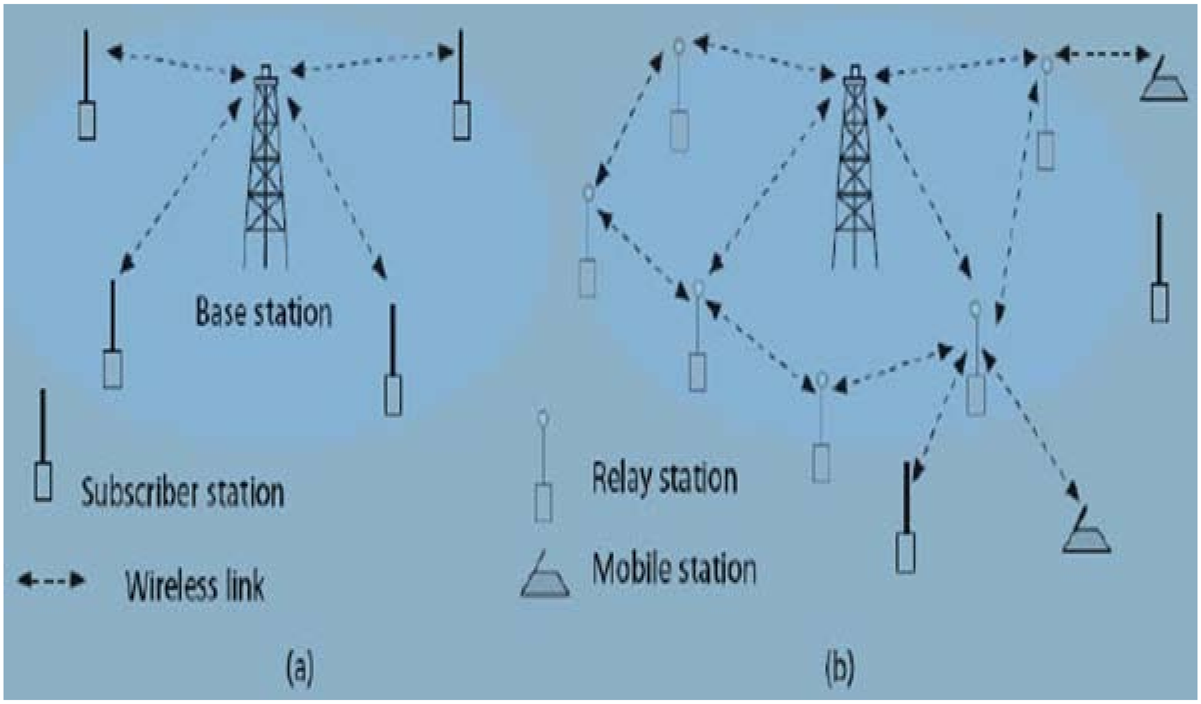

Figure 2.2: WiMAX (a) Point – to – Multipoint (PMP) and (b) Mesh Mode Network [1].

2.4 Technical Information

Technical information of WIMAX is given below.

2.4.1 MAC layer

In MAC layer all SS pass data through a wireless access point. The 802.16 MAC layer uses a scheduling algorithm for which subscriber station needs to complete only one initial entry into the network. After network entry, the subscriber station is allocated an access slot by the base station. The time slots are assigned to the subscriber station. These time slots can enlarge and contract. In addition to being stable under overload and over subscription, the scheduling algorithm can also be more bandwidth efficient. The scheduling algorithm allows the base station to control QoS parameters by balancing the time slots according to the need of subscriber stations.

2.4.2 Physical layer

The PHY Layer is responsible for slot allocation. Slots have one sub channel and one, two or three OFDM symbols depending upon which channel scheme is used. The channel schemes Frequency Division Duplex (FDD) and Time Division Duplex (TDD) are used. It has features support for MIMO antennas and provide NLOS. In PHY Layer of WiMAX data rate varies based on the operating parameters. The OFDM guard time and oversampling rate have good impact. By using multiple antennas at the transmitter and receiver we can further increase the peak rate in multipath channels.

Physical Layer Interfaces: PHY Layer of IEEE 802.16 has the following interfaces.

- **Wireless MAN-SC2:** The WirelessMAN-SC2 uses single carrier modulation technique and has frequency range 10-66 GHz.
- **Wireless MAN-OFDM:** It is based on OFDM modulation with 256-point fast Fourier transform (FFT) within TDMA channel access provide NLOS transmission in the frequency band of 2-11 GHz.
- **Wireless MAN-OFDMA:** It uses the licensed frequency band of 2-11 GHz. It supports the NLOS operation by using the 2048 points of FFT.
- **Wireless HUMAN:** The Wireless HUMAN uses license free frequency band below 11 GHz. It can also use any air interface that have 2-11 GHz frequency band. It uses the TDD as duplexing technique.

Table 2.2: WiMAX PHY Layer Interface Characteristics.

PHY interface	Duplexing Techniques	Frequency Band	Modulation	Propagation Mode
Wireless MAN-SC2	FDD and TDD	10-66 GHz	Single carrier	LOS
Wireless MAN-OFDM	TDD and FDD	2-11 GHz	OFDM	NLOS
Wireless MAN-OFDMA	TDD and FDD	2-11 GHz	2048 FFT point	NLOS
Wireless HUMAN	TDD	2-11 GHz	SC,OFDM,OFDMA	NLOS

2.5 OFDM Basics

OFDM belongs to multicarrier modulation technique that provides high data rates. In high data rate systems, delay spread is greater than symbol length. In NLOS systems, the delay spread will also be large and the wireless broadband system will suffer Inter Symbol Interference

(ISI). To overcome this problem the multicarrier modulation divides the transmitted bit stream into lower stream. The individual sub streams are sent over parallel sub channels. The data rate of a sub channel is less than total data rate, so the sub channel bandwidth is less than total system bandwidth. Thus the ISI of each sub channel is small.

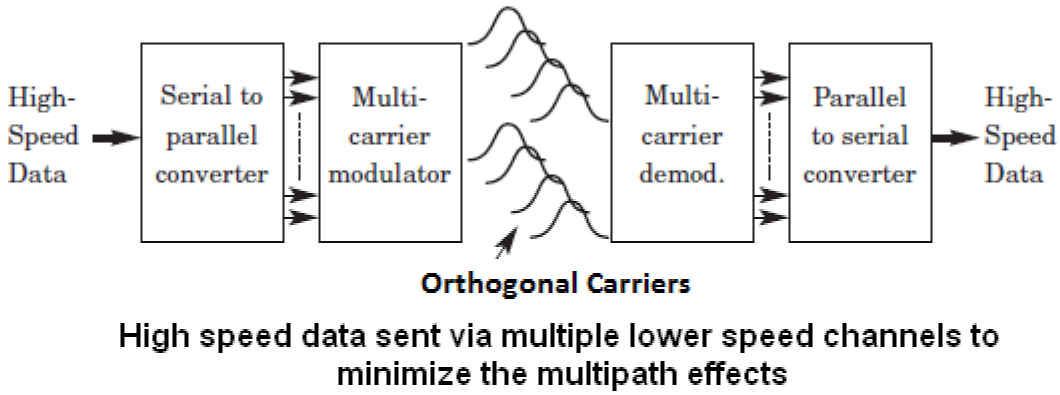

Figure 2.3: OFDM Concept

OFDM has several advantages over other solutions, to obtain high speed transmission.

- Decrease the computational complexity.
- Under excess delay provide less degradation of performance
- Varied frequency diversity.
- Use as a multi-access technique.
- Suitable for coherent demodulation.

2.5.1 OFDM parameter used in WIMAX

OFDM has different implementations at physical layer, for both fixed and mobile versions. Fixed WIMAX version, which is IEEE 802.16-2004 uses 256 FFT-based OFDM physical layer. The mobile WIMAX uses scalable OFDMA based physical layer. In IEEE 802.16e-2005, the FFT sizes can vary from 128 bits to 2,048 bits.

Table 2.3: OFDM Parameters [5].

	Fixed WIMAX at OFDM-Physical layer	**Mobile WIMAX Scalable OFDM-Physical layer**			
Size of FFT	256	128	512	1,024	2,048
Used data of subcarriers	192	72	360	720	1,440
Pilot subcarriers	8	12	60	120	240
Guard band subcarrier	56	44	92	184	368
Cyclic prefix	1/32	1/16	1/8	1/4	
Oversampling rate	Bandwidth 7/6 for 256 OFDM and for 28/25 for multiples of 1.25MHz, 1.5MHz, 2MHz				
Frequency spacing	15.625	10.94			
Symbol time	64	91.4			
Guard time	8	11.4			
OFDM symbol duration ( )	72	102.9			
OFDM symbol in 5ms frame	69	48.0			

OFDM Features:

- The narrow band signals are less sensitive as compared to ISI and frequency selective fading.

- In OFDM, Fast Fourier Transform (FFT) and Inverse Fast Fourier Transform (IFFT) operations ensure that sub channel do not interfere with each other.
- OFDM provides robustness against burst error.
- OFDM support less complex equalization as compared to the equalization in single carrier systems.
- Effective robustness can gain by multipath environments.

2.6 Mobility

Mobility support is available in IEEE 802.16e WiMAX standard. In BWA four scenarios support mobility.

2.6.1 Nomadic:

In this scenario user is allowed to take a fixed subscriber station and reconnect from a different point of attachment.

2.6.2 Portable:

The nomadic access scenario supports the portable devices such as PC card.

2.6.3 Simple mobility:

In this scenario, the subscriber move at speed up to 60 kmph and interruptions are less than 1 sec during handoff.

2.6.4 Full mobility:

The subscriber move at speed up to 120 Kmph and packet loss is less than 1 percent. It support seamless handoff and latency is less than 50 ms.

The IEEE 802.16e-2005 standard defines a framework for supporting mobility management. The standard defines signaling mechanisms for tracking subscriber stations as they move from the coverage range of one base station to another or they move from one paging group to another when idle.

The standard IEEE 802.16e is the amendment of PHY Layer and MAC Layer. The PHY Layer enhancement is DL sub channel zone within MAC frame. The MAC frame is controlled by DL frame prefix and private DL MAPs. The mobility management is used to enhance the MAC layer. Two types of mode are used to reduce the power consumption of MSs. In sleep mode MS is absent from BS and unavailable DL traffic. The idle mode removes the MS requirement provided by multiple BS. The handover procedure allows the “Macro Diversity Handover” and “fast BS switching”.

2.7 QoS in WIMAX

The QoS is a measure of how successfully the signals are transmitted from BS. The four parameters, as follows, are used to describe the QoS.

2.7.1 Bandwidth:

The PHY Layer is a pipe between BS and the client terminal in WIMAX. The active clients are in parallel and share the overall system bandwidth.

2.7.2 Latency:

Latency is the end to end packet transmission time, and occurs in physical layer chain. In IEEE 802.16 systems the latency is almost 5 ms. Latency is affected by how packets quid, different QoS protocols and user characterization are implemented.

2.7.3 Jitter:

Jitter is the variation of latency over different packets and can be limited by number of packet buffering. Mobile terminal has little jitter control in wireless networks and it falls on the base station to ensure that different packets are received at different priority.

2.7.4 Reliability:

Reliability leads to more complications in wireless networks as compared to fixed line ones. The problem arises specifically in mobile networks, where the radio wave propagates in mobile terminal with small antenna and low power in urban area.

2.8 WiMAX Features for Performance Enhancement

WIMAX supports advanced features to improve the performance. These advanced feature support for multiple antenna techniques, hybrid-ARQ, and enhanced frequency reuse and multiple antenna technique are described in some detail in the next chapter.

2.8.1 Advanced Antenna Systems:

The WIMAX standard supports the multi antenna solution to improve system performance. The advanced antenna systems support the variety of multi antenna solutions, such as transmit diversity, Beam forming, and spatial multiplexing, all are used in WIMAX.

2.8.2 Diversity Schemes:

The diversity scheme is a technique which is used for improving the reliability of a message signal. In this technique two or more communication channels are used with different characteristics. Diversity plays an important role in combatting fading and co-channel interference.

2.8.3 Beam Forming:

In this technique the antenna element focuses the transmitted beam in the direction of receiver, to improve the received Signal to Interference Noise Ratio (SINR). Beam forming supports; more coverage area, capacity, reliability, and support for both uplink and downlink.

2.8.4 Spatial multiplexing:

In spatial multiplexing the multiple independent streams are transmitted across multiple antennas. The spatial multiplexing is used to increase the data rate or capacity of the system. WiMAX also supports spatial multiplexing in uplink. The coding across multiple users in the uplink, supporting the spatial multiplexing, is called multiuser collaborative spatial multiplexing.

2.8.5 Hybrid ARQ

The hybrid ARQ system is implemented at physical layer together with Forward Equivalence Class (FEC) and used for link performance. In simple combination of FEC and ARQ, the blocks of data and Cyclic Redundancy Check (CRC) are encoded using FEC coder before transmission. If the decoder is unable to decode the received block, retransmission is requested. The retransmitted coded block is combined with previously detected coded block and serves as the input to the FEC decoder.

There are two types of hybrid H-ARQ, type one is called 1 chase combining, and the second type is called incremental redundancy.

2.9 Modulation techniques

There are three main classes of modulation schemes, which are used to transmit the data.

- Amplitude Shift Keying (ASK)
- Frequency Shift Keying (FSK)
- Phase Shift Keying (PSK)

All techniques are used in digital communication to convey the data. In phase shift keying the phase is changed to represent the data signal. There are two fundamental ways, which are used in phase shift keying.

- The phase itself is used for conveying the information, the demodulator must have the reference signal and compare it to received signal, against phase.
- The change in the phase is used for conveying the information.

2.9.1 Binary Phase Shift Keying (BPSK):

BPSK is sometimes called Phase Reversal Keying; it is the simplest form of phase shift keying. BPSK uses two phases, which are separated by 180^0 and known as two phase shift keying. This modulation is most robust from all PSKs modulation schemes due to its low probability of error. However, it gives lower data rates as compared to other modulation schemes. So for getting higher data rates we use QPSK and 16 QAM.

$$s_1(t) = \sqrt{\frac{2E_b}{T_b}}\cos(2\pi f_c t + \pi) = -\sqrt{\frac{2E_b}{T_b}}\cos(2\pi f_c t) \quad \text{for binary} \qquad (0)$$

$$s_1(t) = \sqrt{\frac{2E_b}{T_b}}\cos(2\pi f_c t) \qquad \text{for binary} \qquad (1)$$

f_c is the frequency of carrier

So, the signal can be represented by single basis function

$$\varphi(t) = \sqrt{\frac{2}{T_b}}\cos(2\pi f_c t)$$

Where 1 is represented by $\sqrt{E_b}\varphi(t)$ and 0 is represented by $-\sqrt{E_b}\varphi(t)$.

CHAPTER 3: MULTIPLE ANTENNA TECHNIQUES

Multiple antenna techniques are used to improve the performance and robustness of wireless links in the telecommunication field. The Multiple Input Multiple Output (MIMO) technique uses an array of antennas for both transmitting and receiving end. Using MIMO techniques we can obtain better wireless communication as compared to other techniques.

The electromagnetic waves transmitted from the antennas bounce around the environment, the receiver receives these electromagnetic waves from multiple directions, with varying delays. The delay varies since the different paths have different length. The Line of Sight (LOS) between the Base Station (BS) and the Subscriber Station (SS) is often very difficult to achieve, because the SS may be located indoors. WIMAX can operate in NLOS environments. To operate in multipath environment, WIMAX uses OFDM or SOFDMA. These both techniques are PHY Layer based [13].

Modern multiple antenna systems can be designed to take advantage of multipath as compared to traditional single antenna systems. When WIMAX is used in conjunction with multiple antenna systems, the throughput and correction of error rate performance is increased by taking advantage of multipath effect.

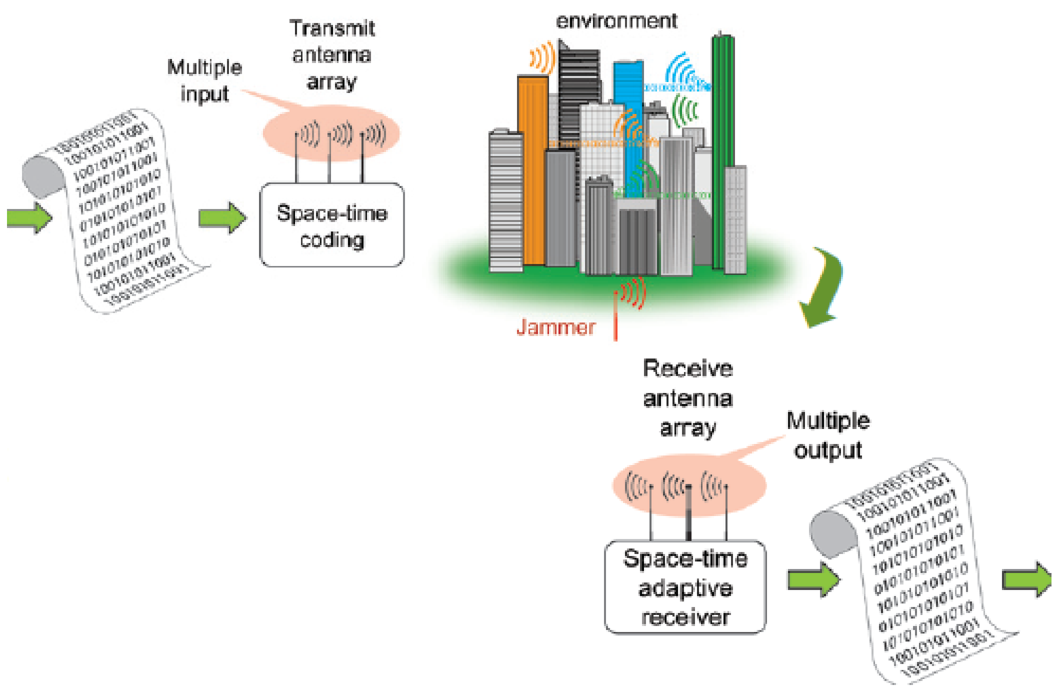

Figure 3.1: Multipath Environment [13].

Multiple antenna techniques are divided into three subclasses.

1. Diversity Schemes
2. Smart Antenna Systems (SAS)
3. MIMO Systems

3.1 Diversity Scheme

Diversity Scheme is a technique, which is used to improve the signal strength. In diversity scheme, two or more communication channels are used. Diversity plays an important role in reduction of fading and elimination of error burst. In diversity schemes multiple versions of the signal are transmitted and received. When these signals are transmitted the Forward Error Correction (FEC) code is added to different parts of the message. Different classes of diversity are given below.

3.1.1 Time diversity:

Multiple versions of the same signals are transmitted at different time instants. The FEC code is added to the message. Then this message is spread in time before the transmission. In other words the elements of a radio signal transmitted at the same moment in time and these elements arrive at the receiver at different moments in time**,** because these signals uses different physical paths, through the use of receiving antenna technology known as rake receivers and multiple input multiple output (MIMO).

3.1.2 Frequency diversity:

In this, the signal is transmitted using different frequency channels, such as spread spectrum. OFDM modulation is also used with subcarrier and FEC.

3.1.3 Space diversity:

In Space diversity the signal is sent over different propagation paths. In wireless communication transmit diversity is used to transmit the signal and reception diversity is used to receive the signal. In this technique, if the antennas are much more than one wavelength away from each other, this is called macro diversity and if the antennas are in the order of one wavelength, then it is called micro diversity.

3.1.4 Polarization diversity:

In this technique multiple versions of signal are transmitted and received. It is used to minimize the effects of selective fading of the horizontal and vertical components of a radio signal. It is usually accomplished through the use of separate vertically and horizontally polarized receiving antennas.

3.1.5 Multiuser diversity:

Multiuser diversity supports opportunistic user scheduling at either transmitter or receiver end. By using scheduling, the transmitter selects the best user from the candidate received according to the quality of each channel.

3.2 Smart Antenna System:

The smart antenna system also called adaptive antenna system (AAS). In smart antenna system, by using signal processing techniques channel model attains channel knowledge to steer the beam towards the desired subscriber while transmitting null steering towards the interferer. The null steering cancels undesired portion of the signal and reduces the gain of radiation pattern obtained from adaptive array antenna. This is achieved by using Beamforming and null steering towards desired user. The process of combining the radiated signal and focusing it in the desired direction is called Beamforming.

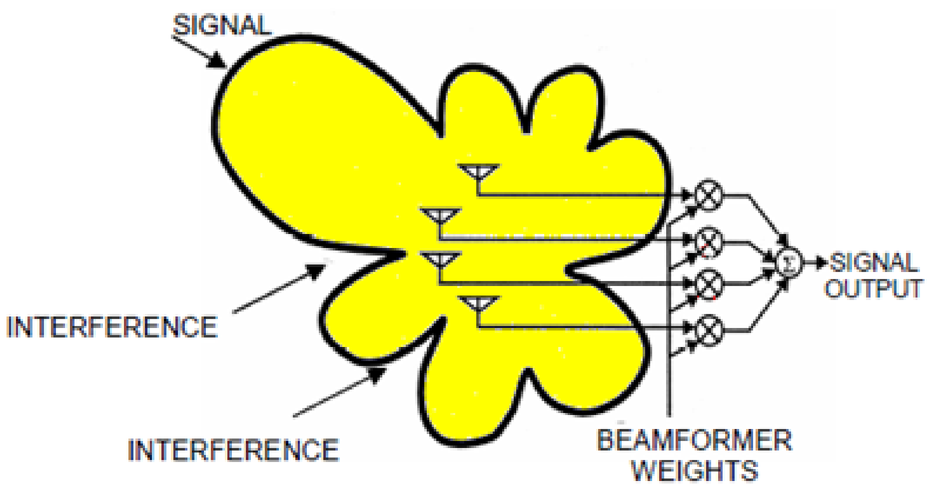

Figure 3.2: Smart Antenna System [14].

3.3 Multiple Input Multiple Output (MIMO) system:

In MIMO technique BS and SS both have minimum of two transmitter and receiver, per channel as shown in figure 3.3.

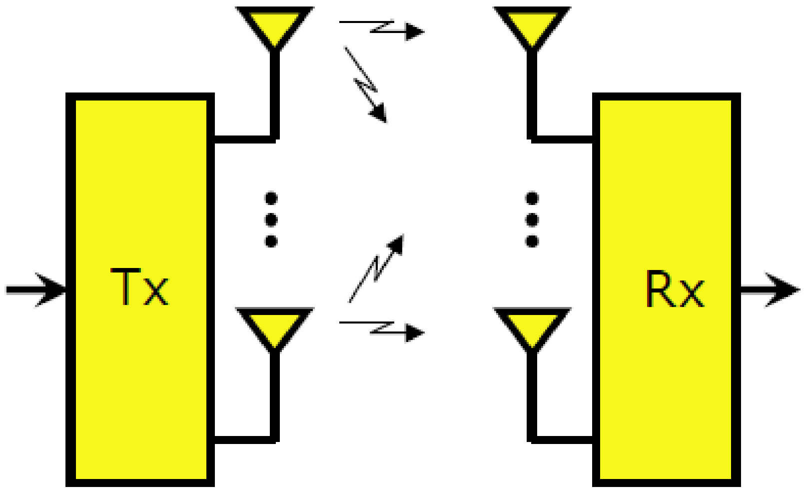

Figure 3.3: General Block Diagram of MIMO System [14].

Generally in 802.16, for diversity schemes, following three techniques are considered [20].

1. Space time coding
2. Antenna Switching
3. Maximum ratio combining

3.3.1 Space time coding technique:

The 802.16 standard supports the Alamouti Scheme. In Space Time Coding, the information is sent on two transmit antennas. The information is sent consecutively in time and is called transmit information in time and space.

The data stream enters the modulator and is modulated into symbols S_1 and S_2. The space time encoder processes the symbols. The symbol S_1 followed by $-S_2^*$ to Antenna 1 and S_2 followed by S_1^* to Antenna 2. The "*" shows the Complex Conjugate of the symbol. The symbols are transmitted in two time period from the BS.

This coding technique is used to increase the system capacity and improve the error rate performance of the system.

3.3.2 Antenna Switching:

Antenna Switching Technique is used for capturing diversity gains. The purpose of the antenna switching is not to combine signals from the multiple antennas available, it is used to simply select the single antenna with the best channel gain at any given time. This is applicable to both downlink and uplink transmission.

3.3.3 Maximum Ratio Combining (MRC):

Maximum Ratio Combining (MRC) is the technique of diversity scheme which estimates channel characteristics for multiple antennas. MRC obtain diversity and array gain but does not involve spatial multiplexing in any way. In maximum ratio combining, the signal of each channel are added together and the gain of these channel is proportional to the Root Mean Square (rms) signal level and inversely proportional to the mean square noise level of these channels. Each channel has different proportionality constants, also known as ratio squared combining.

CHAPTER 4: ALAMOUTI SPACE TIME BLOCK CODE FOR MIMO SYSTEM

There are number of Space Time codes, but this thesis is focusing on the Alamouti code. S.M. Alamouti proposed the code in 1998. The Alamouti code is also called Space Time Block Code (STBC). A block code operates on a "block" of data at a time. In block code output only depends on the current input bits. In convolution codes, the output only depends on the current input bits and on previous inputs. The convolution code may not produce the same output for a given input, because previous input is involved. The block code requires less power, to decode a block code, as compared to convolution code.

The Alamouti coding is described by the following matrix and Y is the encoder output, while X_1 and X_2 are the input symbols. The "*" denotes the complex conjugate.

$$\mathbf{Y} = \begin{bmatrix} \boldsymbol{X_1} & -\boldsymbol{X_2^*} \\ \boldsymbol{X_2} & \boldsymbol{X_1^*} \end{bmatrix}$$

The figure 4.1 is a block diagram of the transmitter module in MIMO system and using the Alamouti code. The binary bits enter a modulator and are converted to "symbols". A symbol from modulator is represented by complex numbers. This symbol can be transmitted directly in a single antenna, Single Input Single Output (SISO), system. In MIMO system the complex symbols are fed into the Alamouti encoder. The Alamouti encoder maps the symbols onto the transmitter by using the above given matrix. In this matrix, rows represent the transmit antennas, and columns represent the time. The element of the matrix tells what symbol is to be transmitted from a particular antenna. The Alamouti code works with pairs of symbols at a time. It takes two time periods to transmit the two symbols [7].

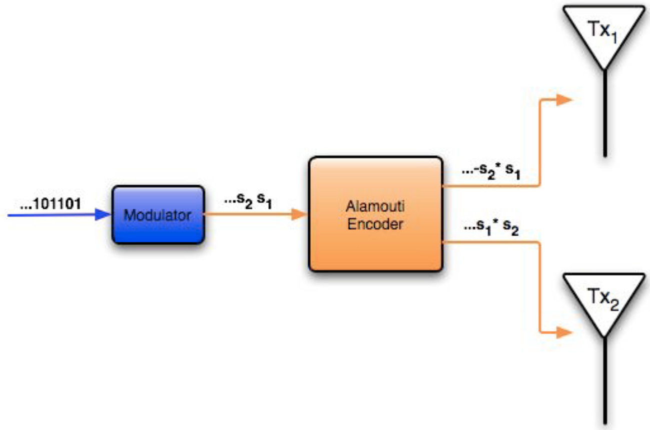

Figure 4.1: MIMO Transmitter (using Alamouti code) [8].

4.2 Rayleigh Fading Channel:

When multiple reflective paths are large in number and there is no line of sight signal component the channel is called a Rayleigh fading channel. The three basic mechanisms that impact signal propagation are reflection, diffraction, and scattering.

Reflection occurs, when a propogating electromagnetic wave strike on a smooth surface. Diffraction occurs when there is a obstruction between the transmitter and receiver.Diffraction accounts for RF energy traveling from transmitter to receiver without line of sight path.

Scattering occurs, when wave passes through the radio medium, consists of small objects. Scattered waves are usually generated by rough surfaces.

Rayleigh Fading Channel is a statistical model. When radio signal passes through a communication channel the power of the signal will vary due to Rayleigh distribution. The Rayleigh disribution describes the statistical time varying of the received envelope of flat fading signal.

Rayleigh fading model has support for tropospheric and ionospheric signal propagation. It is most applicable when there is no distinct dominant path along LOS, between the transmitter and receiver.

In this regard, Jakes introduced a model for Rayleigh fading based on summing sinusoids. Jakes model works equally, if the single path channel is being modelled or multipath frequency-selective channel is required. The Jakes model also popularised the Doppler spectrum associated with Rayleigh fading and as the result this Doppler spectrum is often termed as Jakes spectrum.

4.3 Maximum Ratio Receive Combining Scheme (MRRC):

The baseband representation of the classical two branch MRRC is shown in figure 4.2.

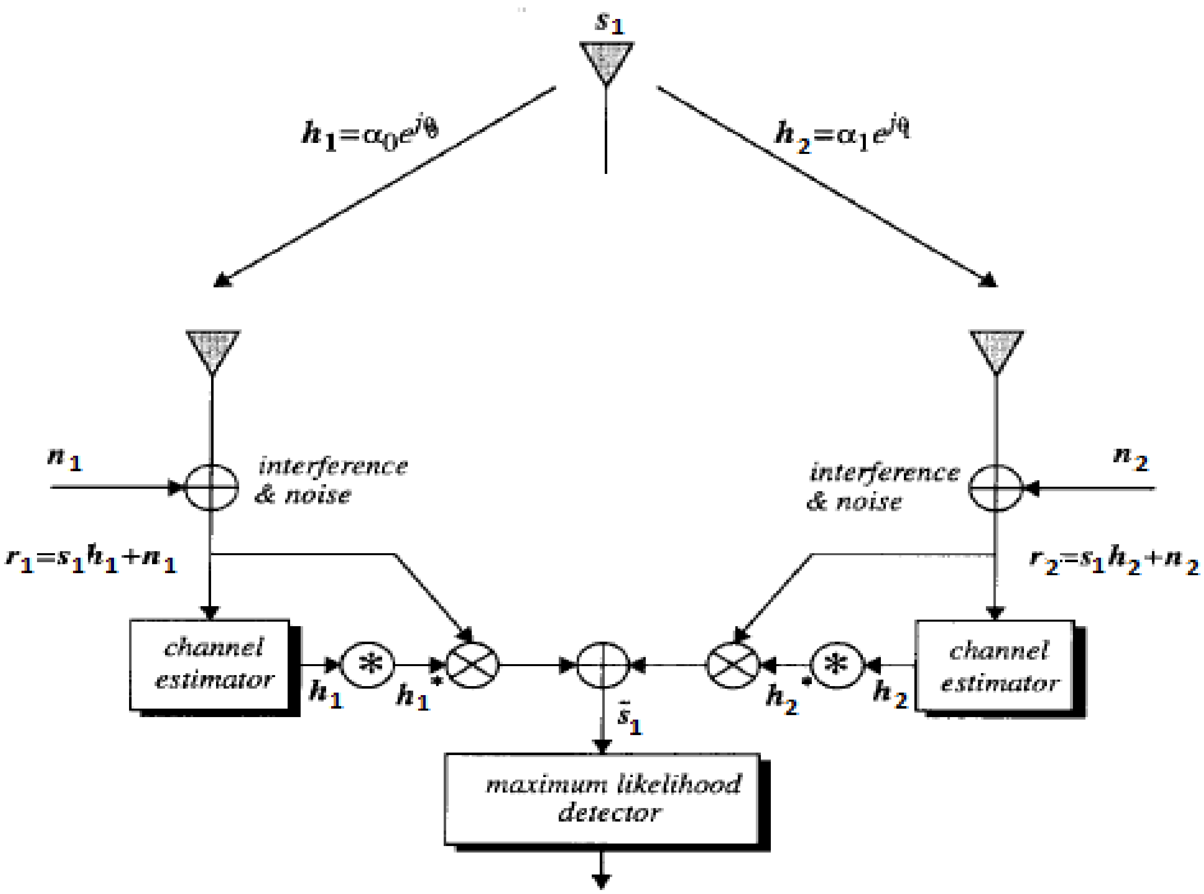

Figure 4.2: Two Branch MRRC [11]

The signal S_1 is sent from the transmitter at a given time. In MRRC the channel has the effect of transmit chain, receive chain and airlink are modeled by complex multiplicative distortion. The complex multiplicative is composed of a magnitude response and a phase response. The channel between the transmit antenna and receive antenna are define by h_1 and h_2. The h_1 represent the zero and h_2 represent the one [11].

$$h_1 = \propto_0 e^{j\theta_0}$$

$$h_2 = \propto_1 e^{j\theta_1} \tag{4.1}$$

At the receiver side, the noise and interference are added. The resulting received baseband signals are as follows.

$$r_1 = h_1 s_1 + n_1$$

$$r_2 = h_2 s_1 + n_2 \tag{4.2}$$

Here n_1 and n_2 represent complex noise and interference in the received baseband signal. We assume that n_1 and n_2 are Gaussian distributed. At the receiver side the maximum likelihood decision rule is used to choose the signal s_i

$$\boldsymbol{d^2}(\boldsymbol{r_1}, \boldsymbol{h_1 s_i}) + \boldsymbol{d^2}(\boldsymbol{r_2}, \boldsymbol{h_2 s_i}) \leq \boldsymbol{d^2}(\boldsymbol{r_1}, \boldsymbol{h_1} . \boldsymbol{s_k}) + \boldsymbol{d^2}(\boldsymbol{r_2}, \boldsymbol{h_2} . \boldsymbol{s_k}), \quad \forall i \neq \boldsymbol{k} \qquad (4.3)$$

The squared Euclidean distance is calculated by the following expression.

$$\boldsymbol{d^2}(a, b) = (a - b)\,(\boldsymbol{a}^* - \boldsymbol{b}^*) \qquad (4.4)$$

So the receiver combining scheme for two branches MRRC is as follows:

$$\boldsymbol{\bar{s}_1} = \boldsymbol{h_1^* r_1} + \boldsymbol{h_2^* r_2}$$

$$= \boldsymbol{h_1^*}(\boldsymbol{h_1 s_1} + \boldsymbol{n_1}) + \boldsymbol{h_2^*}(\boldsymbol{h_2 s_1} + \boldsymbol{n_2})$$

$$= (\propto_0^2 + \propto_1^2)\boldsymbol{s_1} + \boldsymbol{h_1^* n_1} + \boldsymbol{h_2^* n_2} \qquad (4.5)$$

By expanding equation (4.3) and using equation (4.4) and (4.5) the following expression is obtained

Choose s_i if

$$(\propto_0^2 + \propto_1^2)\,|s_i|^2 - \bar{s_1}\boldsymbol{s_i^*} - \bar{s_1}^*\boldsymbol{s_i} \leq (\propto_0^2 + \propto_1^2)\,|\boldsymbol{s_k}|^2 - \boldsymbol{\bar{s}_1 s_k^*} - \boldsymbol{\bar{s}_0^* s_k} \qquad \forall i \neq k \quad (4.6)$$

For PSK signals

$$|s_i|^2 = |s_k|^2 = \boldsymbol{E_s} \qquad \forall i, k \quad (4.7)$$

where E_s is the energy of the signal, so the decision rule may be simplified to the following expression:

Choose s_i iff

$$\boldsymbol{d^2}(\boldsymbol{\bar{s}_1}, \boldsymbol{s_i}) \leq \boldsymbol{d^2}(\boldsymbol{\bar{s}_1}, \boldsymbol{s_k}) \qquad \forall i \neq k \quad (4.8)$$

So the maximal ratio combiner constructs the signal $\bar{s_1}$ and the likelihood detector produces the $\boldsymbol{s_i}$**,** which describe the maximum likelihood estimate.

4.4 Transmit Diversity Scheme (Alamouti Scheme):

4.4.1Two Branch Transmit Diversity with one Receiver:

The baseband representations of the new two branches transmit diversity Scheme shows in figure 4.3.

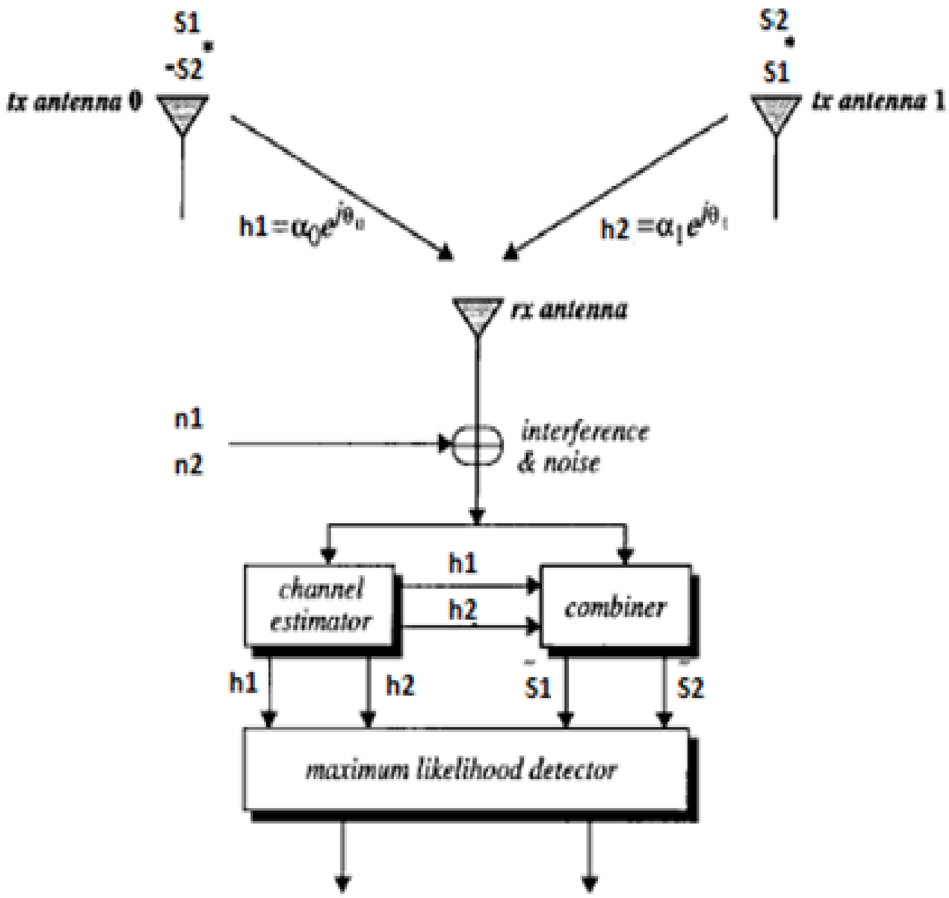

Figure 4.3: Time Diversity with 2 Branch Transmitters and 1 Branch Receiver [11].

This scheme uses two transmit antennas and one receiver antenna, defined from the following functions:

1. The transmission sequences of information symbol are encoded at the transmitter.
2. Combining scheme is applied at the receiver.
3. Decision rule for maximum likelihood detection.

The Encoding and Transmission Sequence:

In Encoding and Transmission Sequence, two signals are simultaneously transmitted at given symbol from the two antennas. The signal, which is transmitted from antenna zero is denoted by s_1 and the signal which is transmitted from antenna one is denoted by s_2. During the next symbol period, the complex conjugate are transmitted from antenna zero and antenna one. The signal -s_2^* is transmitted from antenna zero, and signal s_1^* is transmitted from antenna one, where * is the complex conjugate. This sequence of these antennas is shown in Table 4.1.

The encoding scheme Space Time Coding (STC) is used. Encoding can also be done in space and frequency (Space Frequency Coding); the two adjacent carriers are used instead of two adjacent symbols.

Table 4.1: Encoding and Transmission Sequence for Two Branch Transmission Scheme [11].

	Antenna 0	**Antenna 1**
Time t	s_1	s_2
Time t+T	$-s_2^*$	s_1^*

The channel is modeled by complex multiplicative distortion at time t. The distortion h_1(t) use for transmit antenna zero and h_2(t) for transmit antenna one. The fading is constant across two consecutive symbols, which can be expressed as:

$$h_1(t) = h_1(t + T) = h_1 = \propto_0 e^{j\theta_0}$$

$$h_2(t) = h_2(t + T) = h_2 = \propto_1 e^{j\theta_1} \quad (4.9)$$

where T shows the symbol duration. Then received signal can be expressed as:

$$r_1 = r(t) = h_1 s_1 + h_2 s_2 + n_1$$

$$r_2 = r(t + T) = - h_1 s_2^* + h_2 s_1^* + n_2 \quad (4.10)$$

where r_1 and r_2 are received signals at time t and t+T and n_1 and n_2 are complex random variables. These random variables represent receiver noise and interference.

Combining Scheme:

The combined signals that are sent to the maximum likelihood detector are as follows:

$$\bar{s}_1 = h_1^* r_1 + h_2 r_2^*$$

$$\bar{s}_2 = h_2^* r_1 - h_1 r_2^* \quad (4.11)$$

It is important to note that the combining scheme is different from the MRRC in (4.5). Substituting (4.9) and (4.10) into (4.11) we get

$$\bar{s_1} = (\alpha_0^2 + \alpha_1^2)s_1 + h_1^* n_1 + h_2 n_2^*$$

$$\bar{s_2} = (\alpha_0^2 + \alpha_1^2)s_2 - h_1 n_2^* + h_2^* n_1 \quad (4.12)$$

Maximum Likelihood Decision Rule:

The signals are combined through the Combining Scheme in the combiner. These combined signals are sent to the maximum likelihood detector and for each of the signals $s_1$and s_2, decision rule is used. The decision rule is expressed in equation (4.6) for PSK signals.

The resulting combined signals are given in (4.12). These combined signals are equivalent to that obtained from two branches MRRC in (4.4). The only difference is phase rotation on noise components. This difference does not degrade the effective SNR. Therefore, the resulting two branch transmit diversity scheme with one receiver is equal to that of two branch MRRC.

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4.5 Simulation Results:

In this chapter, new transmit diversity scheme called Alamouti scheme has been analyzed. Fig 4.4 shows the BER of the BPSK vs SNR dB employing Alamouti code at the transmitter in Rayleigh fading channel. From the figure 4.4 it is clear that implementing Alamouti STBC with two transmitting and one receiving antennas achieves the better diversity in terms of BER as with one transmitting and one receiving antennas. These results also provide a practical approach towards the implementation of the BS with two antennas and mobile user with one antenna. It is further shown that theoretical and simulation results match each other closely.

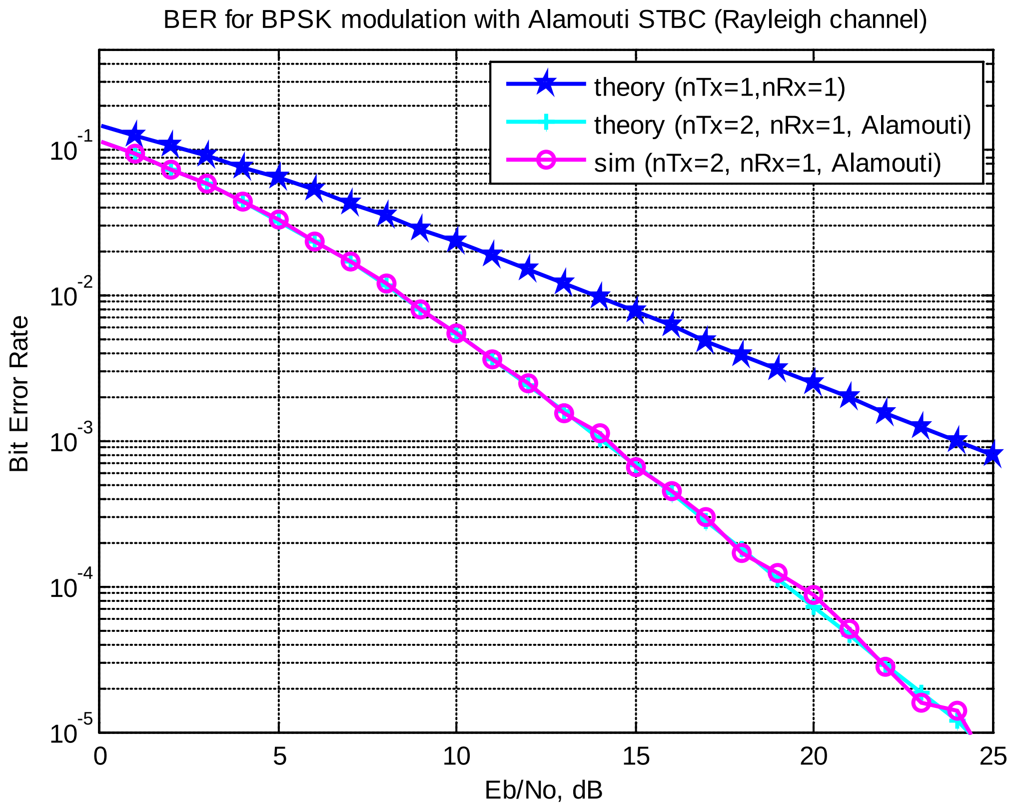

Figure 4.4: BER for BPSK Modulation using Alamouti and MRC Schemes.

The number of simulations performed are 25 and 10^6 bits/ symbols are transmitted for each simulation.

CHAPTER 5: MIMO CAPACITY

5.1 Introduction

The basic concept of MIMO communication is to provide the performance advantages. The MIMO systems provide tremendous capacity gains, which has spurred significant activity to develop transmitter and receiver techniques that realize these capacity benefits and exploit diversity. This chapter describes the Shannon capacity limits of single and multi user MIMO system. The limits of single and multi user MIMO systems show the maximum data rates that can be transmitted over the MIMO channel. The channels have small error probability and assuming no constraints on the delay.

The initial excitement about MIMO systems was described by Foschini and Telatar [17], predicting remarkable capacity growth for wireless system with multiple antennas. The channel exhibits rich scattering and its variation can be tracked. However these predictions are based on unrealistic assumptions in the time varying channel model and how it can be tracked at receiver and as well as transmitter [15].

5.2 Mutual Information and Shannon Capacity

Channel capacity was established by Claude Shannon in 1940s, by using the mathematical theory of communication. The capacity of a channel is denoted by C. The channel capacity C is the maximum rate at which reliable communication can be performed, without any constraints on transmitter and receiver complexity. Shannon showed that for any rate $R < C$, there exist rate R channel codes with arbitrarily small block error probabilities. Thus, for any rate $R < C$ and any desired non-zero probability of error p_e, there exists a rate R code that achieves p_e. The code may have a very long block length and encoding and decoding complexity may also be extremely large. The required block length may increase as the desired p_e is decreased or the rate R is increased towards C. Shannon showed that code operating at rates $R > C$ cannot achieve an arbitrarily small error rate. So the error probability of a code operating at a rate above capacity is bounded away from zero. Therefore, the Shannon channel capacity is truly the fundamental limit to communication.

5.3 Mathematical Definition:

Shannon described that capacity of the channel is defined to be the maximum rate at which reliable communication is possible. It can be simply characterized in terms of mutual information between the input and the output of the channel. The basic channel model consists of a random variable input X, and random variable output Y. The model is generally characterized by the conditional distribution of Y given X. The mutual information of a single user channel is defined as:

$$I(x;y) = \int_{s_x, s_y} f(x,y) \log\left(\frac{f(x,y)}{f(x) f(y)} \right) dxdy$$

Where the integral is taken over the support S_x, S_y of the random variables X and Y, respectively. The $f(x)$, $f(y)$ and $f(x,y)$ denote the probability distribution functions of the random variables. In this expression the log function is typically with respect to base 2 and the units of mutual information are bits per channel use [15].

Shannon proved that the channel capacity of most channels is equal to the mutual information of the channel maximized over all possible input distributions.

$$C = \max_{f(x)} I(X;Y) = \max_{f(x)} \int_{s_x, s_y} f(x,y) \log\left(\frac{f(x,y)}{f(x) f(y)} \right)$$

For time invariant Additive White Gaussian Noise (AWGN) channel with bandwidth B and received SNR γ the maximizing input distribution is Gaussian and gives the result of channel capacity:

$$C = B \log_2 (1+\gamma) bps$$

5.4 MIMO System:

MIMO system transmits two or more data streams in the same channel. The data streams are sent at the same time. MIMO System are also used to obtain the goal of evaluating the capacity of a system using N transmit and M receive antennas. In case of N parallel channels, basically the N Single Input Single Output (SISO) channels operating in parallel**.**

5.4.1 Parallel Channels:

The parallel channels support AWGN with a noise level of σ^2.The received data (b) from input data (a) over N channels is modeled as

$$\mathbf{b} = \mathbf{a} + \mathbf{n}$$

$$\mathrm{E}\{\boldsymbol{n}\boldsymbol{n}^H\} = \sigma^2 \boldsymbol{I}_{\boldsymbol{N}}$$

The energy of the transmitter is denoted by E_s which is allocated across the N channels. The capacity of the N channels is as follows:

$$C = \max_{\{E_n\} \sum_{n=1}^{N} E_n \le E_s, E_n \ge 0} \sum_{n=1}^{N} \log_2 \left(1 + \frac{E_n |h_n|^2}{\sigma_n^2} \right)$$

where E_n is the energy of the nth channels and h_n is the nth fading channels.

5.4.2 Water Filling Algorithm:

The optimal power allocation scheme does not provide all the power to the best channel, because the $\log_2(1+\rho)$ expression for capacity. The capacity grows only as $\log_2$ at high SNR and linearly at low SNR. Applying some power to weaker channels, can actually increase overall capacity. The optimal scheme is also known as water filling [12].

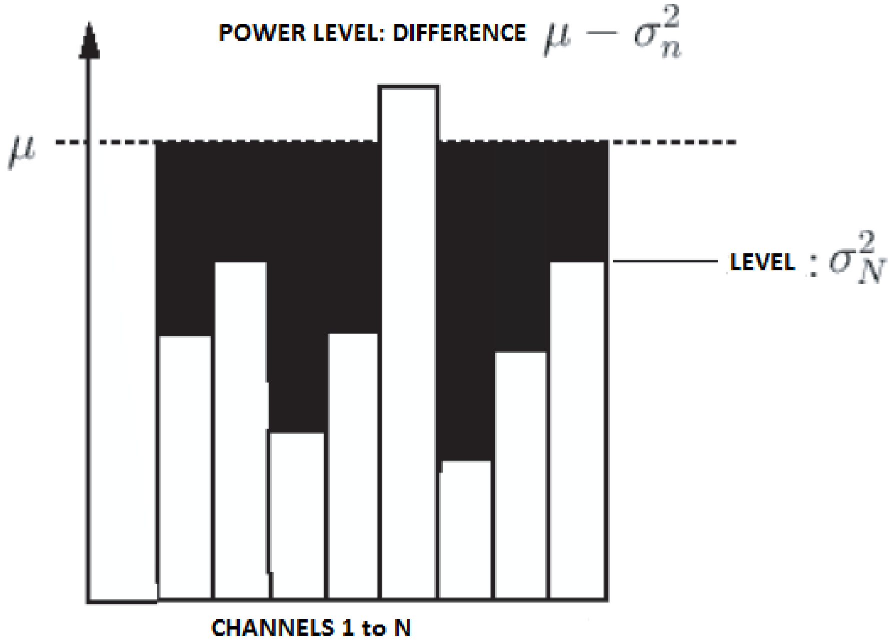

Figure 5.1: Water filling [12]

In the figure 5.1, σ_n^2 refer to the effective noise power, which at each instant is described as $\frac{\sigma^2}{|h_n|^2}$. Waterfilling measure the allocated energy that is on each channel. In channels with lower noise power, more energy will be allocated. In channels with large noise power, the energy allocated is low. Some channels are so weak that the effective noise power becomes very large. Water filling describes that transmitting any information on these channels is a waste of energy. The sum of the allocated energy and the effective noise power $\sigma_n^2 = \sigma^2 / |h_n^2|$ is a constant [12]. The water level is denoted by μ. Finally, if the channels are all equal with σ_n^2 constant, the water filling leads to an equal energy distribution. To find the water level, μ, is used as iterative process.

The capacity on using the waterfilling approach is

$$C = \sum_{n=1}^{N} \log_2 \left(1 + \frac{E_n |h_n|^2}{\sigma^2} \right)$$

If one could focus on the times that the channel is in a "good" condition one could get enormous gains in capacity. This may not always be possible. However, thinking of a multiuser situation, if the channel to each user is changing with time, it is likely that at any time instant, one user has a good channel. By transmitting energy on that channel, overall capacity can be achieved in a multiuser situation. This is a new form of diversity called "opportunistic beamforming".

Finally, if the channel characteristic is not available at the transmitter, clearly the best distribution scheme is to spread the energy equally between all transmitters, i.e. $E_n = E_s / N$ and

$$C = \sum_{n=1}^{N} \log_2 \left(1 + \frac{E_s}{N\sigma^2} \right)$$

Since the log function increases significantly slower than the linear N term, the overall capacity is significantly larger than that for the SISO case.

5.5 Capacity of MIMO System:

MIMO system consists of multiple transmit and receive antennas interconnected with multiple transmission paths. MIMO increases the capacity of system by utilizing multiple antennas both at transmitter and receiver without increasing the bandwidth.

In the situation where the channel is known at both transmitter (Tx) and receiver (Rx) and is used to compute the optimum weight, the power gain in the *k*th subchannel is given by the *k*th eigenvalue, i.e., the SNR for the *k*th subchannel equals

$$\gamma_{k} = \lambda_k \frac{P_k}{\sigma_N^2}$$

Where P_k is the power assigned to the kth subchannel, λ_k is the kth eigenvalue and σ_N^2 is the noise power [20]. For simplicity, it is assumed that σ_N^2 = 1. According to Shannon, the maximum capacity of *K* parallel subchannels equals [18].

$$C = \sum_{k=1}^{K} log_2(1+ \gamma_k)$$

$$= \sum_{k=1}^{K} log_2(1+ \lambda_k \frac{P_k}{M})$$

where M is the number of symbols and mean SNR is defined as

$$SNR = \frac{\boldsymbol{E}[P_{Rx}]}{\sigma_N^2} = \frac{\boldsymbol{E}[P_{Tx}]}{\sigma_N^2}$$

Given the set of eigenvalues $\{\lambda_k\}$, the power P_k allocated to each subchannel k is determined to maximize the capacity by using Gallager's waterfilling theorem [18] such that each subchannel is filled up to a common level D, i.e.

$$\frac{1}{\lambda_1} + P_1 = \cdots = \frac{1}{\lambda_k} + P_k = \cdots = D$$

with a constraint on the total Tx power such that

$$\sum_{k=1}^{K} P_k = P_{Tx}$$

where P_{Tx} is the total transmitted power. This means that the subchannel with the highest gain is allocated with the largest amount of power [19]. In the case where $1/\lambda_k > D$ then P_k= 0.

When the uniform power allocation scheme is employed, the power P_k is adjusted according to

$$P_1 = \cdots = P_k$$

Thus, in the situation where the channel is unknown, the uniform distribution of the power is applicable over the antennas [18] so that the power should be equally distributed between the N elements of the array at the Tx, i.e.,

$$P_n = \frac{P_{Tx}}{N}, \quad \forall\ n = 1...N.$$

5.6 Capacity Analysis:

The capacity of MIMO system is given as follows

$$C = \sum_{k=1}^{K} log_2(1+\lambda_k \frac{P_k}{M})$$

By implementing the above equation using matlab, following result is obtained.

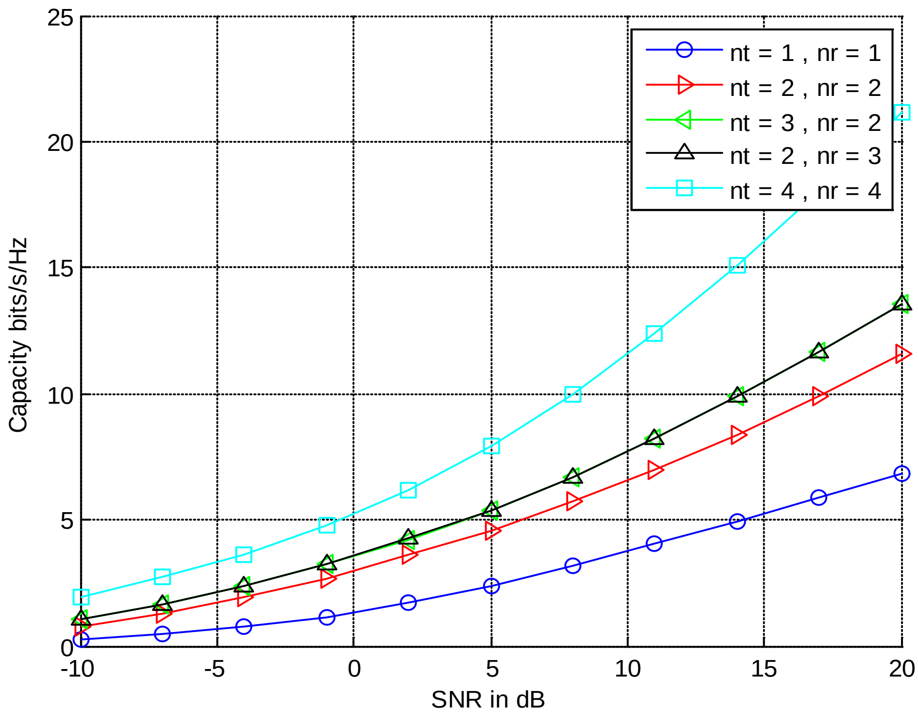

Figure 5.2: Capacity Analysis of MIMO System

Figure 5.2 shows, an analysis of the capacity of the system having multiple transmitters and receivers. The capacity of a MIMO system has been plotted against SNR *in* dB. This provides a fundamental limit on the data throughput in MIMO systems. From the Fig 5.2, it is clear that with increase in the number of antennas at the both sides capacity increases linearly i.e. with *nt=4* and *nr=4,* we have achieved highest capacity in MIMO systems. It is also worth mentioning that when we have *nt=2* and *nr=3,* the result is same with *nt=3* and *nr=2,* which shows that on increasing number of antennas at either side of the MIMO system will have same effect in rising the capacity.

CHAPTER 6: System Model and simulation Results

System Model

The system model used for the simulation is shown in figure below, and is described as follows.

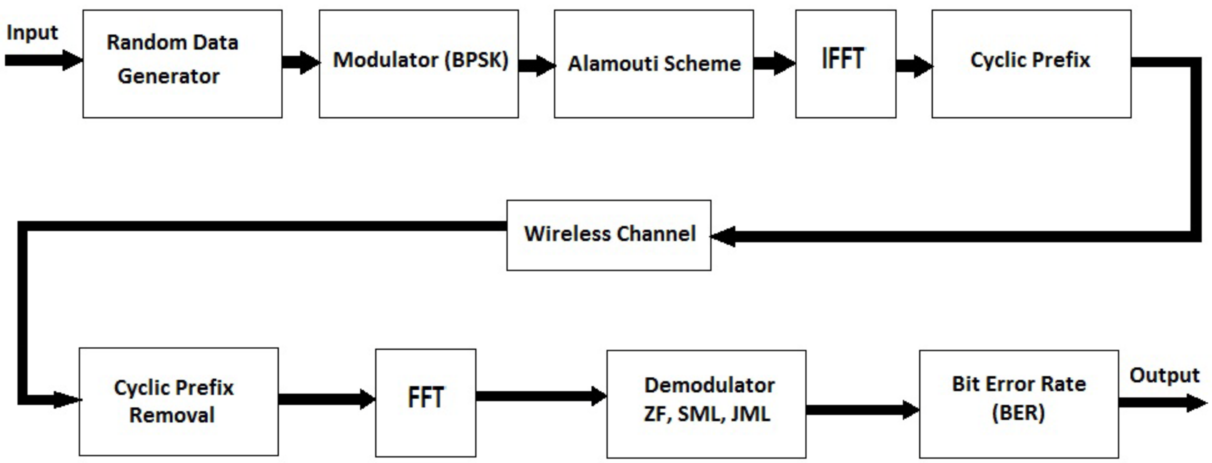

Figure 6.1: Block Diagrame (System Model)

Transmitter module

The input data is generated in the form of random numbers. These numbers are in the form of ones and zeros, i.e (110000111001).The generated data is then passed to modulator. The modulation scheme BPSK is used to map the bits into symbols. Then the data is sent to the Alamouti scheme generator.

After successful data modulation Inverse Fast Fourier Transform was applied on the modulated data.

The t-th time domain sample at the n-th subcarrier at the output of IFFT is given by following equation.

$$x_t = \sum_{n=0}^{N-1} x_n \exp\left\{ j\frac{2\pi tn}{N} \right\} \qquad 0 \le t \le N-1$$

where N is the number of subcarriers and X_n is the data symbol. As a result OFDM symbol λt is generated. Cyclic prefix (CP) is added to the data once data is converted into time domain. The addition of CP reduces the multipath propagation and provides a resistance against ISI. When data is sent from the transmitter toward the receiver side, it travels through a wireless network. The wireless network faces environmental challenges once the signal is on air on its way towards, the receiver side. Whenever a deployment of a wireless communication system is considered, the first thing is to design a channel model. In order to design the channel model following thing must be kept in mind.

- Path loss
- Co-channel interference
- Fading characteristics
- Doppler Spread

a) Path Loss

When an electromagnetic wave propagates through a free space, the power density of the wave decreases which results in path loss or signal attenuation.There are some factors which affect path loss such as different environments, propagation medium, distance between the transmitter and the receiver, location and height of antennas.

b) Fading Characteristics

In multipath fading, the received signal experiences variation in its amplitude, phase and angle in a multipath propagation environment. Small scale fading has also been addressed in this channel model due to fixed deployment of transmit and receive antenna. When there is no line of sight signal component and there are multiple reflective paths then small scale fading is called Rayleigh fading. When there is a line of sight component along with the multiple reflective paths then small scale fading is described by Rician pdf.

c) Co-channel interference

Co-channel interference is one of the major obstacles, which occurs during the wireless communication. It occurs when the same frequency from two different transmitters reaches the same receiver simultaneously, but in case of one transmitter and one receiver co-channel interference does not affect.

d) Doppler Spread

Doppler spread is basically the movement of the wireless communicating devices or due to the relative motion of the objects in the environment. There is difference between the Doppler spectrum of fixed and mobile channel. In case of fixed wireless channel, the Doppler PSD of the scatter component is mainly distributed around f=0Hz.

Receiver Module

The receiver process starts with the removal of the cyclic prefix that was added on the transmitted signal as described on transmitter side. After cyclic prefix removal, the data was converted from frequency domain to time domain by using FFT. When data conversion is completed the data is passed to De-modulator. The data is modulated according to the modulation scheme which is implemented during the transmitter side.

In this chapter, system model has been analyzed to see the performance of BER of BPSK in OFDM–SFBC WiMAX system over the Rayleigh fading channel. Since 128 sub carriers of OFDM has been taken along with 12 multipath links. The sampling frequency is considered to be 800,000 samples/sec. Similar results were implemented by changing the decoding algorithm. Three famous decoding algorithms, i.e. conventional Simple maximum likelihood, Joint maximum likelihood and zero forcing equalizer have been implemented.

Zero Forcing Equalizer:

Zero forcing equalizer refers to linear equalization algorithm used in communication system and inverts the frequency response of the channel. If the channel response for a particular channel is H(S) then the input signal is multiplied by the reciprocal of this. This is used to remove the effect of channel from the received signal ISI. The zero-forcing equalizer removes all ISI. It is ideal when the channel is noiseless. When the channel is noisy, the zero forcing equalizer will amplify the noise greatly at some frequencies.

Joint Maximum Likelihood:

Joint Maximum Likelihood (JML) scheme was developed for more precise channel estimator based on the assumption of exponential multipath decay. Theoretically, it improves the estimation performance of channel gains and multipath delays compared with traditional maximum likelihood estimator.

Results:

The BER performance of BPSK SFBC-OFDM system has been analyzed. The simulation has been performed in MATLAB. The performance comparison has been done with 1Tx and 1Rx antenna and 2Tx and 1Rx antenna. From the figure 6.2 it is clear that with increase from one to two antennas at the transmitting side the BER performance is improved. It can also be seen that with increase in SNR the performance gain of two antennas is increasing. Also it is clear that by implementing conventional ZF, SML and JML decoding algorithms BER performance is increased significantly in the high SNR regime.

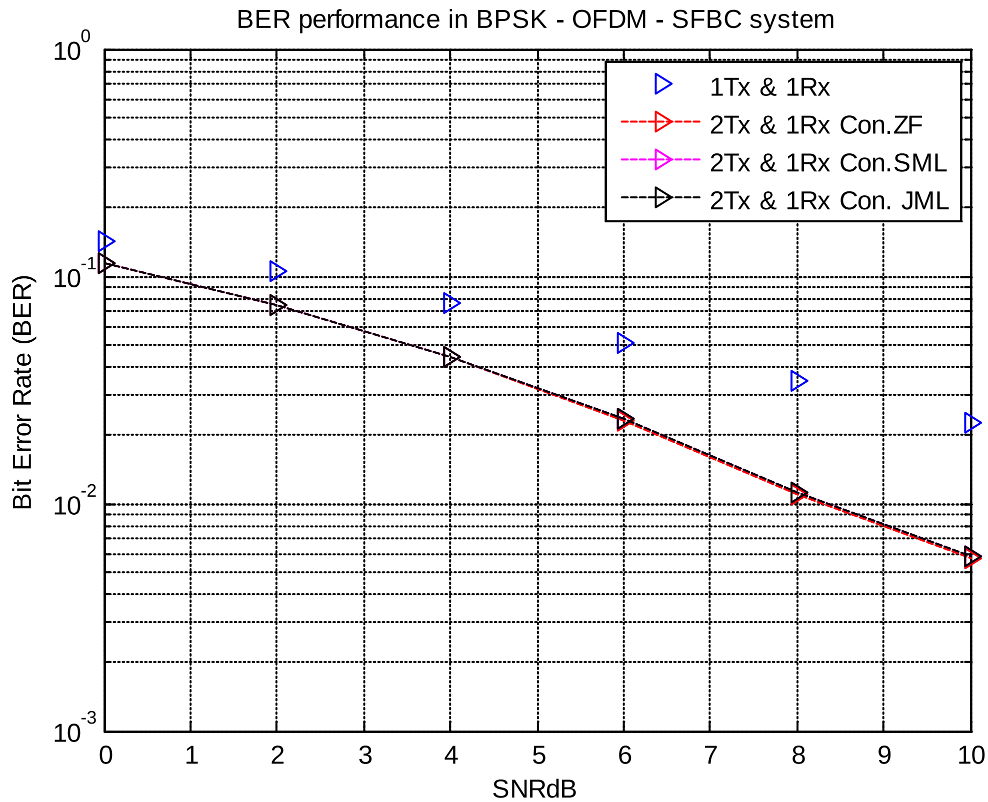

Figure 6.2: BER performance in BPSK, OFDM-SFBC system

CONCLUSION

The research work shows, that modern wireless systems requires high data rate. The MIMO techniques are physical layer based and essential part of the IEEE 802.16e-2005. The simulation results of Alamouti STBC with two transmitting and one receiving antenna achieves better diversity in terms of BER as with one transmitting and one receiving antenna From the simulation results, it is clear, that theoretical and simulation result matches closely with each other. Moreover the results of MIMO capacity shows that increase in number of antennas at the both side's capacity increases linearly. Figure 5.2 shows that, when *nt=4* and *nr=4* we achieve the highest capacity as compared with nt=2 and nr=3 and nt=3 and nr=2 respectively in MIMO system. The results of *nt=2* and *nr=3* is the same as *nt=3* and *nr=2*.Increasing the number of antennas at either side of MIMO system will have the same effect of raising the capacity. It is clear from the figure 6.2 with two transmitting and one receiving antenna and applying conventional ZF, SML, and JML decoding algorithm, the diversity of two antennas improved at lower SNR.

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