PERFORMANCE ENHANCEMENT ANALYSIS OF MODERN WIRELESS NETWORKS USING MIMO TECHNIQUE

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PERFORMANCE ENHANCEMENT ANALYSIS OF MODERN WIRELESS NETWORKS USING MIMO TECHNIQUE

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Title of the Thesis: **Performance Enhancement Analysis of Modern Wireless Networks Using MIMO Technique.**

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I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science.

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This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

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ABSTRACT

PERFORMANCE ENHANCEMENT ANALYSIS OF MODERN WIRELESS NETWORKS USING MIMO TECHNIQUE

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The systems that utilizing multiple transmit and multiple receive antennas are commonly known as Multiple-Input Multiple-Output (MIMO) systems. This wireless networking technology can greatly improves wireless communication system by exploiting the multipath propagation constructively. These paths can be exploited to provide redundancy of transmitted data, thus improving the reliability of transmission (diversity gain) or increasing the number of simultaneously transmitted data streams and increasing the capacity of the wireless system (multiplexing gain) and decreasing bit error rate. This thesis introduces a comparative studies that determines the diversity and channel capacity enhancements, resulting from using our proposed MIMO wireless model. The antenna configurations for this model uses new microstrip bandpass filter to prevent the lower image sideband as far as possible for these antennas.These enhancements has been analysed in term of Bit Error Rate (BER) and bit rate of data transmission for the diversity and capacity enhancements, respectively.

Keywords: Wireless Computer Networks, MIMO, Rayleigh Fading Channel, Diversity Systems, BER.

ÖZ

MIMOYÖNTEMİ İLEMODERNKABLOSUZ AĞLARINPERFORMANSARTTIRILMASI ANALİZİ

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Birden fazla verici ve birden fazla kullanan antenlersistemleri genellikle Çoklu Giriş Çoklu-Çıkış (MIMO) sistemler olarak bilinir. Bu kablosuz ağ teknolojisi büyük ölçüde yapıcıyollu yayılma istismar ederek kablosuz iletişim sistemi geliştirir. Bu yollar, böylece iletim (çeşitlilik kazancı)güvenilirliğini artırmak veya aynı anda iletilen veri akışlarınınsayısını artırarak vekablosuz sistem (çoğullama kazancı)kapasitesinin artırılması ve bit hata oranını azaltarak, iletilen veri artıklık sağlamak için kullanılabilir. Bu tez bizim önerilen MIMO kablosuz modeli kullanılarak elde edilen,çeşitlilik ve kanal kapasitesi geliştirmeleri belirleyen karşılaştırmalı çalışmalar tanıttı. Bu model içinanten konfigürasyonları bu antennas.Bunlar analiz edilmiş ve için mümkün olduğunca düşük görüntü yan bandı önlemek için yeni mikro bant geçiren filtre kullanır kapasite geliştirmeleri, sırasıyla.

Anahtar Kelimeler: KablosuzBilgisayar Sistemi, MIMO, RayleighZaiyflanmek Kanal, ÇeşitlilikSistemleri, BER.

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LIST OF ABBREVIATIONS

2G	Second Generation
3G	Third Generation
4G	Fourth Generation
AMPS	Advanced Mobile Phone Service
AWGN	Additive White Gaussian Noise
BEP	Bit Error Probability
BER	Bit Error Rate
BLAST	Bell Labs Layered Space -Time
BPSK	Binary Phase Shift Keying
CDMA	Code Division Multiple Access
CSI	Channel State Information
D-AMPS	Digital AMPS
dB	Decibels
D-BLAST	Diagonal-Bell Labs Layered Space-Time
DOA	Direction-of-Arrival
DSL	Digital Subscriber Line
EGC	Equal Gain Combining
EVD	Eigen Value Decomposition
FDMA	Frequency Division Multiple Access
GSM	Global System for Mobile Communication
I.I.D.	Independent and Identically Distributed
IEEE	Institute of Electrical and Electronic Engineers
IMT-2000	International Mobile Communications-2000
IP	Internet Protocol
ISI	Inter Symbol Interference
ITU	International Telecommunication Union

LOS	Line of Sight
MIMO	Multiple-Input Multiple-Output
MISO	Multiple-Input Single-Output
MMSE	Minimum Mean Square Error
MRC	Maximal Ratio Combining
MRT	Maximal Ratio Transmission
MS	Mobile Station
OFDM	Orthogonal Frequency Division Multiplexing
PDF	Probability Density Function
QoS	Quality of Service
SC	Selection Combining
SIMO	Single-Input Multiple-Output
SISO	Single-Input Single -Output
SM	Spatial Multiplexing
SMS	Short Message Service
SNR	Signal to Noise Ratio
SOS	Sum of Sinusoidal
STBC	Space -Time Block Code
STC	Space -Time Coding
SVD	Singular Value Decomposition
TDMA	Time Division Multiple Access
UMTS	Universal Mobile Telecommunication System
V-BLAST	Vertical Bell Labs layered Space -Time
WCDMA	Wideband Code Division Multiple Access
WF	Water-Filling
WLAN	Wireless Local Area Networks
WMAN	Wireless Metropolitan Area Networks
ZF	Zero Forcing

LIST OF SYMBOLS

Symbol	Definition
B_C	Channel coherence bandwidth
B_W	Bandwidth
T_s	Symbol duration
T_C	Coherence time of the channel
v	Speed of mobile
c	Speed of light
C	Channel capacity
f_s	Sampling frequency
f_c	Carrier frequency
f_d	Doppler frequency
N_o	Noise power spectral density
E_b/N_o	Bit energy to noise ratio
γ_b	Effective bit energy to noise ratio
K	*Ricean K-factor* : power ratio between line-of-sight and scattered components
$I_0(\cdot)$	Zero order modified Bessel function of the first kind
M	Number of paths for fading channel
M_R	The number of receive antennas
M_T	The number of transmit antennas
$erfc(\cdot)$	Complementary error function
P_b	Bit error probability
h	Vector of Channel Coefficients
H	A MIMO flat-fading channel
I_m	$m \times m$ Identity matrix
τmax	Maximum Delay Spread of Channel
λ	Wavelength
$(\cdot)^*$	Conjugate of a matrix
$(\cdot)^T$	Transpose of a matrix
$(\cdot)^H$	Conjugate transpose (Hermitian) of a matrix
$(\cdot)^P$	Pseudo-inverse of a matrix
$\lambda(\cdot)$	Eigen values of matrix
$\|a\|$	Absolute value of scalar a
$\|\|\cdot\|\|$	Norm. of a vector or a matrix
$\|\|\cdot\|\|^2$	Norm. of matrix(sum of squared magnitudes of elements)
$diag(\cdot)$	Elements placed along the diagonal of a matrix
$\log_2(\cdot)$	Base 2 logarithm
$\tilde{x}$	Estimate of signal x

CHAPTER 1

1.1. Background

Wireless communications is a quickly increasing section of the communications industry, with the potential to supply efficient and fast information exchange among portable devices situated anywhere in the world. It has been the topic of study since 1960s, the tremendous development of wireless communication technology is due to a confluence of several factors. First, the demand of wireless connectivity is explosively increased. Second, the spectacular growth of VISL technology has facilitated small-area and low-power accomplishment of complicated signal processing algorism and coding algorism. Third, second generation wireless communication standards, like CDMA, GSM, TDMA, make it possible to transmit voice and low volume digital data. Furthermore, third generation of wireless communications can offer users more advanced service that achieves greater capacity through improved spectral efficiency [1].

Prospective purposes activated by this technology consist of multimedia Internet-enabled cell phones, smart homes and appliances, automated highway systems, video teleconferencing and distance learning, and autonomous sensor networks. However, there are two significant technical challenges in supporting these applications: first is the occurrence of fading: the time deviation of the channel because of small-scale effect of multi-path fading, in addition to large-scale effect as in pass loss by distance attenuation and shadowing by blockages. Second, since wireless sender and receiver need to be in touch over air, there is momentous interference between them. Overall the challenges are mostly because of restricted accessibility of radio frequency spectrum and a complex time-varying wireless environment (fading and multipath).

In nowadays, the key goal in wireless communication is to increase data rate and improve transmission reliability. In other words, because of the growing request for superior data rates, enhanced quality of service, less dropped calls, greater network capacity and user coverage calls for innovative techniques that improve spectral efficiency and channel reliability, more technologies in wireless communication are introduced, like MIMO techniques.

1.2. The Literature Survey

In 1993, A. Wittneben [2] proposed one of the earliest generation of spatial transmit diversity, known as delay diversity technique, where a signal is sent from one antenna, then delayed one time slot, and sent from the other antenna. Signal processing is placed at the receiver to decode the superposition of the creative and time-delayed signals.

In 1998, S. M. Alamouti [3] developed diversity scheme using two transmit antennas and one receive antenna, the scheme gives the same diversity order as a maximal - ratio combining (MRC) at the receiver side, with one transmit antenna, and dual antennas. There is no need for any bandwidth expansion in this new scheme, all feedbacks from the receive to the transmit antennas, and its degree of evaluation complication is same as MRC.

In 2002, K. Kalliola [4] presented a new system for radio links measurements including space and polarization dimensions to analyze the radio propagation in wideband mobile communication systems. He verified the advantage of the developed measurement systems by achieving channel measurements at 2 GHz and analyzing the experimental data. He also studied the spatial channels in mobile and base stations, as well as the double-directional channel that completely characterizes the propagation between two antennas.

In 2004, A. H. Al-Hassan [5] studied the data transmission over the mobile radio channel. He introduced a software radio receiver design and simulation, then he attempted to develop this software over the mobile radio channel. He also used many techniques to improve the performance of the data transmission like equalization and diversity. Selection Switching Combining (SSC) diversity technique was used in his simulation test.

In 2005, S. H. Krishnamurthy [6] studied on the electromagnetic (EM) waves properties of antennas and the scattering environment in terms of dependent capacity, the limitation on performance parameter of estimation algorithms at the receiver side and the basic limits on the capacity that volume-limited multiple-antenna systems may be achieved. He used the theoretical methods to derive a channel propagation scheme for multi antennas in the multi fading channel.

In 2006, A. Wilzeck ,etal, [7] proposed MIMO test-bed, which employs a 2-antenna transmitter and a 4-antenna receiver in”offline” mode, where pre-processed data is sent over-air and logged for later processing. The receiver permits 512 MBytes of memory per receive antenna and a sampling frequency of a maximum of 100 MHz, which results in a logging time of 2.68 s with 14-bit resolution. The testbed is based on Sundance’s modular digital signal processing platform and plug-in Radio Frequency (RF) components manufactured by Mini-Circuits.Also, bandpass filters at 2.4 GHz resonant frequency have been used to prevent image bands and enhace the operation of adopted system.

In 2008, D. Q. Truing, N. Prayongpun, and K. Roof [8] considered new two models of antenna selection in Rayleigh channels such the Maximal Ratio Transmission (MRT) and Orthogonal Space-Time Block Code technique (OSTBC). The simulated results show that, the proposed antenna selection scheme may get a performance near by the optimum selection with low level of complexity.

In 2009, A. Lozano, and N. Jindal [9] provided principals on the tradeoff property between transmit antenna diversity and spatial multiplexing. They showed the difference between the techniques of transmission that using full spatial multiplexing and MIMO communication techniques for diversity purposes.

In 2011, P. Bhatnagar,et.al [10], submitted an improvement for OFDM system employing Space Time Block Coding(STBC) and MIMO techniques over Rayleigh channels using BPSK and QPSK digital modulation techniques to overcome subchannel interference. Results showed that SNR increases with decrease in bit error rate magnitudes while it is decremented by increasing throughput of the system.

In 2013, S.P.Premnath, et al [11], proposed a recent rapid algorithm for antenna collection in wireless MIMO systems. This scheme realizes same output capacity as the best possible selection method and the fast algorithm at a much less computational rate. The adopted straightforward G-circles method decreases the complexity considerably with realistic performance loss. It can also be efficiently organized in correlation matrix-based antenna selections.

1.3. Aim of the Work

The aim of this thesis can be summarized by the following:

1. Design a developed MIMO wireless model, which can be used via Rielagh channel with satisfactory bit rate and bit error rate .Also new bandpass filter with high performance to filter out the image bands (harmonics) as good as possible has been proposed to be used with transmit and receive antennas of MIMO wireless channel model.

2. To improve the performance of wireless radio channel by exploiting spatial diversity, through the use of multiple input multiple output (MIMO) antennas.

3. Study and analyze the improvement of capacity gained from using MIMO systems.

1.4. Thesis Outline

This thesis is arranged in five chaptersas follows:

Chapter one presents an introduction with literature survey and aim of this thesis.

Chapter two gives the overview of wireless networks and wireless fading channel characteristicswith different types .

Chapter three begins with a brief description of MIMO communication system. Then, methods of transmission from multiple antennas are introduced. Later, STBC diversity technique is introduced for MIMO system. Finally, capacity enhancements from using multiple antennas and microstrip bandpass filters have been analyzed.

Chapter four presents the simulation results and discussions using the developed design of MIMO wireless model, which is used in all the simulations and measurements.

Chapter five includes the conclusions and suggestions for future work.

CHAPTER 2

WIRELESS NETWORKS AND CHANNEL FADING

2.1. Introduction

There are several places where wireless computer networks are used. The most common applications include networks that reside within homes or office buildings or cellular phone networks. There are many reasons people use wireless networks rather than, or in addition to wired networks [12]. Wireless networks are easier to install since no wires need to be placed. Due to the ease of installation, the cost of a wireless network is less than the cost of a wired network. Wireless networks are also much easier to expand due to the fact that additional wire does not need to be installed. The main advantage of wireless networks is the ability of the user to move around while he or she is connected to the network.

There are two main categories of wireless networks that are presently in use. The first type is the infrastructure network. This type of network is also referred to as a cellular network. The main features of this type of network include the fact that all communication is controlled by a base station, the area where that the network covers is divided into regions or cells, and that data can be sent from a network controlled by one base station to a network controlled by another base station using roaming techniques. **Figure 1** depicts a typical infrastructure network.

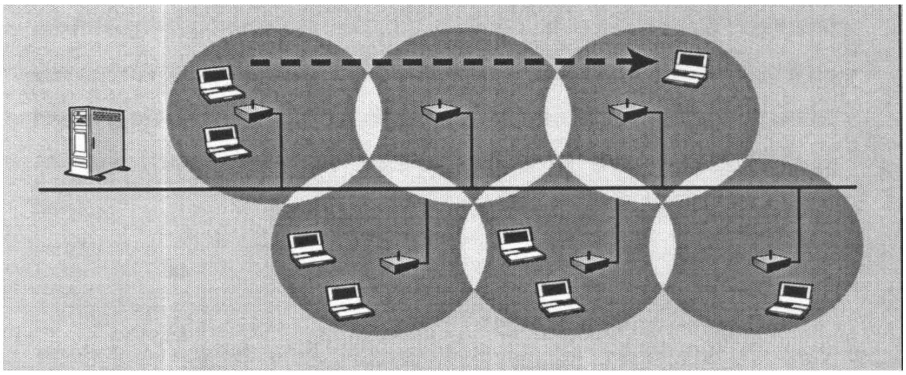


Figure 1 Infrastructure Network [12]

The second type of wireless network is the ad hoc network. With this type of network, there is no base station controlling the communication and no specific structure.**Figure 2** depicts a typical ad hoc network. The main goals of this type of network include multiple access and random access. Multiple access means that there can be many communication links existing at the same time. Random access means that a new device or node can be added to the network at any time.

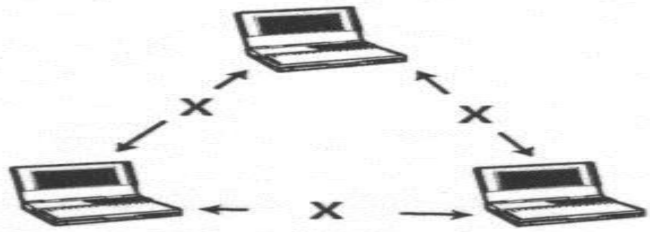


Figure 2 Ad Hoc Network [12]

2.2. Generations Cellular Wireless Networks

1. First Generation

The first generation cellular wireless networks used analog technologies to communicate. This type of system is used for cordless telephones and analog cellular telephones [13]. All transactions use FM modulation and go through a base station. **Figure 2** illustrates a typical communication link within a first generation cellular wireless network. The user's transmit data went through a base station to the mobile switching center (MSC) where the data was sent to another base station and to another user. All the network operations take place in the MSC.

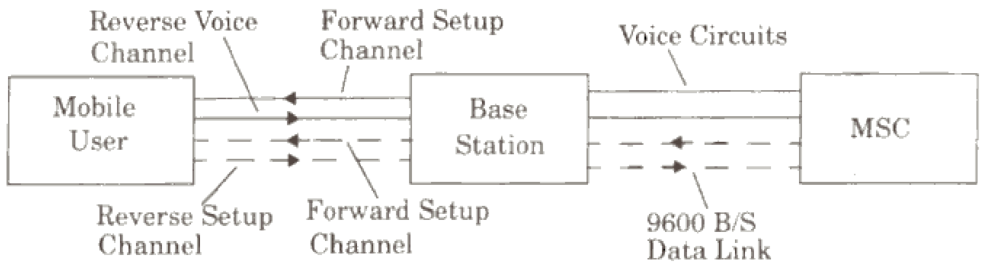


Figure 3 Communication in a First Generation Cellular Wireless Network [13]

First generation systems were capable of transmitting analog speech and data. Transmission within these systems was inefficient and used a very low data rate. For this reason, few data transmissions took place. First generation wireless systems use the 900MHz frequency spectrum, use analog frequency division multiple access, and have a data rate of 2.4kilobits/second [14].

2. Second Generation

Second generation cellular wireless networks use digital technologies to communicate. As with first generation systems, transactions within second generation systems also go through a base station. Where second generation systems differ from first generation systems is that many base stations are connected to base station controllers (BSCs) and the BSCs are connected to the MSC, rather than having the base stations connect to the MSC. By introducing the BSCs, much of the processing the first generation MSC was responsible for can be transferred to the BSCs. A standardized communication between the BSC and MSC was established to allow components produced by different manufacturers in the same system.**Figure3** illustrates the configuration of a typical communication link within a second generation wireless network [13].

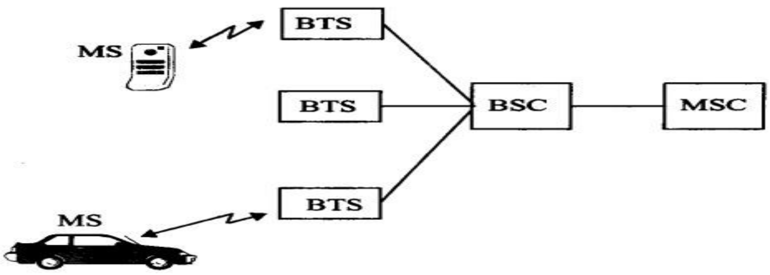


Figure 4 Communication in a Second Generation Wireless Network[13]

Second generation systems are not only used for voice, they are also used for data transmissions. Second generation systems can perform high rate data transfers and facsimiles. These systems use the 1800MHz frequency spectrum, use time division multiple access, and have a data rate of 9.6kilobits/second.

3. Third Generation

Third generation cellular wireless networks are in the final developmental stages and entering the usage stage. The goal of third generation systems is to provide standards that can be used for a wide variety of wireless applications. Third generations systems will also allow universal access throughout the entire world. These systems also aim to remove the difference between cordless telephones and cellular telephones. The goal is to have a universal personal communicator that can communicate using voice, data, and video information [13].

Third generation systems fell short of the original goal. There is not one system that can be used worldwide. There were very data rates expected for third generation systems, but the high data rates were not achieved. Third generation systems operate in the 2GHz frequency band, use code division multiple access, and have a data rate of 64kilobites/second.

4. Fourth Generation

Fourth generation cellular wireless networks are in the early developmental. The fourth generation systems will use the 40GHz and 60GHz frequency bands and will use orthogonal frequency division multiplexing. The actual data rate is unknown, but the target data rate is 100megabits/second.

2.3 Multipath Propagation Mechanisms

The mechanisms behind electromagnetic wave propagation through the mobile channel are wide and varied, however, they can be generally classified as reflection, diffraction and scattering [15,16]. They can be described as follows:

1. **Reflection:** This occurs when electromagnetic waves bounce off objects whose dimensions are huge in relation to the wavelength of the propagating wave. They typically happen from the surface of the earth and buildings and walls as explained in **Figure 5-a**. When the surface of the object is flat, the angle of reflection is similar to the angle of incidence.

2. **Diffraction:** Diffraction occurs when the electromagnetic signal strikes an edge or corner of a structure that is large in terms of wavelength, as in building places, making energy to arrive at shadowed areas that have no LOS factor from the transmitter as shown in **Figure 5-b**. The received power for a upright polarized wave diffracted over encircling hills is physically more powerful than that diffracted over a knife-edge, but the received power for a horizontal polarization wave over the round hills is less than that over a knife-edge.

3. **Scattering:** Scattering arises when the wave goes through or returned from an object with dimensions less significant than the wavelength. If the surface of the scattering object is accidental, the signal energy is scattered in various ways as shown in **Figure 5-c**. Rough surfaces, tiny objects, or other indiscretions in the channel originate scattering.

All of these phenomena occur in a typical wireless channel as waves propagate and interact with surrounding objects.

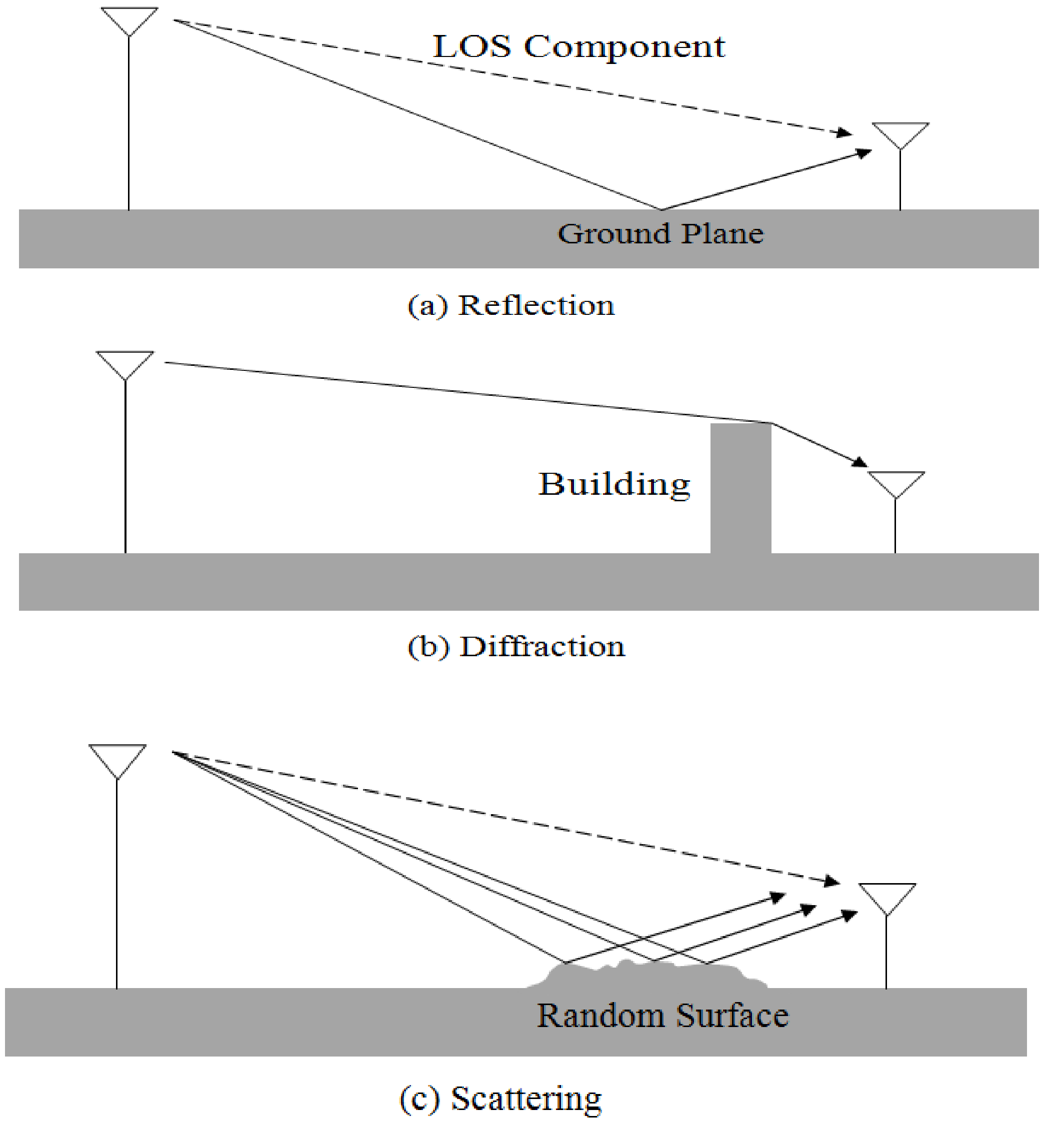


Figure 5 Multipath propagation mechanisms

2.3.1. Large-scale Fading Versus Small-scale Fading

The changed amplitude of the received signal in time and frequency, known as fading. Fading is due to multipath propagation, known as multipath fading (induction), or shadowing disorders affect propagation of radio waves, called shadow fading. Based on what is known causes signal fading, cellular mobile radio (CMR) channel is characterized by either the large or small-scale statistics [17,18].

Large-scale fading is the rate of attenuated signal power, since the movement of a long distance up to thousands of kilometers, and small-scale fading is experienced as asmaal varied amplitude and phase of signal with the rapid fluctuations result in a spatial distance between transmitter and receiver especially in half wave length systems[19,20].

Large-scale and small-scale envelope fading channel models are usually distributed by a Rayleigh distribution and science [20]. In this study, is considered to be only a small scale fading.

2.3.2. Fading Parameters

They classified as follows [20]:

2.3.2.1. Delay Spread and Coherence Bandwidth

When a narrow pulse by a multipath propagation channel, distorted signal of transmitted pulse at various times will get to the receiver, so that the received signal width in the time domain greater than the original sent signal pulse. This is called propagation delay. Often expressed as an excess of the maximum delay time (T_m) which is time span from first and last path recognized from receive side [21].

The maximum additional delay (T_m) is related in the frequency domain to coherence bandwidth which is level of delay spread. Coherence bandwidth,B_{coh} shows how far the signal frequency varying degrees of discoloration. It can be seen thatB_{coh} is related to T_m by [21,22]:

$$B_{coh} \approx \frac{1}{T_m} \tag{2.1}$$

2.3.2.2. Doppler Spread and Coherence Time

For mobile communications case where the mobile receiver travels through the standing wave propagation pattern of the channel, the fading nature of the received signal at the mobile can be quantified by Doppler frequency [20,22]:

$$f_d = f_c \frac{V_{sr}}{C_{lig}} \qquad (2.2)$$

Where, $f_c$is carrier frequency, $V_{sr}$is speed between the transmitter and receiver, $C_{lig}$is the speed of light, θ is the incident angle of signal reception. Note that, Doppler frequency is maximum (f_{max}) when cos(θ) is +1 or −1. Signal getting direction of motion will exhibt a positive Doppler shift, but those reaches the opposite direction of movement will show a negative Doppler shift. Therefore, arriving from different directions for the multipath components of a received signal is relied on Doppler spread which leads to more bandwidth of the signal. This phenomenon is known as Doppler spread, denoted by B_d [20,22].

To describe the channel over varied time, useful property of coherent time, referred as T_{coh} is defined as the channel impulse response duration which is substantially constant. Doppler spread and coherence time are related to each other by following expression [21]:

$$T_{coh} \approx \frac{1}{B_d} \qquad (2.3)$$

2.3.3. Types of Scale Fading of Small Values

The bandwidth and symbol period of signal as well as RMS delay spread, Doppler spread for channel between the different transmission signals will suffer from various fading. The dispersion of time and the dispersion of mobile radio channel frequency mechanism are in four possible different effects, depending on the transmitted signal, the channel, the nature and speed of performance. When multipath delay spread resulting flat fading and frequency selective fading, Doppler shift will lead to fast fading and slow fading. **Figure 6** shows a tree of small scale fading based on multipath time delay spread or Doppler spread [22].

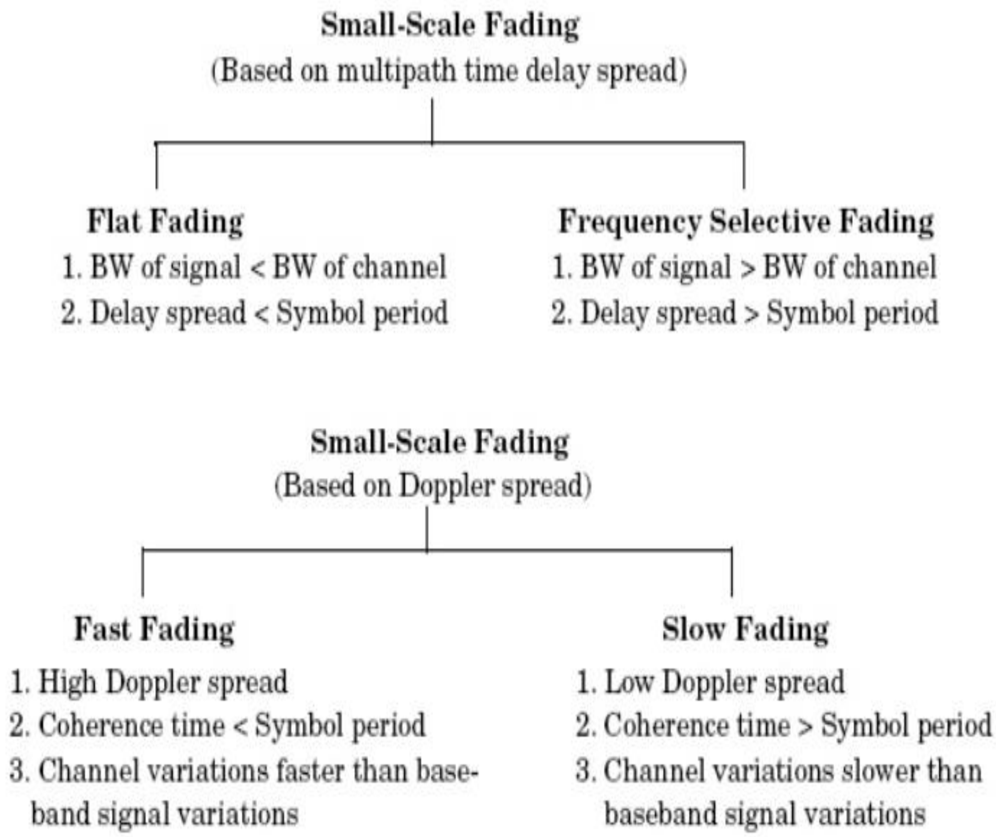


Figure 6 Fading of small scale Tree [22]

2.3.3.1. Frequency non-selective Fading vs. Frequency Selective Fading

If transmitted signal bandwidth (B) is small unlike coherence bandwidth (B_c), so all of the signal frequency components are substantially through the same degree of fading. Then, the channel is divided into flat fading frequencies . Noted that, since (B_c), is inversely proportional to (T_m) for non-selective channel symbol duration, (T_s) is higher than (T_m). So, the delay between different paths relative to the symbol duration is relatively small. It is assumed that there is only one copy of the received signal can gotten. The magnitude of phase and gain for signal coming with (T_m) can be found by superposition of all these copies.

If the signal sent with big bandwidth unlike (B_c), the various frequency components of the signal (which is different by more than (B_c))would suffer different levels of fading. This channel is called as frequency selective. Because of reciprocal relationships, (T_s) is small compared with (T_m). Large delays between different paths may be big values with respect (T_s). Then, multiple copies of the signal could be received [23].

2.3.3.2. Slow Fading Versus Fast Fading

If (T_s) is small (T_{coh}), then the channel is known as slow fading. Slow fading channel, are often modeled in interval time-invariant channels for symbol interval s. If (T_{coh}) close to or less than (T_s), the channel must be called as quick fading[29,30].

When the Doppler spread bigger (B_d) than the bandwidth of the sent signal (B), changing in channel is speedy or speedier than changing in signal. It is known as fast fading.When (B_d)is much smaller than the bandwidth of the sent signal (B), the channel will change slowly to varying signal. This is mostly referred as slow fading [22,24].

2.4.Wireless Channel Distributions

Signal fading means that the hasty varying in delivered signal power over a tiny passing through time interval or space. This happens because in multipath propagation surroundings, the delivered signal by the mobile at every direction in space can be made of a big amount of plane waves having arbitrarily allocated phases, amplitudes, postponements and angles of arrival. These multipath components merge in vectors manner at the receiver antenna. They may merge usefully or damagingly at various positions in space, making the signal power to be different with location. When the elements in a radio channel are predetermined, and channel variations are assumed to be merely owing to the action of the mobile, the signal declining or fading is a simply spatial occurrence. A receiver going at elevated speed can cross via some fades in a small period of time. If the mobile goes at short speed, or is fixed, in that case the receiver will undergo a deep fade for an expanded time interval. Dependable contact can at that time be very complicated due to very low signal-to-noise ratio (SNR) at places of huge fades. The probability density function of the Rayleigh distribution is [16]:

$$p(r) = \begin{cases} \frac{r}{\sigma^2}\exp(-\frac{r^2}{\sigma^2}) & r \geq 0. \\ 0 & otherwise, \end{cases} \qquad (2.4)$$

Where σ^2 is distribution parameter. A plot of the Rayleigh probability density function is explained in **Figure 7**. The Rayleigh distribution is associated with the zero-mean Gaussian distribution in the manner as follows: Assume X_1 and X_Q be two autonomous, similarly distributed, zero-mean Gaussian random variables with variance σ^2 .The minor probability density functions of X_1 and X_Q are evaluated by :

$$f(x) = \frac{1}{\sqrt{2\pi\sigma^2}}\exp(-\frac{x^2}{2\sigma^2}) \qquad , -\infty \langle x \langle \infty . \qquad (2.5)$$

Then the random variable R , defined as :

$$R = \sqrt{X_1^2 + X_Q^2} \qquad (2.6)$$

Is distributed in relation to the Rayleigh probability density function given in Equation (2.5). The detail that the Rayleigh distribution presents a good matching to the measured signal amplitudes in a non-line-of-sight situations can be described as follows. If a signal is sent through a multipath propagation path, the in-phase and quadrature-phase components of the received signal are amounts of many random variables. Since there is no line-of-sight or dominant path, these random variables are around zero-mean. Hence, by the central limit theorem, the in-phase and quadrature-phases components can be approximately as zero mean Gaussian random processes.

The amplitude, at that time, is approximately Rayleigh distributed.

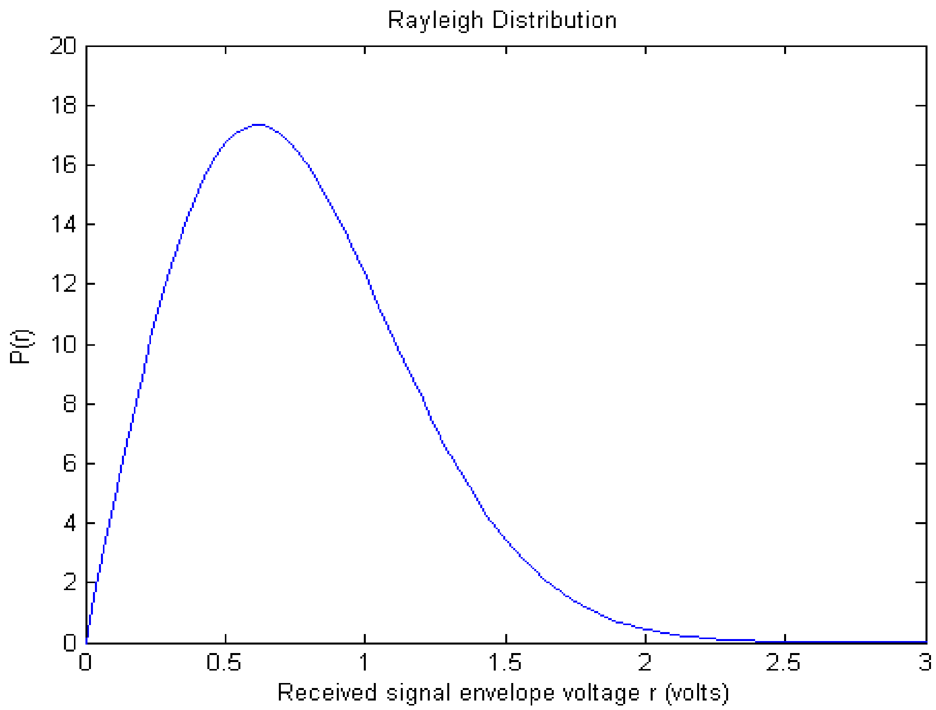


Figure 7 Rayleigh probability density function(pdf).

When line-of-sight paths are found to be in a multipath propagation environment, or when there is a central reflected path, the Ricean distribution is a fine numerical classification of the signal amplitude distribution [15,16]. The Ricean distribution is corresponding to the Gaussian distribution in such way similar to the connection between the Rayleigh and Gaussian distributions. For example, let X_1 and X_Q be independent Gaussian random variables with variance σ^2. Moreover, let that $E[X_1] = \mu$ and $E[X_Q] = 0$. Then the random variable R, defined in Equation 6, is distributed according to the Ricean distribution. Therefore, one can observe that when a dominant path exist in a multipath propagation environment, by the central limit theorem, the signal amplitudes are something like Ricean distributed if the amount of paths is very high. The probability density function of the Ricean distribution can be given by [16]:

$$f(r) = \begin{cases} \frac{r}{\sigma^2} I_0\left(\frac{r\mu}{\sigma^2}\right) \exp\left(-\frac{r^2+\mu^2}{2\sigma^2}\right), & r \geq 0, \\ 0 & otherwise, \end{cases} \qquad (2.7)$$

Where

$$I_0(x) \equiv \frac{1}{2\pi} \int_0^{2\pi} \exp(x \cos\theta) d\theta. \qquad (2.8)$$

is the zeroth-order modified Bessel function of the first type. There are dual important parameters in Equation (2.8). σ^2 is the variance of the underlying Gaussian random variable and μ is the amplitude of the line-of-sight or main component if $\mu = 0$ corresponds to the Rayleigh distribution. As μ be likely to infinity, the Ricean distribution converges to a Gaussian distribution.

2.5. Jakes Fading Wireless Channel Model

Jakes fading model is used for simulating time-correlated Rayleigh fading wireless communication channels. This method was determined by Jakes in 1974 and it is commonly used nowadays. The model has been slightly reformulated in order to ensure multiple uncorrelated waveforms [20].

The Jakes fading model uses a sum of weighted oscillators with discretefrequencies spanning the Doppler spectrum. First, the model assumes that there are equally strong N_{ray}rays getting at a moving receiver with uniform arrival angles, α_r. This assumption places the arrival angles at [16]

$$\alpha_r = \frac{2\pi r}{N_{ray}} , \qquad 1 \le r \le N_{ray} \qquad (2.9)$$

The ray r would then experience a Doppler shift of

$$w_r = 2\pi f_{max} \, cos(\alpha_r) = w_{max} \, cos(\alpha_r) \qquad (2.10)$$

Where the maximum Doppler shift w_{max} is given by:

$$w_{max} = 2\pi\left(\frac{V_{sr}}{C_{lig}}\right)f_c \tag{2.11}$$

Where f_c is the carrier frequency, V_{sr} is the velocity difference from the sender to the receiver, C_{lig} is the speed of light. Note that using the definition for α_r given above, the magnitudes of the Doppler shifts possess quadrantal symmetry except at the angles 0 and π. Due to this quadrantal symmetry, the fading waveform with (N_{osc}+1) complex oscillators can be modeled, where [20].

$$N_{osc} = \frac{1}{2}\left(\frac{N_{ray}}{2} - 1\right) \tag{2.12}$$

The (N_{osc} +1)st complex oscillator has the frequency w_{max} and is used for the purpose of frequency shifting from the carrier.

The in-phase and quadrature components are derived from the oscillators by summing the outputs of the available individual oscillators multiplied by proper gain factors. The quadrature components are in the same phase and appear as [20].

$$X_i(t) = 2\sum_{r=1}^{N_{osc}} \cos(\beta_r)\cos(w_r t) + \sqrt{2}\cos(\alpha)\cos(w_{max}t) \tag{2.13}$$

$$X_q(t) = 2\sum_{r=1}^{N_{osc}} \sin(\beta_r)\cos(w_r t) + \sqrt{2}\sin(\alpha)\cos(w_{max}t) \tag{2.14}$$

And the final output waveform is [20]:

$$Y(t) = X_i(t)\,cos(w_c t) + X_q(t)sin(w_c t) \tag{2.15}$$

Jakes selects α= 0 or $\pi/4$, and $\beta_r = \dfrac{\pi r}{N_{osc} + 1}$.

With this model, the use of large number of weighted oscillators leads to a more accurate Rayleigh fading model. It has been shown that Rayleigh fading can be accurately simulated with this method using $N_{osc} \leq 8$. The complete model block diagram of Jakes model is shown in **Figure 8** [25].

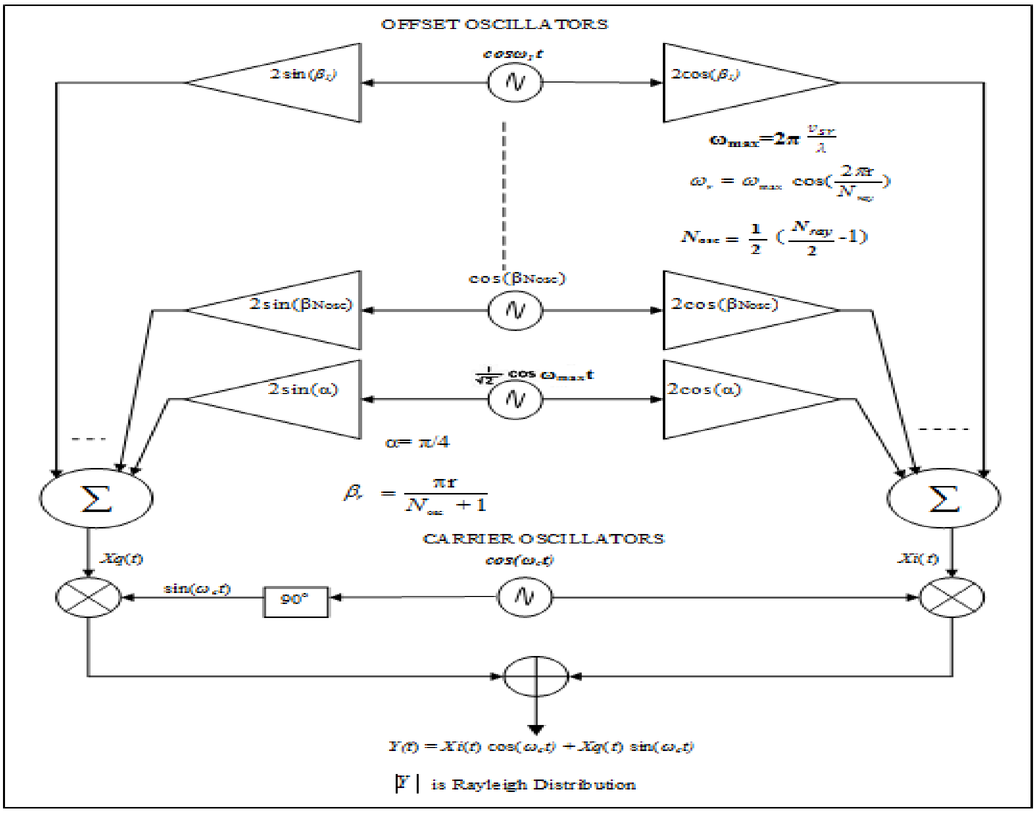


Figure 8 Block diagram of Jake's model[25]

2.6.Single Carrier Modulation (SCM)

A single carrier (SC) system is well-known digital transmission system where data symbols are travelled as a constant symbol-rate serial stream of modulated amplitude and/or phase pulses, which in turn modulate a sinusoidal carrier [26].The transmission of high data rates normally involves a short symbol duration T_s. As a result of multipath propagation in the radio channel, distortions are detected in the received signal, which come into view as inter-symbol-interference (ISI) of the consecutive modulation symbols. This situation is strictly very unstable when the maximum delay T_m is very large, unlike T_s. In this case, the ISI affects many neighboring sent symbols [27]. That limits the highest data rate of single-carrier systems in multipath fading wireless channels [28].

To enhance the efficiency and robustness to overcome frequency selective fading narrow band interaction that occurs in SC modulation, multicarrier modulation (MCM) is used. For unity carrier system, one interferer may cause the whole link fail, but in a multicarrier system, just a small rate of subcarriers will be failed. By error correction technique,false subcarriers can be corrected. As shown in **Figure 9**, in single carrier modulation system, the fading channel does not allow any signal to pass, data symbol is lost sporadically [28].

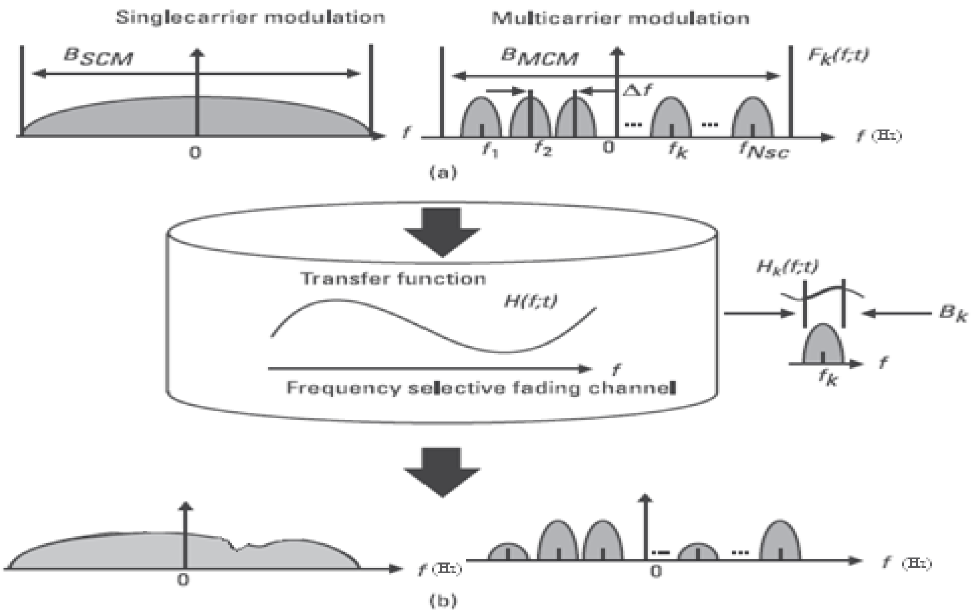


Figure 9 SCM and MCM: (a) sent signals in frequency domain spectrum. And (b) received signals in frequency domain spectrum [28].

CHAPTER 3

MIMO WIRELESS COMMUNICATION

3.1. Introduction

MIMO wireless communication indicates transmissions over wireless channels created by multiple antennas at transmitter and receiver sides. The major benefits of using multiple antennas are more enhanced performance achieved through diversity and the greater data rate through spatial multiplexing.

MIMO scheme can be performed in various ways, if the advantage of MIMO diversity is used to cop the fading then the same signals must be sent through different MIMO antennas, and at the receive end, the different antennas will receive the same signals moved through diversity links. If we want to use MIMO scheme for increasing capacity then different streams of data must be sent simultaneously through the different MIMO antennas without the automatic-repeat request.

Generally Rayleigh fading links are considered to be a serious problem in the wireless communication caused by multipath signal propagation. But, in the MIMO system a multi -path signal is utilized in order to enhance system capacity. Multi-antennatransmitter and/ or receiverwith clients emergingMIMO-OFDMwhichisamain technology in the applications of 4G, IEEE802.16,Digital VideoBroadcasting(DVB-T)[29,30].

3.2. MIMO Technology Advantages

The most important advantages ofMIMO schemes aregain of array, gain of spatial diversity, gain of spatial multiplexing and interaction suppression.A brief describes each of these gains as following [31,32]

1) Array gain**:**Average radio signalreceptiongain of the array is measured according to increased SNRat the receiver due to the effect of a coherent combining wireless system. Arraygain increases the resistance to noise thereby enhancing thecoverage range of the wireless network. Theimprovementcan be done with the exactly handle ends of sending or receiving signals, so the coherent combining of transmission signals are at the receiver.

2) Spatial diversity gain**:**Inawirelesssystem,a receiversignal powers are randomly fluctuates.Diversity is an effectiveway tocombat fading, and providethe receiverwith multiple copiesof sentsignalspatial frequency or timeto be achieved.As more and moreindependentcopies(copy numberis oftenreferred to asthe diversity order), at least one, there is no exhibited deep fadingincreases,thereby increasing theprobability ofreception qualityand reliability. A MIMOchannel with$N_T$sending antennas andN_R receiving antennas exhibit $N_T N_R$ independently fading links, and most big diversity gain equals to $N_T N_R$.

3) Spatial multiplexing gain**:** MIMOsystem provides a linear raising in capacity(average bit rate), with no need to use ofadditional spectrum or increase in transmit power.Referred to asspatialmultiplexing gain, thegainof theantenna scan be gotten from asingleindependent data streams. In the appropriatechannel conditions, such aswealthyscatteringenvironment, the receiver can separatedata stream.In addition, eachdata streamchannelundergoes at least the samequality as compared witha single-input single-output system to effectivelyincrease capacity by of multiplied factor equals to the numberof streams.Generally, it is possible to safelyobtainthe MIMO channel whichis equal tothe smallestnumber of streamsofsendingantennas and receiving antennas, i.e., $\min\{N_T, N_R\}$. The Spatial Multiplexing (SM) gain enhances the capacity of a wireless networkexploitingsimilar carrier and time duration.

4) Interference suppression**:** The interaction phenomenasinthe wireless channel result by a plurality ofusers to sharetime and frequency resources. MIMO system interference may resist the use of spatial dimensionsto enlarge the separation between users. Therefore, the systemcan be adjusted to be not liable tointerference andthe distancebetween the base stationusing thesame time/frequency channel is possibly decreased in the sake of requirements of system capacity improvement.

3.3. MIMO Fading Channel Model

Figure 10 shows a MIMO system with $N_T$sending and $N_R$receiving antennas.For a narrowband channel can be represented bymatrix H with dimensions $N_T \times N_R$, the complex transmission coefficient between element $i \epsilon$ [1,2,….., N_T] at the transmitter and element j ϵ [1,2,…., N_R] at the receiver at time t is represented byh_{ij}.

The MIMO channel with time domain can be acted as [31].

$$H = \begin{bmatrix} h_{1,1} & h_{1,2} & \cdots & h_{1,N_T} \\ h_{2,1} & h_{2,2} & \cdots & h_{2,N_T} \\ \vdots & \vdots & \ddots & \vdots \\ h_{N_R,1} & h_{N_R,2} & \cdots & h_{N_R,N_T} \end{bmatrix} \qquad (3.1)$$

Hence, a system transmitting the signal vector x = [x_1, x_2,….,x_{N_T}]^T, where $x_i(t)$ is the sent signal from the ith element would result in the signal vector y = [y_1, y_2,…..,y_{N_R}]^T being received, where $y_j(t)$ is the signal received by the jthelement, and

$$y = Hx + z \qquad (3.2)$$

The received signal vector$y$is the N_R×1 and x is the N_T×1 sent signal vector while $z$is the noise vector [30].

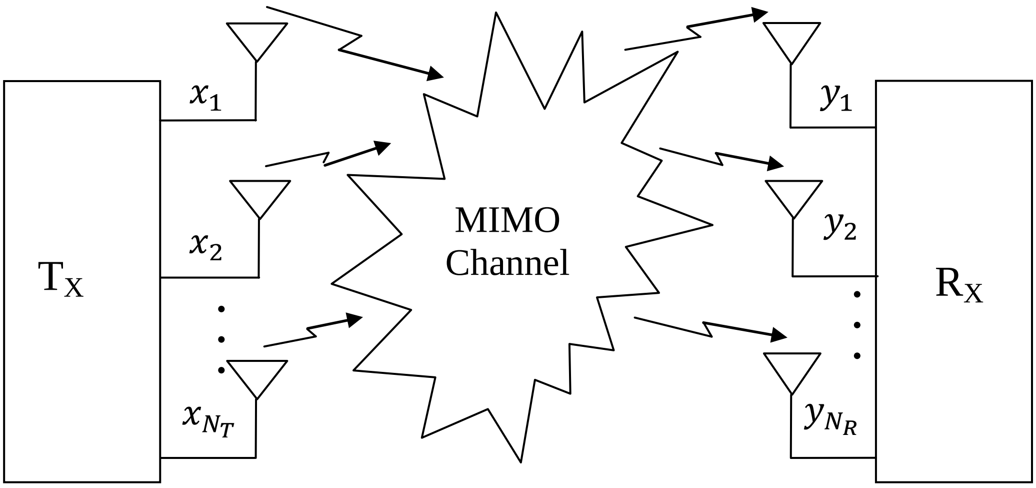


Figure 10 General MIMO system with N_T sending antennas and N_R receiving antennas

3.4. MIMO Transceiver Design

Transceiver algorithms for MIMO systems can be broadly classified into dual groups: diversity maximization rateschemes and maximization schemes. MIMO systems within these categories are called*Spatial Multiplexing (SM)* techniques and *spatial diversity* techniques, respectively. Spatial multiplexingtechniques such as *Bell Labs layered* Space-Time(BLAST) predominantly aim at a multiplexing gain, (i.e., an increasing inspeed as compared to a SISO system). In spatial diversity techniques a maximum diversity gain are provided, for fixed transmission rate, (i.e., decreasing error rates) such as, space-time coding techniques,thatarebased on the principle of appropriately sending redundant symbols over the channel, from different antennas to increase reliability of transmission [30].

3.4.1.Spatial Diversity Techniques

Chapter two described how the multipath channel causes significant impairments to the signal quality in mobile radio communication systems. As signals move between the sender and receiver, they become reflected, scattered, and diffracted. In addition, user's mobility gives rise to Doppler shift in the carrier frequency. As a result, those signals undergo fading (i.e., they rise and fall in their strength). When the signal power goes down considerably, the communication media is supposed to be in fade. This provides increasing to high Bit Error Rates (BER) [16].

To overcome the effect of fading on the error rate, diversity methods are regularly used which is applied to multi-antenna systems (the employment of multiple antennas at the transmitter and/or the receiver) . The standard of diversity is to supply the receiver with multiple copies of sent signal. Each of these copies is called diversity branch. If these copies are influenced by autonomous fading situations, the probability that all branches are in fade at the same time is decreased noticeably .In a wireless communications system, these effects in an enhancement in the required SNR or $E_s/N_o$is required to attain a given quality of service in terms Bit Error Rate (BER) [32].lately, systems using multiple antennas at transmitter and/or receiver got a lot interest. The spatial partition among the multiple antennas is selected in order that the diversity branches have uncorrelated fading. Contrasting time and frequency diversity, space diversity does not make any loss in bandwidth efficiency. This property is very gorgeous for elevated data rate wireless communications. In space, a variety of combining techniques, i.e., Maximum-Ratio Combining (MRC), Equal Gain Combining (EGC) and Selection Combining (SC), may be used at the receiver. Space-time codes which exploit diversity across space and time can also be used at the transmitter side [32].

In the class of spatial diversity, there are dual essential kinds of diversity that must be reported:

i. **Polarization diversity:**In this category of diversity, horizontal and vertical polarization signals are sent by two unusual polarized antennas and received in the same way by two different polarized antennas at the receiver. The benefit of different polarizations is to ensure that there is no correlation among the data streams. In addition to that, the two polarization antennas can be installed at the same place and no worry has to be taken about the antenna separation. However, polarization diversity can achieve only two branches of diversity. The drawback of this scheme is that a 3 dB extra power has to be transmitted because the transmitted signal must be fed to both polarized antennas at the transmitter.

ii. **Angle diversity:**This applies at carrier frequencies more than 10 GHz. In this case, as the sent signals are extremely dispersed in space, the received signals from various routes are self-governing to each other. Therefore, two or more directional antennas can be positioned in different directions at the receiver spot to present uncorrelated reproductions of the sent signals.

3.4.1.1.Alamouti Scheme

The easiestformat of space time block codes was developedbyAlamouti in 1998. He proposed this technique for dualsending antennas and one receive antenna .In the Alamouti encoder, dual consecutive symbolsx_1 andx_2 are encoded, and the code matrix is given as in [3]:

$$X = \begin{bmatrix} x_1 & -x_2^* \\ x_2 & x_1^* \end{bmatrix} \quad (3.3)$$

In equation (3.3), the column in the beginning stands for the first transmission period (T) and the 2nd column the 2nd transmission period (2T). The 1st row related to the symbols sent from the 1st antenna and the 2nd row related to the symbols sent from the 2nd antenna. Namely,the encoding is done in both the space(across dual antennas) and time (dualsendingdurations) domains. This represents as space-time coding[32].

The encoder outputs are sent in two consecutive transmission periods from dual transmit antennas as shown in **Figure 11**. During 1st transmission period, dual signals x_1 and $x_2$are sentat sametime from 1st and 2nd antenna, respectively. In the 2nd transmission period, two signals $-x_2^*$ andx_1^* are sent on time from 1st and 2nd antenna, respectively, where $*$ denotes the complex conjugate[31].

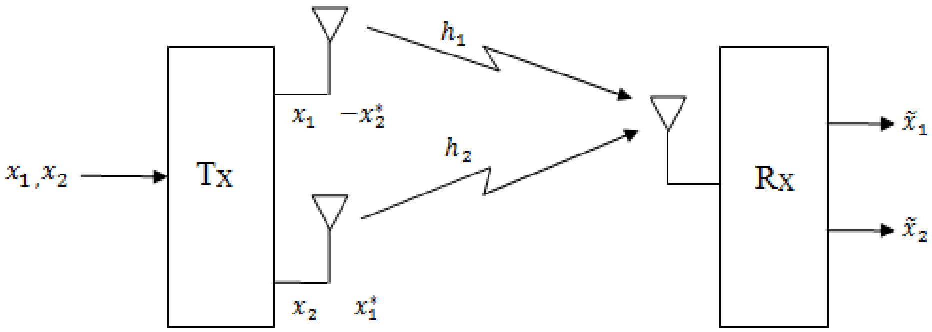


Figure 11 Alamoutiencoder

$$X^1 = [x_1, -x_2^*] \text{and } \mathrm{X}^2 = [\mathrm{x}_2, \mathrm{x}_1^*] \quad (3.4)$$

Where X^1 and $X^2$is the data sequence from 1st antenna and 2nd antenna, respectively.The basic property of the Alamouti scheme is the sent sequences from the dualsending antennas are orthogonal, because of zero inner product value of the sequences X^1 and X^2, This inner product is given by [33].

$$X^1 . X^2 = x_1 x_2^* - x_2^* x_1 = 0 \qquad (3.5)$$

The code matrix in Equation (18) is a complex-orthogonal matrix, that is[30]

$$X . X^H = \begin{bmatrix} |\mathrm{x}_1|^2 + |\mathrm{x}_2|^2 & 0 \\ 0 & |\mathrm{x}_1|^2 + |\mathrm{x}_2|^2 \end{bmatrix} = (|\mathrm{x}_1|^2 + |\mathrm{x}_2|^2)\mathrm{I}_2 \qquad (3.6)$$

WhereI_2 is a 2 × 2 identity matrix.

At the receiving side, single receive antenna is used and the diversity analysis is based on ML signal detection. **Figure 12** explains the block diagram of the receiver for the Alamouti scheme. The fading channel parameters from 1st and 2nd sending antennas to the receive antenna at time t are symboled by $h_1(t)$and $h_2(t)$, respectively.

Considertwo sent consecutivesymbolsfor fadingcoefficientare fixed, they can bewritten as:

$$h_1(t) = h_1(t + T) = h_1 = |h_1| e^{j\theta_1} \qquad (3.7)$$

$$h_2(t) = h_2(t+T) = h_2 = |h_2|e^{j\theta_2} \quad (3.8)$$

Where $|h_i|$and θ_i ,i = 0, 1, are the amplitude gain and phase shift for the path from sending antenna i to the receiving antenna, and T is the symbol duration. The receiver receives y_1 and y_2 denoting the two received signals across two consecutive symbol intervals for time t and $t+T$, respectively .The received signals may be written as [30,33] :

$$y_1 = h_1x_1 + h_2x_2 + n_1 \quad (3.9)$$

$$y_2 = h_1x_2^* + h_2x_1^* + n_2 \quad (3.10)$$

Wheren_1 and $n_2$are independent complex variables with zero mean and unity variance, representing AWGN samples at time t and t + T, respectively. In the combiner-aided by the channel estimator, which provides perfect estimation in which the channel coefficients, h_1 and h_2 , are sufficientlyfamiliar to the receiver [33].

For this instance,easy signal processing is performed so as to separate the signals x_1 and x_2. Specifically, the maximum likelihood detector reduces highly the decision metric:

$$|y_1 - h_1\breve{x}_1 - h_2\breve{x}_2|^2 + |y_2 + h_1\breve{x}_2^* - h_2\breve{x}_1^*|^2 \quad (3.11)$$

By whole possible magnitudes of$\breve{x}_1$ and$\breve{x}_2$. Substituting (3.9) and (3.10) into (3.11), the maximum likelihood decoding can be stood for

$$(\breve{x}_1, \breve{x}_2) = arg_{(\breve{x}_1,\breve{x}_2)\in C}^{min}(|h_1|^2 + |h_2|^2 - 1)(|\breve{x}_1|^2 + |\breve{x}_2|^2) + d^2(\tilde{x}_1, \breve{x}_1) + d^2(\tilde{x}_2, \breve{x}_2) \quad (3.12)$$

C stands forall possible groupsfor modulated symbol pairs$(\breve{x}_1, \breve{x}_2)$, $\tilde{x}_1$ and $\tilde{x}_2$are two decision statistics built by emerged received signals with channel state information.

The following statistics are used for decision and they calculated by:

$$\tilde{x}_1 = h_1^*y_1 + h_2y_2^* \quad (3.13)$$

$$\tilde{x}_2 = h_2^*y_1 - h_1y_2^* \quad (3.14)$$

$h_1$andh_2 are channel realization, the decision statistics $\tilde{x}_i$, i = 1, 2, is only a function ofx_i, i = 1, 2. By the way, the maximum likelihood decoding principle may composedof dual independent decoding equations for $x_1$and x_2, by [33]

$$\check{x}_1 = arg_{\check{x}_1 \in S}^{min}(|h_1|^2 + |h_2|^2 - 1)|\check{x}_1|^2 + d^2(\tilde{x}_1, \check{x}_1) \quad (3.15)$$

$$\check{x}_2 = arg_{\check{x}_2 \in S}^{min}(|h_1|^2 + |h_2|^2 - 1)|\check{x}_2|^2 + d^2(\tilde{x}_2, \check{x}_2) \quad (3.16)$$

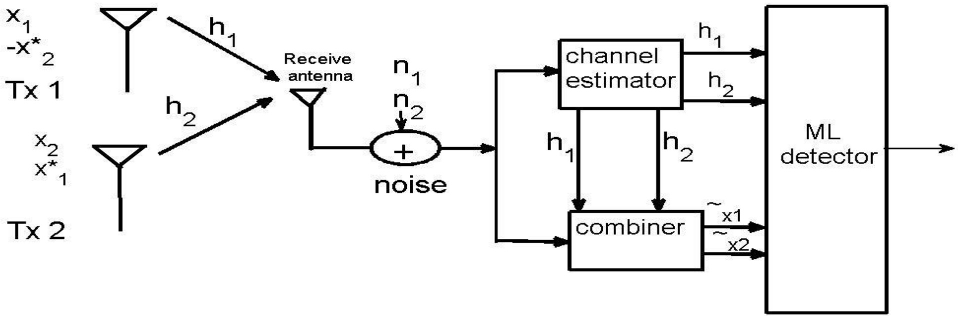


Figure 12 The Alamouti scheme receiver

AlamoutiSTBC have been used in multiple wirelessstandards such asWCDMA and CDMA2000 because of the followingfeatures.Firstly,it implements thefulldiversityofany signal(real or complex) constellationin the fulltransfer rate.Secondly, itdoes not require theCSIat sender. Thirdly, themaximum likelihood decodingat the receiverincludes justlinear processingbecause of orthogonal codenature [31].

3.4.1.2. The Alamouti Scheme with Multiple Transmit Antennas

The Alamouti scheme brought in a revolution of sorts in multiantenna systems by providing full diversity of two without (CSI) at the sender and a very simple maximum likelihood decoding system at the receiver may be performed by simple linear processing. Maximum likelihood decoders provide full diversity gain of $N_R$receive antennas. Hence, such a system provides a guaranteed overall diversity gain of 2N_R, in the case of not using CSI at the sender. This is achieved by orthogonally feature among the sequences produced by two sending antennas. Due to these reasons, the approach was used generally to an arbitrary number of sending antennas using the orthogonal designs theory. This approach is known as space-time block codes (STBCs) [32].

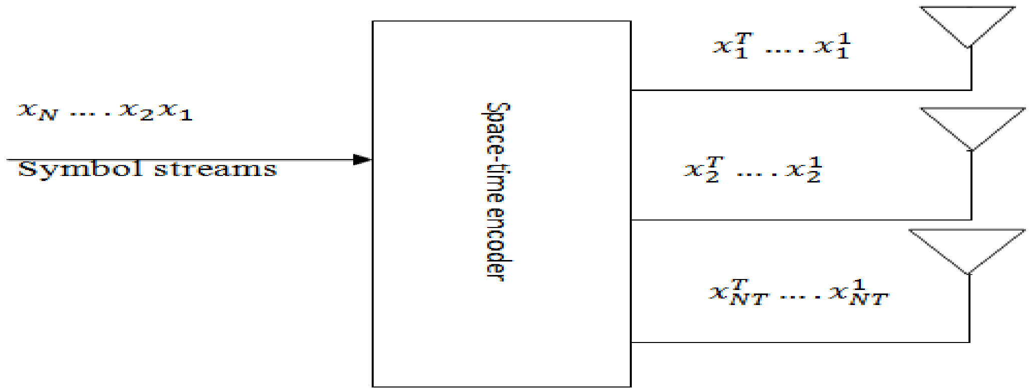


Figure 13 Space-time block encoder.

Generally, the resultant space time block encoder is a codeword matrix **x** with dimension of $N_T \times T$. Here $N_T$is the number of sending antenna and T represents the number of symbols for each block. The matrix**x** is based on orthogonality. designs such that [33]

$$\mathbf{x}.\mathbf{x}^H = c(|x_1|^2 + |x_2|^2 + \cdots + |x_i|^2)I_{N_T} \quad (3.17)$$

Where c is a constant,$N_T$representssending antennas number,$\mathbf{x}^H$ is the Hermitian of **x**, and $I_{N_T}$is and $N_T \times N_T$unity matrix. The*i*th row of x stands for the symbols sent from the *i*th sending antenna respectively in T transmission intervals, whereas the *j*th column of **x**stands for the symbols sentsame timeby $N_T$sending antennas at time *j*. The *j*th column of x is related as a space-time symbol sent at time *j*. The element of **x** in the *i*th row and *j*th column,$x_{i,j}$, i = 1, 2, . . . , N_T&j = 1, 2, . . . ,T, represents the signal sent from the antenna i at time j.The property in equation (3.18) indicates that thetransmission matrix row vectors **x** are orthogonal to each other, which is,[30]

$$\mathbf{x}_i.\mathbf{x}_j = \sum_{t=1}^{T} x_{i,t}.x_{j,t}^* = 0\,, i \neq j\,, \quad i,j \in \{1,2, \dots, N_T\} \quad (3.18)$$

Where $\mathbf{x}_i.\mathbf{x}_j$stands for the inner product of the sequences $\mathbf{x}_i$ and $\mathbf{x}_i$.The orthogonality activates to implementsthe completesending diversity for specifiedsending antennas. Inaddition, it permits the receiver to separate the sent signals from various antennas and hence, a casual maximum likelihood decoding which is relied on linear processing of the received signals [33].

3.4.1.3. The Alamouti Scheme with Multiple Receive Antennas

The Alamouti scheme may beused for a system with dualsending and $N_R$receiveantennas. The encoding sending process for this scheme is similar to the case of one receive antenna. It is considered that r_1^i and r_2^i are the received signals at the i^hreceive antenna at 1st and 2nd symbol period,consecutively [33].

$$r_1^i = h_{i,1}x_1 + h_{i,2}x_2 + n_1^i \tag{3.19}$$

$$r_2^i = -h_{i,1}x_2^* + h_{i,2}x_1^* + n_2^i \tag{3.20}$$

Where $h_{i,j}$ ($j = 1, 2$; $i = 1, 2, . . . , N_R$) is the fading coefficient for the path from sending antenna j to receiving antenna i, and n_1^i and n_2^i are the noise signals for receiving antenna i at 1st and 2nd symbol periods, respectively.

The receiver emergerproducesdual decision statistics according to linear set of the received signals. The decision statistics, represented by $\tilde{x}_1$and $\tilde{x}_2$, are written as [33].

$$\tilde{x}_1 = \sum_{j=1}^{N_R} h_{j,1}^* r_1^j + h_{j,2}\left(r_2^j\right)^* \tag{3.21}$$

$$\tilde{x}_2 = \sum_{j=1}^{N_R} h_{j,2}^* r_1^j - h_{j,1}\left(r_2^j\right)^* \tag{3.22}$$

3.4.2. Spatial Multiplexing (SM)

In thespatial multiplexingMIMO system, independent data streamson the same time sentbyvarious antennaasofa MIMO systemto maximizethe transmission rate .The total bit rate as compared to one antenna system is improved by N_T factor in the case of no additional transmission power. The output gain acts as bit rate (in comparison to oneantenna system) is known as multiplexing gain [33].

The earliest known spatial-multiplexing receiver was invented and prototyped in Bell Labs and is called *Bell Labs layered Space-Time* (BLAST). There are two different BLAST architectures, the *DiagonalBLAST* (D-BLAST) and its subsequent version, *Vertical BLAST* (V-BLAST). The encoder of the D-BLAST is very similar to that of V-BLAST. However, the main difference is in the way the signals are transmitted from different antennas. In V-BLAST, all signals from each layer are transmitted from the same antenna, whereas in D-BLAST, they are shifted in time before transmission. This shifting increases the decoding complexity. V-BLAST was subsequently labeledso as to decrease the complexity and malfunction of D-BLAST. In this work only V-BLAST is considered.

3.5. Transceiver Structure

Figure 14 presents a basic SM scheme, where the sender and receiver have plurality of antennas i.e.($N_T = N_R$). At sender, the message bit sequence is divided into N_T sub-sequences, which are modulated and the antenna configurator takes symbols from the modulator, and transmitsjust single symbol to each antenna.The antennas send the symbols on same time and frequency band. In the receiver, the sentinformation message are separated by using an interference-cancellation type of algorithm[29,34].

The sent signalsfromdifferent antennas propagate throughautonomous distributedpath with interference to each other during reception .Signal detectionat the receiver oflinear and nonlinearreceiver technologyis characterized byperformance and complexity mutual relation.

A low complex option is to adopt a linear receivers, for example, relied on zero-forcing (ZF) or minimum mean square error (MMSErules. However, the error performance is usually low, especially during using the ZF method. Generally, it is necessary that $N_R \geq N_T$, in order to reliably separate the received data stream. However, if the number of receive antennas bigger than the number of sending antennas (NR> NT),in the case, it is satisfied to achieve spatial diversity gain[44,45].

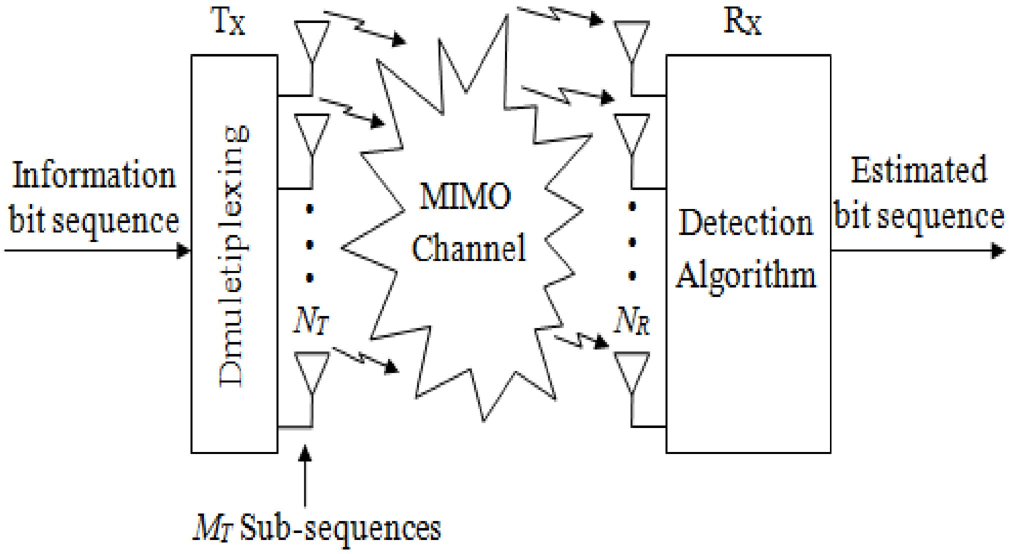


Figure 14 Basic principle of Spatial Multiplexing (SM)

3.6. Zero-Forcing (ZF) Method

The simplest, but at least efficient decoding method using inversed matrix. As matrix inversion exists only for square matrices, there is a more general expression known as, pseudo-inversematrix, which can be used for square and non square matrices. The interference is suppressed by multiplication in the received signal with the inversed pseudo of the channel matrix. This may be also known as Zero Forcing (ZF) approach. Hence, the ZF combiner weight W_{ZF} is given by [30].

$$W_{ZF} = \left(H^H H\right)^{-1} H^H \tag{3.23}$$

Where $(.)^H$ referred as Hermitian transpose operation and H is the channel matrix. The zero-forcing detector totally nullifies the interference from sent signal by multiplying the received signal y given in Equation (3.2) with the ZF weight W_{ZF}, giving an estimated received vector $\tilde{x}$:

$$\tilde{x} = W_{ZF}y = W_{ZF}(Hx + z) = x + \left(H^{H}H\right)^{-1} H^{H}z \tag{3.24}$$

The main drawback of this approach is the noise enhancement. If the matrix $H^H H$ has too small eigenvalues, its inverse probably very big values that boost the noise samples. A better performance may be performed using same method called Minimum Mean-Square Error (MMSE), where the SNR is determined during evaluating the inversed matrix to implement MMSE [35].

3.7. Minimum Mean-Square Error (MMSE) Method

Zero-forcing receiver is a logical alternative MMSE receiver, which tries to hit a balance between the spatial suppressed interaction and noise enhancement by reducing as far as possible mean square error sent vectors x and the received vector which is a linear combination and referred as $W_{MMSE}\ y$ [33].

$$\min E\{(x - W_{MMSE}y)^2\} \tag{3.25}$$

Where W_{MMSE} is an $N_R \times N_T$ matrix representing the MMSE combiner weight and it is given by [44].

$$W_{MMSE} = \left(H^H H + \sigma_z^2\, I\right)^{-1} H^H \tag{3.26}$$

Where σ_z^2 represents noise variance and I is an $N_T \times N_T$ unity matrix. An estimated received vector $\tilde{x}$ is therefore given by [30].

$$\tilde{x} = W_{MMSE}y = W_{MMSE}(Hx + z) = x + (H^H + \sigma_z^2\, I)^{-1}H^H z \tag{3.27}$$

When the SNR getsbig, the MMSE detector will reach to the ZF detector at low SNR, it inhibits the case of inverted eigenvalues.

3.8. Channel Capacity

As known, the channel capacity is defined as the maximum possible transmission rate such that the probability of error is arbitrary small [22,33].In 1948, the mathematical foundations of information transmission were established by Shannon. In his work, he demonstrated that, by suitableinformation encoding, errors generated by a noisy channel can be eliminated to any wanted level without need of information rate transfer. In case of, Additive White Gaussian Noise (AWGN) channel, he derived the most famous formula of channel capacity, which is given by [36].

$$C = B_W \log_2\left(1 + \frac{E_s}{N_o}\right) \quad (3.28)$$

C represents the channel capacity [bit/s] unit, $B_W$stands for the channel bandwidth in Hertz [Hz], E_s is the total transmitted energy, and N_o is the noise power spectral density, which equivalent to the total noise power divided by the noise equivalent bandwidth (i.e, $N_o = N/B_W$). In addition to white Gaussian noise.

The mobile wireless channels are under other impairments (i.e., channel fading) as mentioned in chaptertwo, which reduces the channel capacity significantly.Thus, channel capacity becomesas follows [37,38]

$$C = B_W \log_2\left(1 + \frac{E_s}{N_o}|h|^2\right) \quad (3.29)$$

Where $|h|^2$ is the average channel fading gain. For deep fading conditions, the channel capacity degrades significantly. The capacity in Equation (44) depends on Channel State Information (CSI) which is defined by whether the value of instantaneous channel gain h is familiar to the sending and receiving sides or not. Channel State Information (CSI) at transmitter plays an important role to maximize the channel capacity in MISO and MIMO systems, but it is difficult to be obtained. However, CSI at receiver can be obtained through the transmission of a training sequence [37]. Throughout this section,CSI is assumed to be known to the receiver. On the other hand, the sender CSI is studied for two cases (i.e. known and unknown CSI).

In the next sections, channel capacity of Rayleigh fading channels for various system architectures such as SISO, SIMO, MISO and MIMO is studied. Then, the analytical model that analyzes the behavior of these systems over flat fading channel is presented.

3.8.1. SISO Channel Capacity

In Single-Input Single-Output (SISO) systems, the normalized Shannon capacity formula per unit bandwidth (i.e., B_W =1Hz) of such systemsis given by [38].

$$C = \log_2\left(1 + \frac{E_s}{N_o}|h|^2\right) \quad (3.30)$$

Where C is the capacity in bit per second per Hertz [bit/sec/Hz] of channel bandwidth. The limitation of SISO systems is the capacity raises very slowly with the log of SNR and in general it is low. Moreover, fading can cause large fluctuations in the signal power level.

Only temporal and frequency domain processing are possible for SISO system.Spatial domain processing cannot be applied for this system [39].

3.8.2. SIMO Channel Capacity

Single-Input Multiple-Output (SIMO) systems have one antenna at the sender and plurality of antennas at the receiver. While SIMO system includes only a single transmit antenna, the Channel State Information (CSI) at the sender provides no capacity increase. Thus, the capacity can be derived by making use of matrix determinant as follows [37]

$$C = \log_2 det\left(I_{M_R} + \frac{E_s}{N_o} H^H H\right) = \log_2\left(1 + \frac{E_s}{N_o}\sum_{i=1}^{M_R}|h_i|^2\right) (3.31)$$

Where, $H^H H = \sum_{i=1}^{M_R}|h_i|^2$, which is the summation of channel gains for all receive antennas [46]. If the channel matrix elements are normalized and similar as $|h_1|^2 = |h_2|^2 = \cdots |h_{M_R}|^2 = 1$, then channel capacity becomes

$$C = \log_2 det\left(1 + M_R \frac{E_s}{N_o}\right) \qquad (3.32)$$

Therefore, by using multiple receive antennas; the system can achieves a capacity increasesof$M_R$relative to the SISO case. This increment of SNR is known as array gain [37].

3.8.3. MISO Channel Capacity

Multiple-Input Single-Output (MISO) systems have plurality of antennas at sender and just one antenna at the receiver. When the sender does not have the CSI, the transmission power is distributed equally betweenwhole sending antennas (M_T).Hence, the capacity is calculated by [37]:

$$C = \log_2\left(1 + \frac{E_s}{M_T N_o}\sum_{j=1}^{M_T}\left|h_j\right|^2\right) (3.33)$$

Where $\sum_{j=1}^{M_T}\left|h_j\right|^2$ is the summation of channelgains for all transmit antennas. In Equation (36), while the power is equally divided among$M_T$transmit antennas, when the channel coefficients are equal and normalized as $\sum_{j=1}^{M_T}\left|h_j\right|^2 = M_T$, then the maximum value of MISO capacity approaches the ideal AWGN channel with single antenna at sender and receiver (SISO system) [32,37].

It is important to note here there is no array gain in transmit diversity. Unlike the receive diversity case (SIMO system) where the total received SNR is increased due to array gain [23]. However ,as the CSI is familiarto the sender, the capacity of MISO system becomes [39]

$$C = log_2\left(1 + \frac{E_s}{N_o}\sum_{j=1}^{M_T}\left|h_j\right|^2\right) \quad (3.34)$$

Therefore, the MISO capacity equals the SIMO capacity as the CSI is familiarto the sender [37].

3.8.4. MIMO Channel Capacity

With the advent of the Internet and rapid proliferation of computational and communication devices, the demand for higher data rates is ever growing. In many circumstances, the wireless medium is an effective means of delivering a high data rate at a cost lower than that of wireline techniques (such as cable modems and digital subscriber line (DSL) modems) [32]. Limited bandwidth and power makes the use of plurality of antennas at sending and receiving ends of the link (i.e. MIMO system) indispensable in meeting the increasing demand for data and it offers a significant capacity gains over single antenna systems, or transmit/receive diversity systems [40]. In this section, detailed studies and analysis of MIMO capacity is covered,withchannel not familiar to the sender and withchannel familiar to the sender.

3.8.5. Channel Unknown to the Transmitter

In the case of no feedback in the communication system, and the channel is knownfor receiving side but not familiar at the sender. The sent power is distributed equally likely into $M_T$sending antennas [22,36], and the MIMO channel capacity is given by [22,21].

$$C = \log_2 det\left(I_{M_R} + \frac{E_s}{M_T N_o} HH^H\right) (3.35)$$

The MIMO channel is usually interpreted as a group of parallel eigen-channels, by using the eigenvalues of the MIMO channel matrix H. The matrix HH^H with $M_R \times M_R$ dimensions is usually diagonal zed using Eigen value decomposition (EVD) to find its eigenvalues [32].

The eigen value decomposition (EVD) of such a matrix is given by $Q\Lambda Q^H$ (i.e., $HH^H = Q\Lambda Q^H$) . Based on this fact, Equation (45) may be rearranged as [63].

$$C = \log_2 det\left(I_{M_R} + \frac{E_s}{M_T N_o} Q\Lambda Q^H\right) (3.36)$$

Q is a matrixof eigenvectors of $M_R \times M_R$ dimensions satisfying, $QQ^H = Q^H Q = I_{MR}$,while $\Lambda = diag\{\lambda_1, \lambda_2, \ldots, \lambda_{MR}\}$, is a diagonal matrix with a non-negative square roots of the eigenvalues. These eigenvalues are ordered so that,$\lambda_i \geq \lambda_{i+1}$ [32,36].
By applying identity property,$det(I + AB) = det(I + BA)$, and the property of Eigenvectors,$QQ^H = I_{MR}$,Eq. (4.28) can be reduced to [2,32].

$$C = \log_2 det\left(I_{M_R} + \frac{E_s}{M_T N_o} \Lambda\right) \quad = \sum_{i=1}^{r} log_2\left(1 + \frac{E_s}{M_T N_o}\ \lambda_i\right) (3.37)$$

$r$represents the rank of the channel, which implies that,$r \leq min\ (M_R, M_T)$ and $\lambda_i (i = 1, 2, \ldots, r)$ are the not negative eigenvalues of HH^H.
Eq. (3.37) shows of the MIMO channel capacity as a summation of the capacities of r SISO channels as illustrated in **Figure 15**, everyoneas power gain of λ_i ($i = 1, 2, \ldots, r$) and transmit energy ofE_s/M_T [32,36].

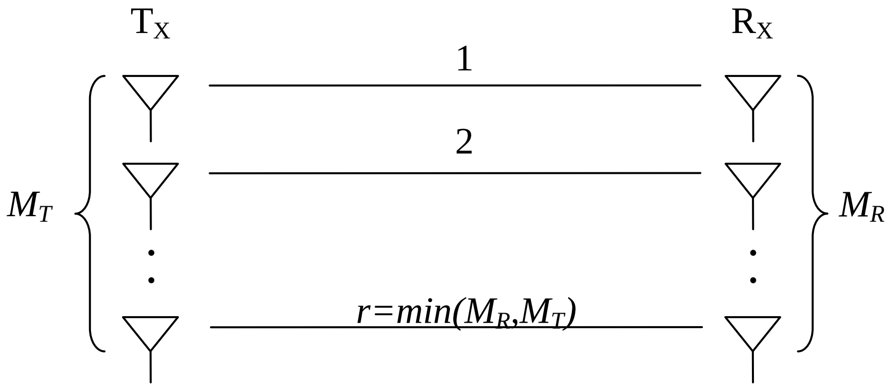


Figure 15 Conversion of the MIMO channel into *r* SISO subchannels

3.8.6.Channel Known to the Transmitter

In wireless communications, channel state information (CSI) stands for known channel belongings of a communication medium. This information explains how a signal propagates from the sender to the receiver and corresponds to the mutual effect of, for instance, scattering, fading, and power decay with distance. The CSI creates it potential to adjust transmissions to present channel circumstances, which is important for achieving sustainable communication with high data rates in multiantenna systems. If the channel is familiarfor senderand receiver ends, so Singular Value Decomposition (SVD) may be used to convert the MIMO channel intocombination of parallel subchannels. Hence, the MIMO channel matrix *H* can be written as [41]:

$$H = U\Sigma V^H \qquad (3.38)$$

Where Σ is an $M_R \times M_T$ non-negative and diagonal matrix,U and V are $M_R \times M_R$, and $M_T \times M_T$, each one is unitary matrix. That is, $UU^H = I_{MR}$, and $VV^H = I_{MT}$. The diagonal entries of $\Sigma$are not negative square roots of the eigenvalues of matrix HH^H. The eigenvalues on the diagonal are positive numbers with a descending order, such that $\lambda_i \geq \lambda_{i+1}$ [36].

By multiplying the inverse of U and V at sending and receiving sides respectively, the channel with interaction can be transformed into a group of independent singular value channels, as shown in **Figure 16** and the input-output relationship given [41].

$$\tilde{y} = \sqrt{\frac{E_s}{M_T}} U^H H V \tilde{x} + U^H n = \sqrt{\frac{E_s}{M_T}} \Sigma \tilde{x} + \tilde{n} (3.39)$$

Where $\tilde{y}$ is the transformed received signal vector of size $r \times 1$ and $\tilde{n}$ is the transformed AWGN vector with size of $r \times 1$. The rank of the channel $H$is r. Equation (54) explains that with the channel knowledge at the sender, H can be easilybroken into$r$ parallel SISO channels satisfying [32].

$$\tilde{y}_i = \sqrt{\frac{E_s}{M_T}} \sqrt{\lambda_i} \tilde{x}_i + \tilde{n}_i , \quad i = 1, 2, \dots, r \qquad (3.40)$$

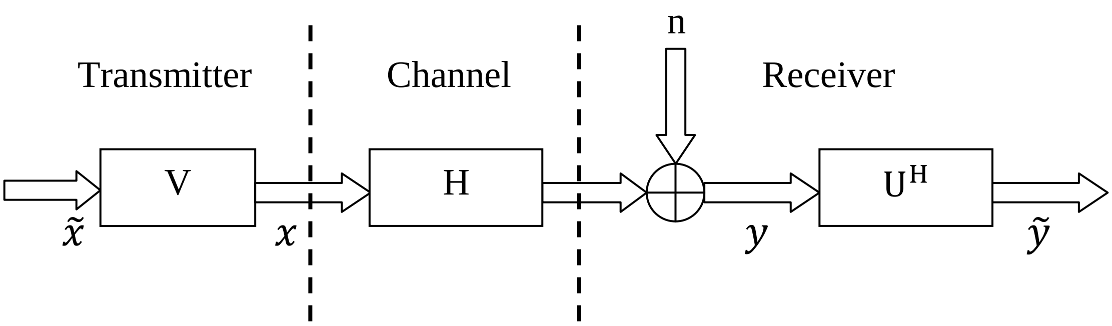


Figure 16. Decomposition of *H* as the channel parameters are familiar to the sender and receiver

Water-Filling (WF) Method

Consider a MIMO channel where the channel parameters are known at the transmitter. The‘‘water-filling principle’’ can be derived by maximizing the MIMO channel capacity under the rule that more power is allocated to the channel that is in good condition and less or none at all to the bad channels.

The capacity given by Equation (52) can be raised by allocating the sent energy to different antennas dependent on “Water-Filling” rule [39].WF is an energy distribution strategy based on SVD, derived to provide the upper bound on data throughput across the MIMO channel. It allocates more energy when the channel is in good condition and less when the channel state gets worse. By using this method, the capacity of the system is given by [33,41].

$$C = \max_{\sum_{i=1}^{r}\gamma_i} \sum_{i=1}^{r} \log_2\left(1 + \frac{E_s\gamma_i}{M_T N_o}\ \lambda_i\right) \tag{3.41}$$

Where $\gamma_i(i = 1, 2, \ldots, r)$represents the transmitted energy amount in the i^{th} subchannel such that [22].

$$\sum_{i=1}^{r} \gamma_i = M_T \tag{3.42}$$

By applying Lagangain method, the best possible allocated energy policy, $\gamma_i{}^{opt}$, satisfies [22,42].

$$\gamma_i{}^{opt} = \left(\mu - \frac{M_T N_o}{E_s\lambda_i}\right)^+, \qquad i = 1, 2, \ldots, r \tag{3.43}$$

Where μ is chosen so that$\sum_{i=1}^{r} \gamma_i{}^{opt} = M_T$ and $(x)^+$implies [22,42]

$$(x)^+ = \begin{cases} x & if\ x \geq 0 \\ 0 & if\ x < 0 \end{cases} \tag{3.44}$$

The constant μ given in Equation (3.43) is calculated by [32]

$$\mu = \frac{M_T}{r}\left[1 + \frac{N_o}{E_s}\sum_{i=1}^{r}\frac{1}{\lambda_i}\right] \tag{3.45}$$

Some remarks on Water-Filling (WF)method [22,43]:

1. μIs usuallytaken as reference to water level. It determines the power distribution for all subchannels [41].

2. If the power allotted to the channel with the lowest gain is negative (i.e.λ_i< 0),this channel is discarded by setting $\gamma_i^{opt} = 0$.the best possible allocated energy strategy, therefore, allocates power to those spatial subchannels that are non-negative. Fig. 3.8 illustrates the WF algorithm [32].

3. Because this algorithm only focuses on fair-quality channels and stops the bad ones during each realized channel, it is to be supposed that this criteria aims a capacity which is equivalent or more than the situation during the channel is not known to the sender [32].

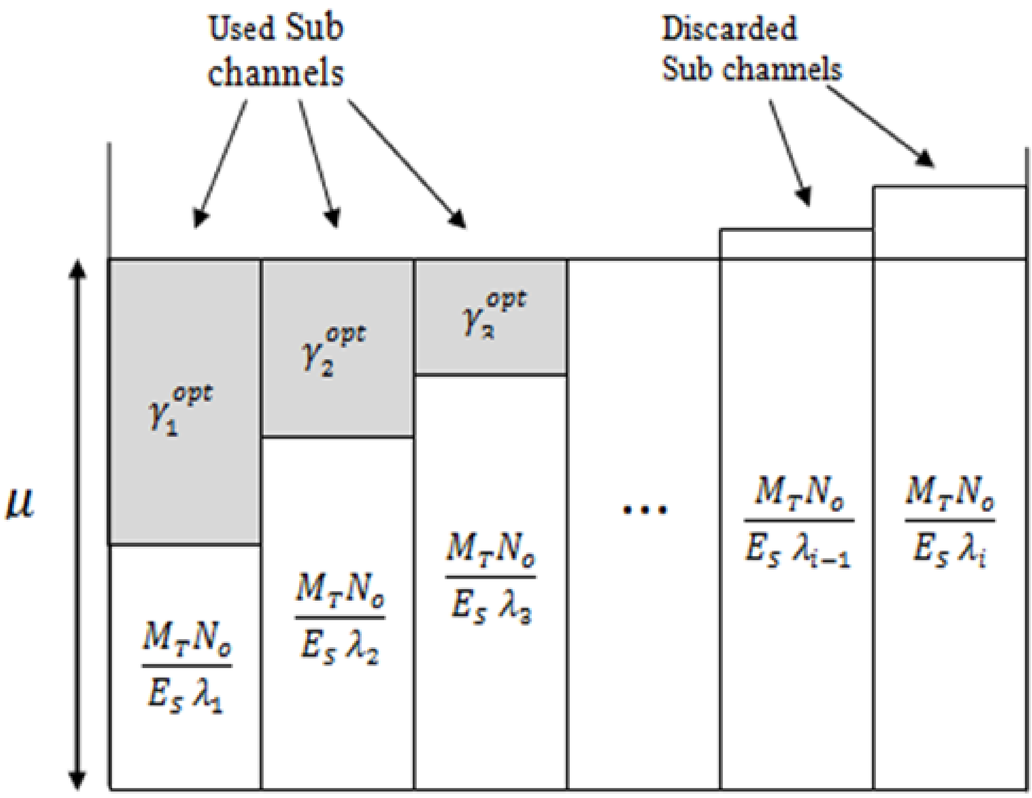


Figure 17 Principle of Water-Filling (WF) algorithm

3.9. Microstrip Bandpass Filters

The microstrip resonators consists of two conducting planes separated by a dielectric layer with a permittivity ε_r and a thickness h as well as a width *w*and a thickness *t* whichis on the top of a dielectric substrateas in **Figure 18** [44].

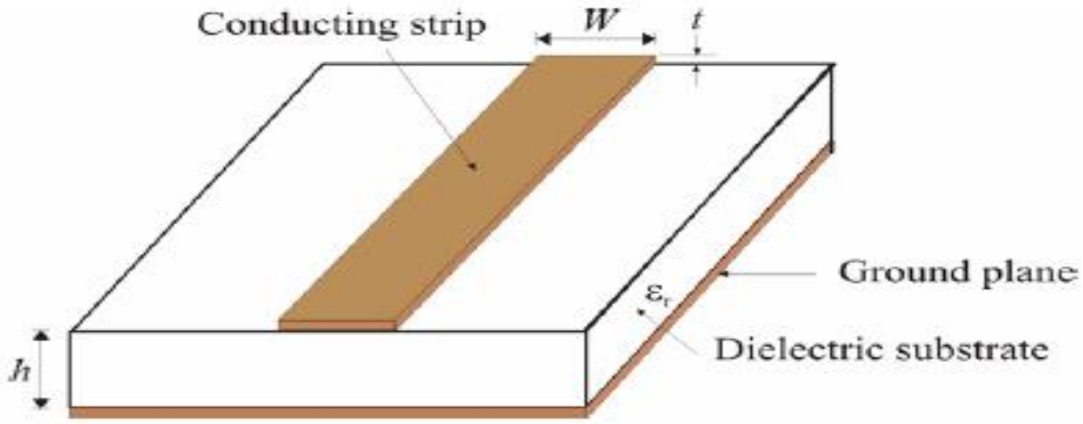


Figure 18 Microstrip transmission line

An analog bandpass filters are available in many wireless systems which allows signals in a specific band of frequencies to pass, while signals at all other frequencies are rejected .They can be realized using one or more resonators, coupled to each other. Actually , a resonator is any physical component that stores both magnetic and electric energy in a frequency-dependent way. At fundemental frequency, the magnetic and electric current distributions in the resonator are equally stored [44].

Self-designed Band Pass Filters (BPF) are used to reject image side bands as good as possible in modern MIMO wireless systems. Accordingly, to highly reject the lower image of the sent signal, a sharp edged band pass filter (BPF) is required [7].

CHAPTER 4

SIMULATION RESULTS AND DISCUSSION

4.1.Introduction

MIMO wireless communication indicates transmissions over wireless channels formed by multiple antennas at transmitter and receiver sides. The main advantages of employing multiple antennas are more enhanced performance obtained through diversity and the greater data rate through spatial multiplexing.

MIMO scheme can be performed in various ways, if the advantage of MIMO diversity is used to cop the fading then the same signals must be sent through different MIMO antennas, and at the receive end, the different antennas will receive the same signals moved through diversity links. If we want to use MIMO scheme for increasing capacity then different streams of data must be sent simultaneously through the different MIMO antennas without the automatic-repeat request.

The parameters which have been used in the simulation of the introduced channel model are shown in **Table 1**. It is important here to mention that, all the simulations of BER performance and capacity measurements introduced in this work were done with maximum velocity of mobile receiver set to 100 Km/hr and sampling frequency of f_s = 10 kHz. Other measurements depend on different values of these parameters, which will be stated for each case.

Figure 19 shows the simulation of 2×2 MIMO channel in a rich scattering environment between the transmitter and receiver. The probability density function PDF is depicted in **Figure 20** for each channel. It shows a very good congruence between simulation and theoretical results.

Table 1 Theadopted channel model parameters

Parameter	Magnitudes
Carrier frequency f_c	2400 MHz
Sampling frequency f_s	10 KHz, 12 KHz
No. of transmitted bits L_S	10^6 bit
Used Modulation type	2PSK,32PSK and 64PSK
Lower limit number of arriving waves N_1 related to each channel	40
Upper limit number of arriving waves N_2 related to each channel	80
Speed of mobile v	80 Km/hr
No. of transmit antennas M_T	1, 2,3,4
No. of receive antennas M_R	1, 2, 3, 4

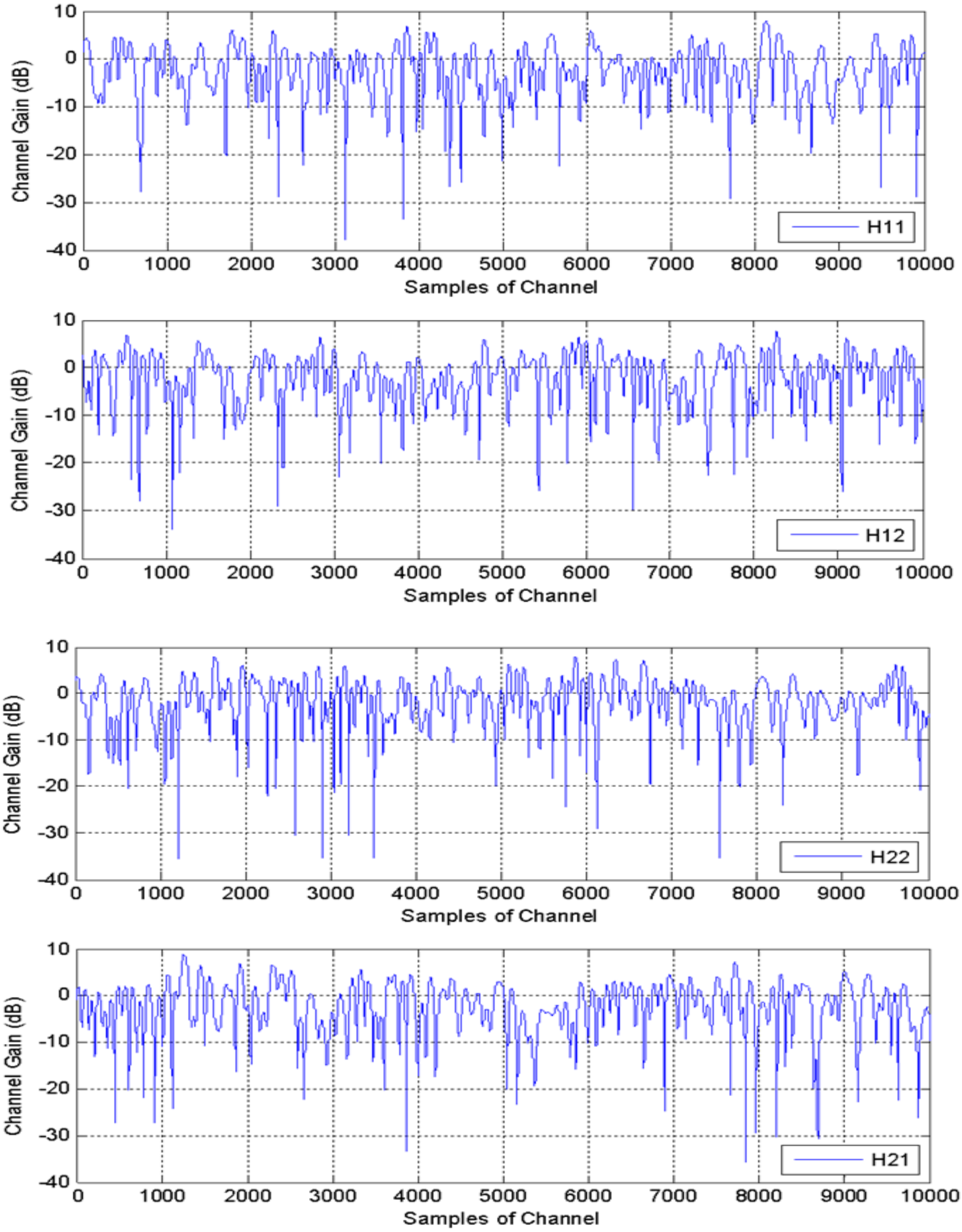


Figure 19 2×2 MIMO channel at v = 80 Km/hr andf_s = 12 kHz. H_{ij} denotes the channel gain between j^{th} transmit antenna and i^{th} receive antenna

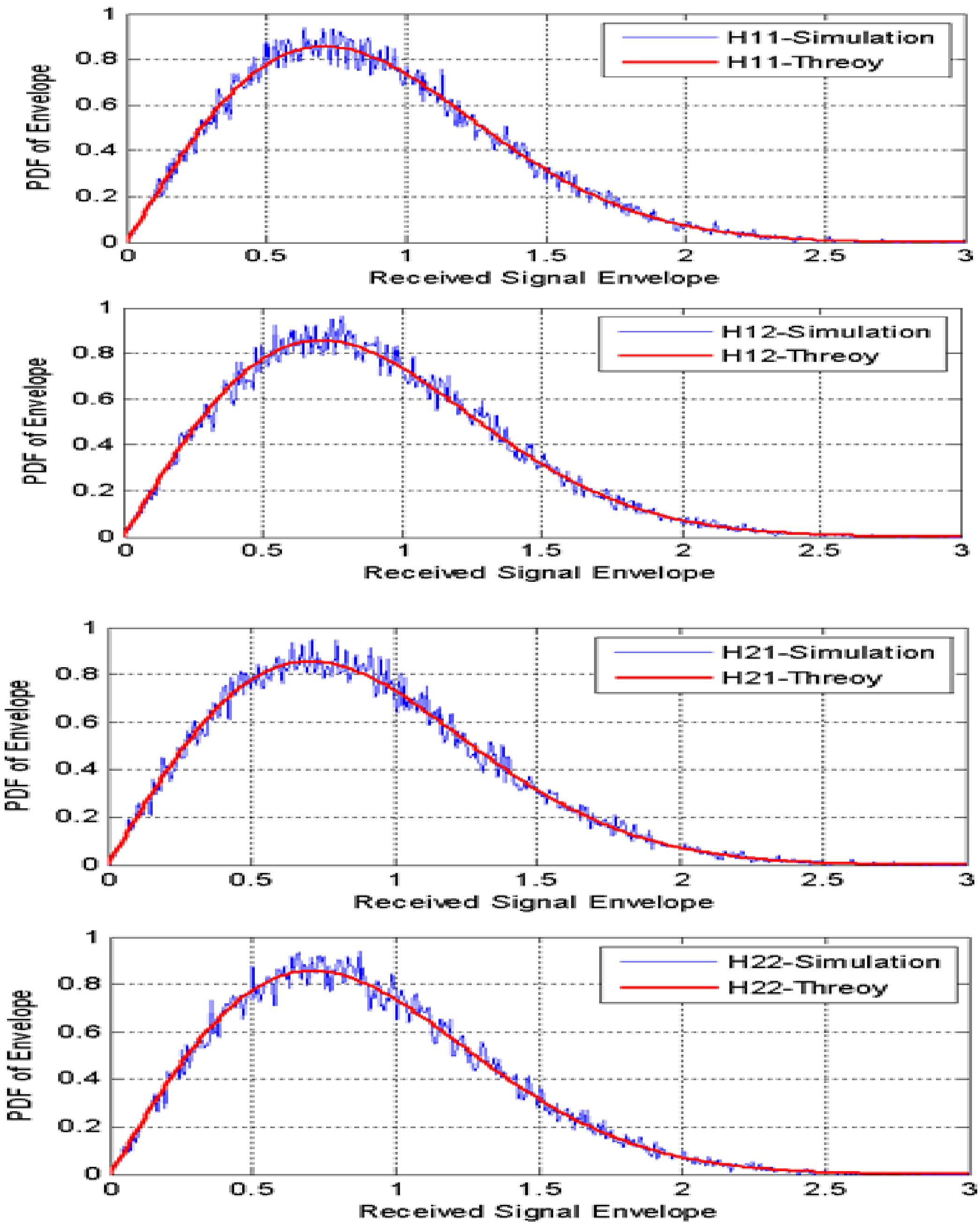


Figure 20 The PDFs of 2 ×2 MIMO. H_{ij} denotes the PDF of the channel between j^{th} transmit antenna and i^{th} receive antenna

4.2 MIMO System Model of IEEE802.11a Using 2PSK Constellations

In MIMO systems, Alamouti scheme has been implemented widely. The transmit diversity idea given by Alamouti was the space time block coding (STBC). The implementation of block diagram of MIMO is with the help of STBC encoder and decoder at the transmit and receive ends is shown in **Figure 21**.

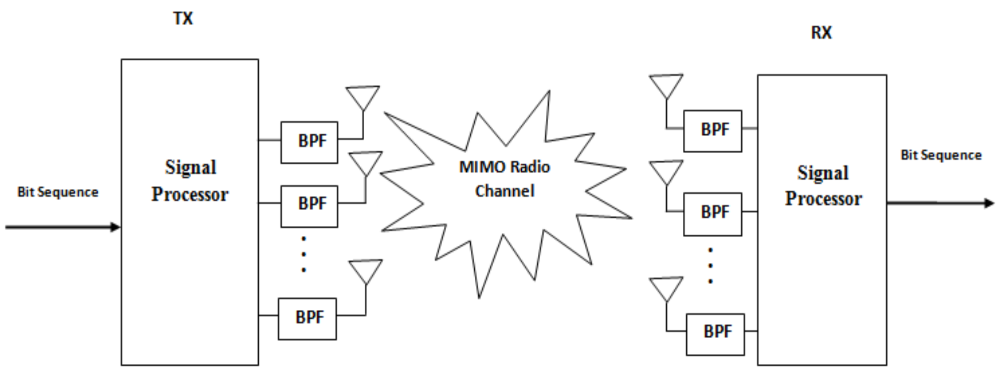


Figure 21 The proposed MIMO system model

Here also the implementation and characteristic of self-designed Band Pass Filters (BPF) are reported, which are used to reject image bands. Design aim for the BPF is to use 2.4 GHz ISM-Band and to filter out the lower image sideband as good as possible. To completely reject the lower image of the transmitted signal, a sharp edged band pass filter (BPF) is needed.

We used AWR2009 simulator in the design and simulation of that BPF. This simulator provides circuit (schematic) and electro-magnetic (Momentum) simulation technology that offer good performance in capacity, accuracy, speed and convergence. The BPF is designed as Microstrip Patch Filter (MPF), which provide a high performance of the bandpass frequency response between the input and the output port.

Microstrip Patch Filter as in**Figure 22**, has been etched using a substrate with a relative dielectric constant of 10.8 and a substrate thickness of 1.27 mm. Two 50 ohm feed lines as input and output (I/O) ports are placed in left up and right bottom corners of the filter. The proposed filter dimensions have overall of 10.6 x 9 mm^2 and m=n=k=3 mm while q=0.8 mm and p=1 mm.It has been simulated and evaluated using AWR2009 electromagnetic simulator. The corresponding simulation results of return loss and transmission responses are shown in **Figure 23**. In this figure, pass band has resonance frequencies of 2.4 GHz with bandwidth of 90 MHz , - 30.465 dB return loss and -0.16 dB insertion loss , can be observed clearly.The proposed filter has less insertion loss and smaller than fiters used in MIMO wireless system reported in [7] as it can be seen from**Figures 24-25** and **Table 2**.

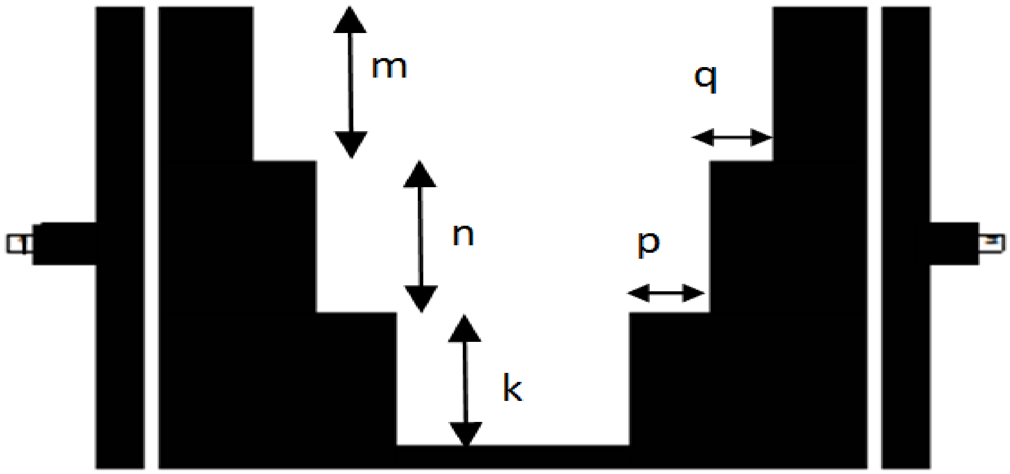


Figure 22 The modelled layout MPF

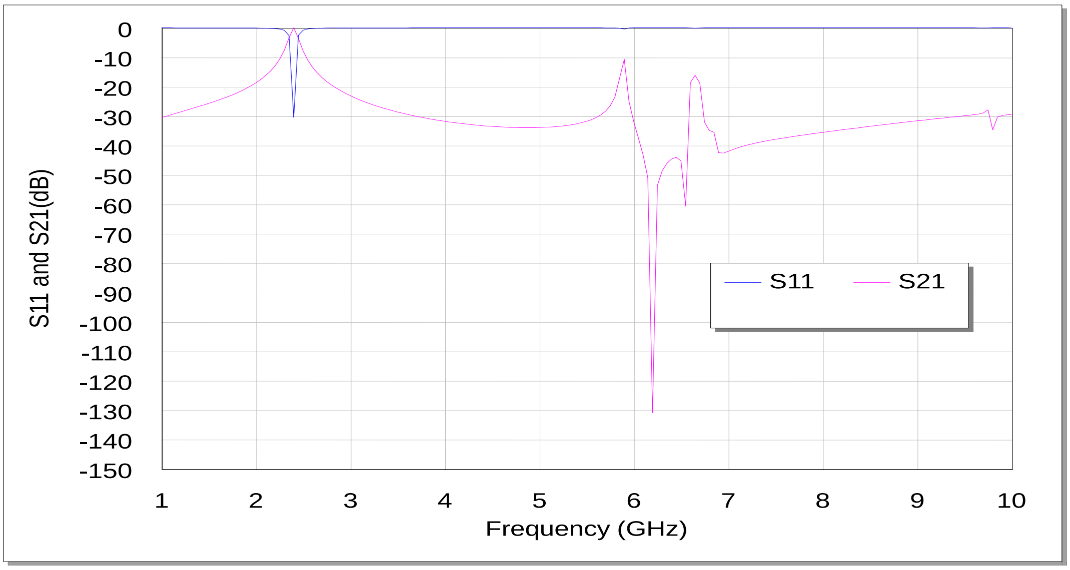


Figure 23 The return loss and transmission responses of MPF

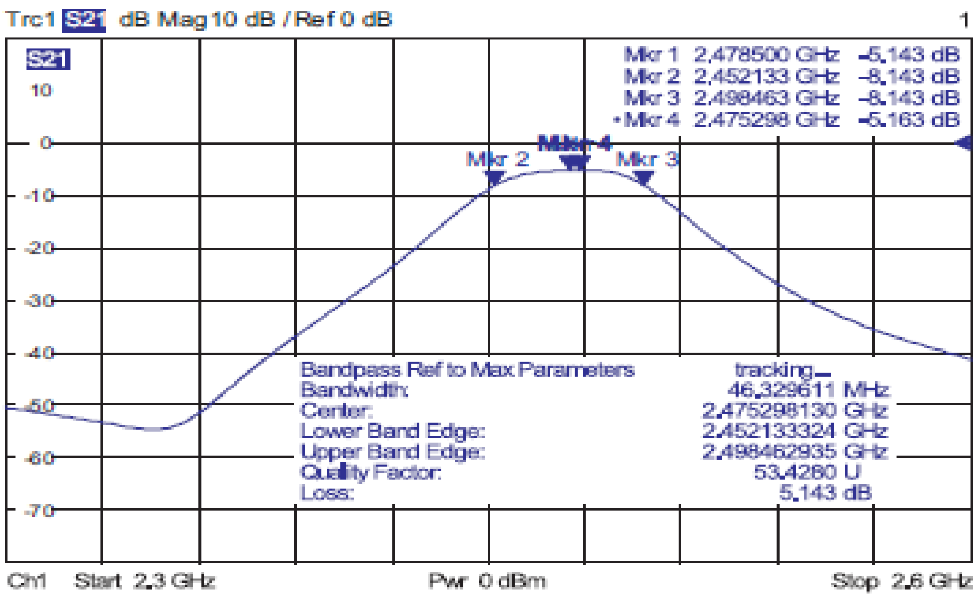


Figure 24 Self-designed Band-Pass-Filterresponse of [7]

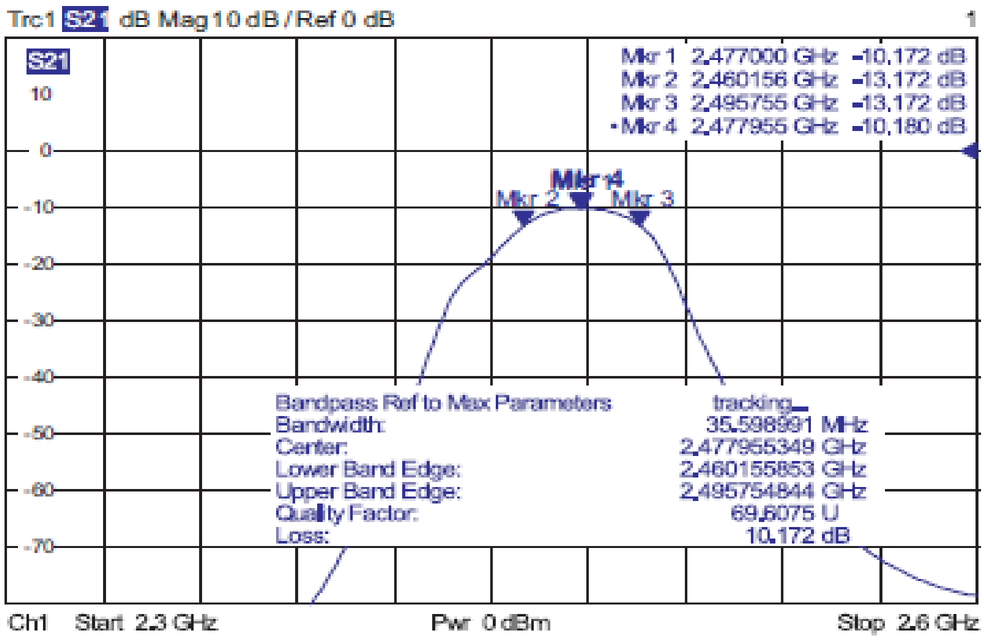


Figure 25 Two Cascaded Self-designed Band-Pass-Filterresponse of [7]

Table 2 Comparison of proposed BPF for proposed MIMO system with [7] at same frequency,2.4GHz

Filter Parameters	Our Work	Self designed BPF reported in [7]	Two cascaded Self designed BPF reported in [7]
Insertion Loss(dB),S21	0.16	5.143	10.172
Dielectric constant and substrate thickness	10.8,1.27 mm	3.65, 0.81 mm	3.65, 0.81 mm
Filter Size	Smallest	Larger	The largest

In order to get insight into the nature of current distributions of the proposed microstrip filter, simulation response for the surface current density at operating frequency of operation, 2.4GHz is depicted in **Figure 26**using sonnet simulator , where the red colour indicates the highest coupling effect while the blue colour indicates the lowest one.

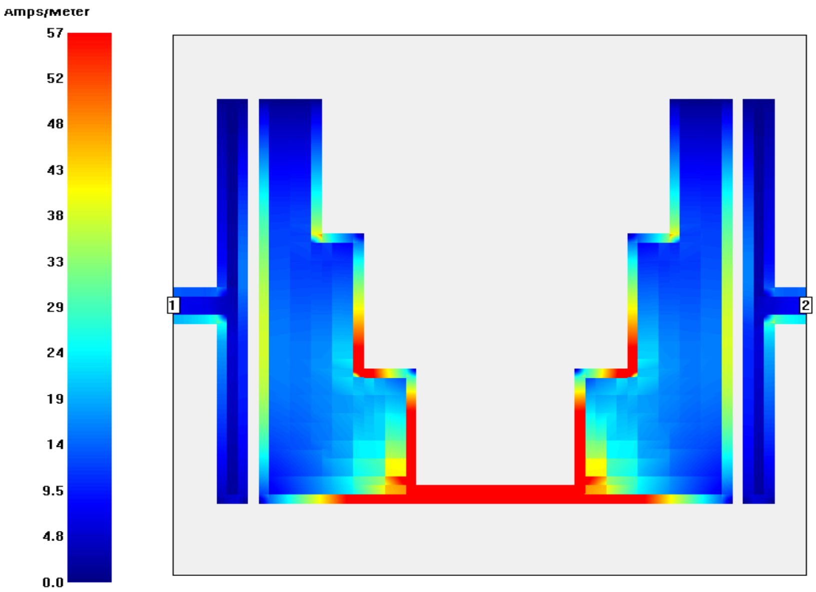


Figure 26 Current density distributions of MPF at 2.4GHz

By the effect of this filter, the steps ofMatlab simulation for computing BER for different M-ary PSK using STBC techniques are as following:

1. Generation of 2PSK,32PSK and 64PSK .
2. Choosing antenna configurations.
3. Assuming a transmission sequence has been used, for example $\{X_1, X_2, X_3, \ldots.\}$.Normally, X_1 will be sent in the first time slot, X_2 in the second time slot, X_3 and so on.
4. Encode these sequences using STBC encoder.
5. Modulate these sequence using binary PSK.
6. Calculate channel matrix, transmission matrix and received signal per receiver antenna.
7. Demodulate received signals.
8. Decode demodulated signals using STBC decoder
9. Counting the number of bit errors.
10. Repeat the same for multiple values of S/N.
11. Plot the bit error rate versus S/N using semilogy command.

Data encoding is performed by a channel code and the encoded data is divided into plurality of data streams simultaneously transmitted using a plurality of transmit antennas. The received signal at each receive antenna is a linear BERresponses with respect to S/N (bit energy to noise power spectral density) for binary PSK levels over Rayleigh channel have been depicted in **Figure 27**. It shows as the number of transmit and receive antennas are increased; the BER keeps on decreasing and provide better BER performance due to spatial diversity.

It is worth pointing that SIMO antenna configurations (1x2 and 1x4) have better BER responses as compared with (2x1 and 4x1) MISO antenna configurations. This is because the series of the information received from the active channel leads to antenna diversity order of 4 and 8 ,where diversity order is twice the number of receive antennas . Although there is more complexity in receiver sides. With number of symbols = 1000000 (transmitted), we can only measure BER down to 10^{-5} reliably .It is necessary to indicate that if the number of symbols increases the output exponential responses for BER will be smoother and more clear. The optimal BER can be observed in (4 x 4) transceiver configurations.

Figures28-29 explain the simulated bit error for 32 and 64 PSK digital modulations.

Figures 30-31show some simulated bit error rate for the same digital modulation levels reported in [45].Our proposed model has minimum BER $<10^{-5}$ as compared to all graph results of [45] which has lowest BER $<10^{-2}$.

By the way,the BER gained by our proposed MIMO wireless model is less than all BER responses for MIMO result responses reported in [45].

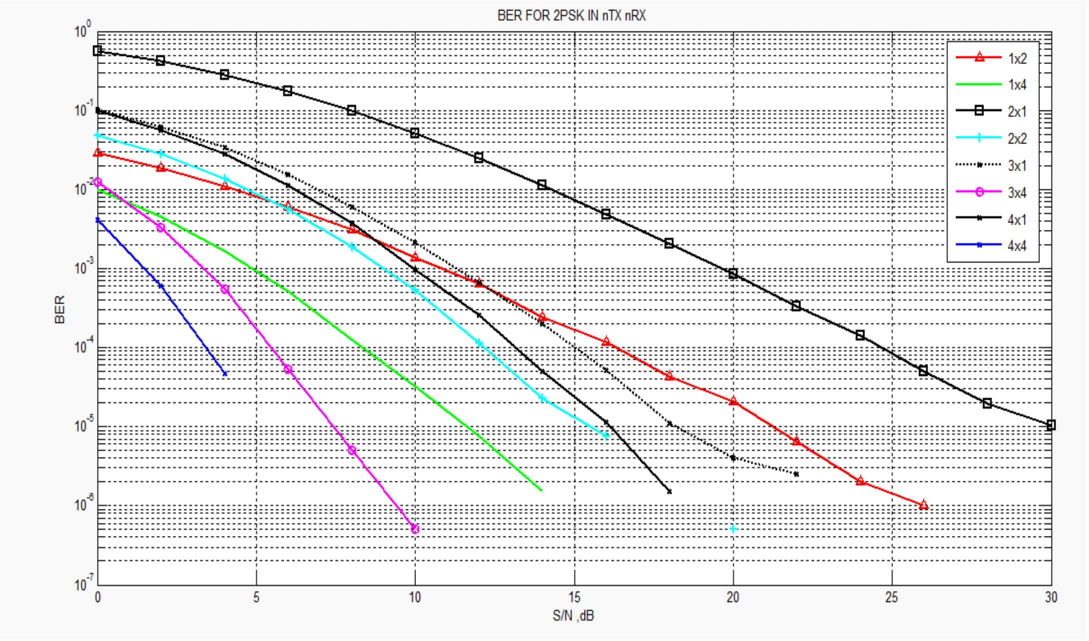


Figure 27 Simulated BER curves of 2 PSK MIMO System with different antenna configurations

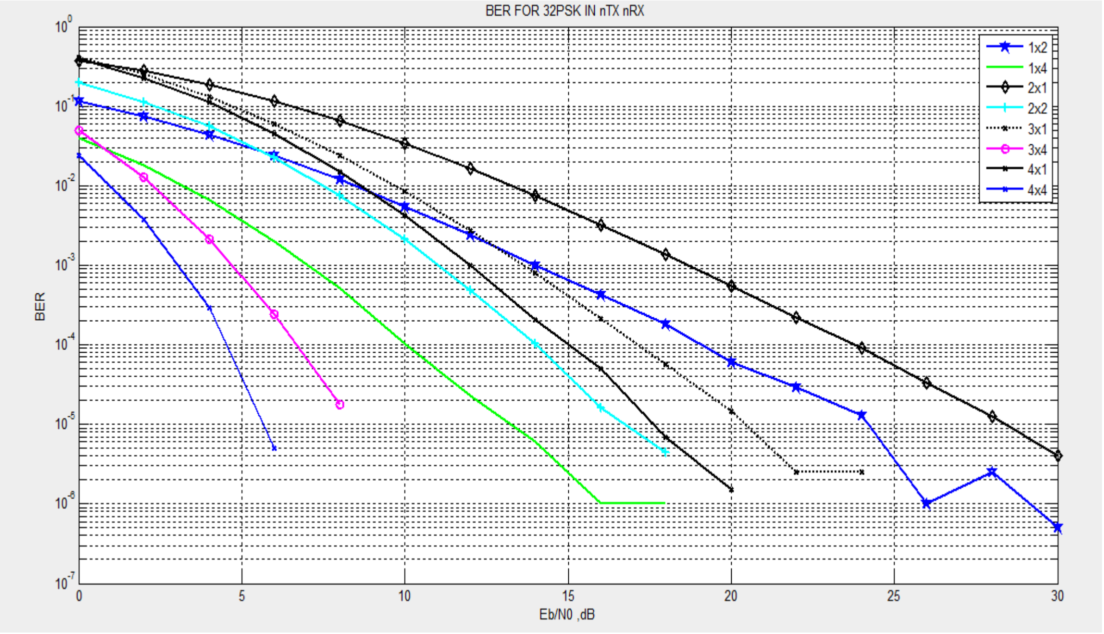


Figure 28 Simulated BER curves of 32 PSK MIMO System with different antenna configurations

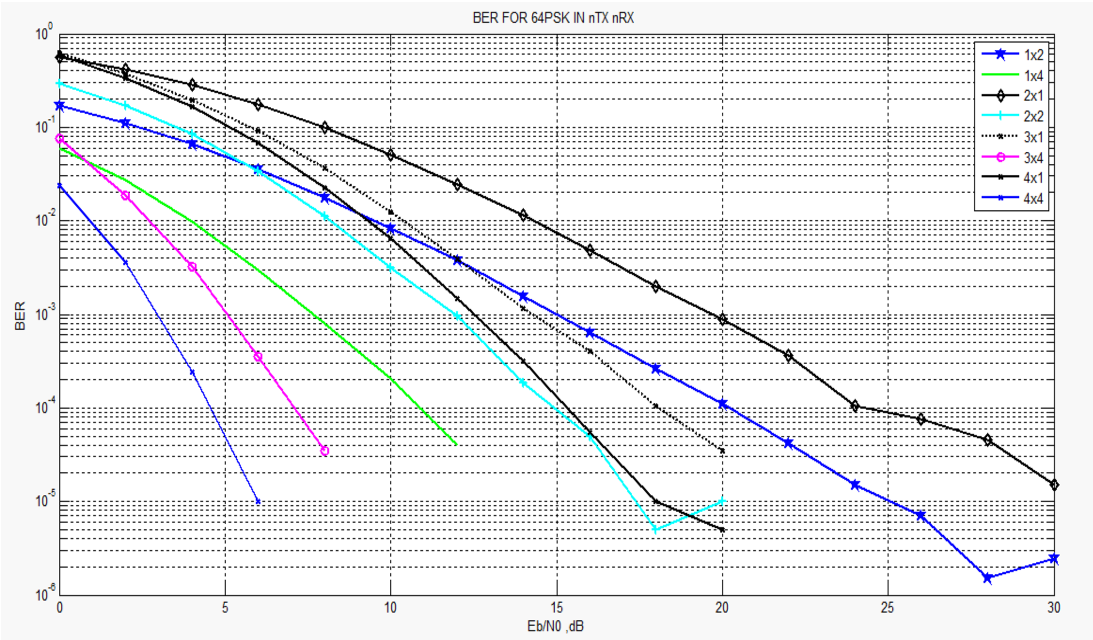


Figure 29 Simulated BER curves of 64 PSK MIMO System with different antenna configurations

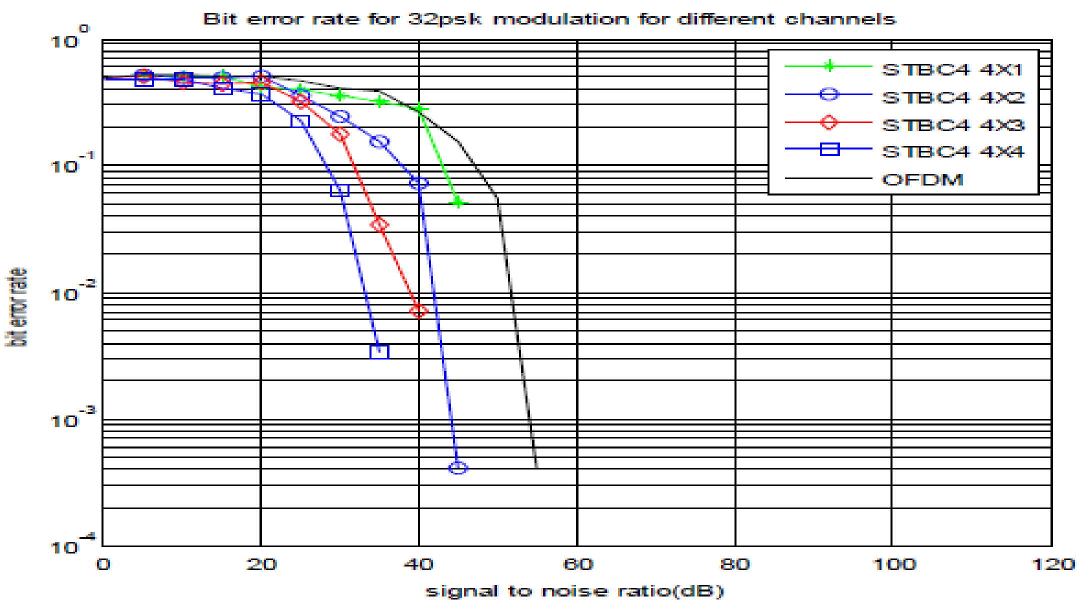


Figure 30 Simulated BER curves of 32 PSK MIMO System reported in [45]

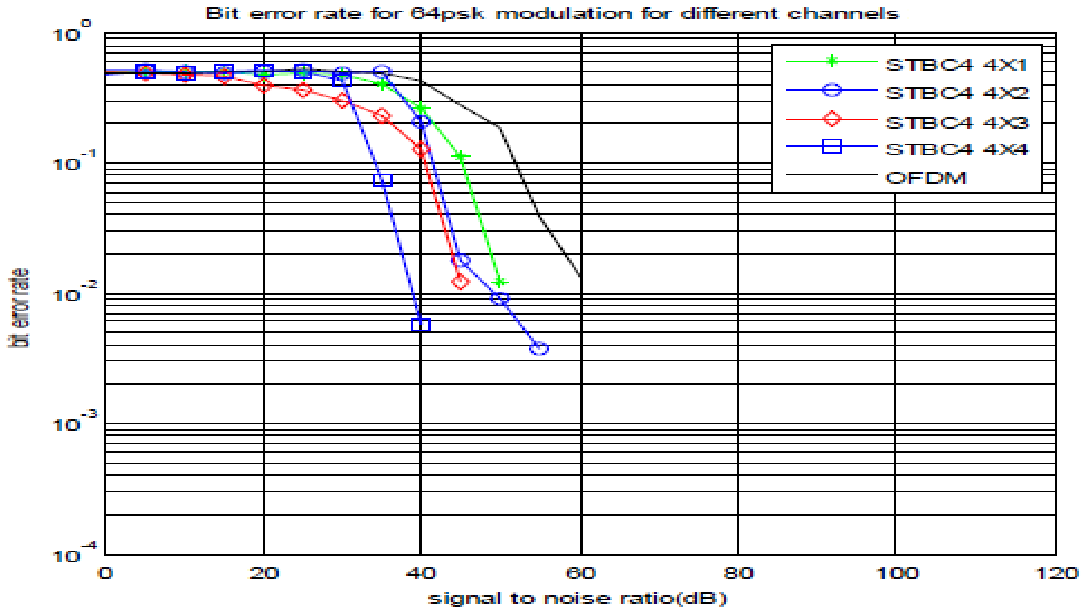


Figure 31 Simulated BER curves of 64 PSK MIMO System reported in [45]

4.3. Channel Capacity

In this section, simulation results and tests of channel capacity for SISO, SIMO, MISO, and MIMO systems will be discussed under various assumptions with regards to the availability of CSI at the receiver and/or the transmitter. In addition to that, it should be noted that the transmitted signal bandwidth B_W is normalized to be 1Hz for all the above systems.

The program of channel capacity for SISO, SIMO, MISO, and MIMO systems has the same construction steps to be generated. Hence these systems have a shared program flow chart, which is illustrated in **Figure 32**.

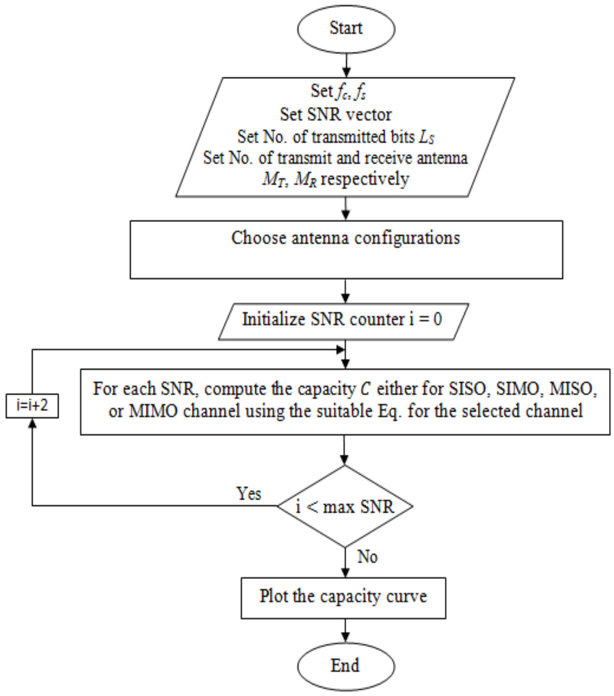
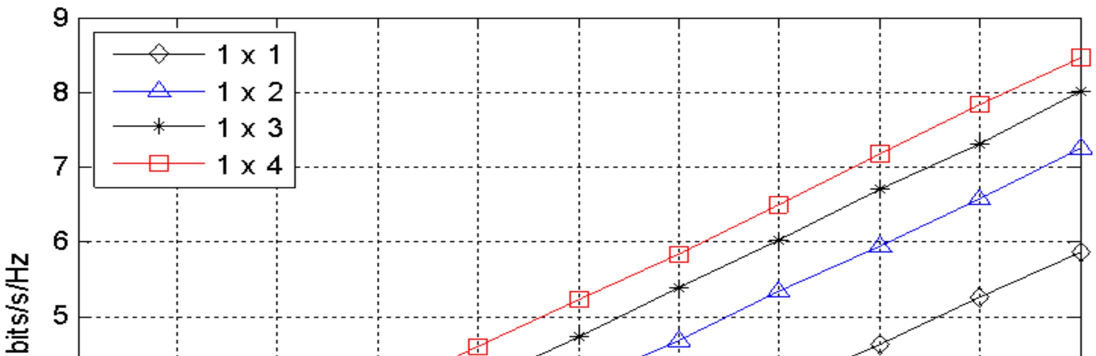


Figure 32 SISO, SIMO, MISO, and MIMO channel capacity flow chart

4.3.1. Channel Capacity of SIMO system

The addition of receive antennas yields a logarithmic increase in capacity in SIMO channels, due to the array gain of the receive antennas. However, knowledge of the channel at the transmitter for this system provides no additional benefit. The channel capacityof SIMO system is shown in **Figure 33**for M_R = 2, 3 and 4. From **Figure 33**, it can be seen that SIMO system has a channel capacities at SNR = 18 dB of about 6.572 bit/s/Hz, 7.3 bit/s/Hz, and 7.822 bit/s/Hz for M_R = 2, 3, and 4, respectively. The maximum capacity improvement for SIMO system over SISO system was achieved by using 1×4 transmission, which is about 2.577 bit/s/Hz at SNR = 18 dB.



4.3.2 Channel Capacity of MISO system

For MISO system, when CSI is unknown, the transmit power will be equally divided between all the transmit antennas. This yields in a very low capacity improvement over SISO system. If CSI is known to the transmitter, MISO capacity channel will be improved. This is shown in **Figure 34**.

From**Figure 34**, it can be seen that, when the transmitter has no CSI, MISO system achieves a capacity improvement over SISO system at SNR = 18 dB by about 0.422 bit/s/Hz and 0.544 bit/s/Hz for M_T = 2, and 3, respectively. If CSI is available at the transmitter, these capacities can be farther improved over SISO system, and it will be about 1.367 bit/s/Hz and 2.072 bit/s/Hz for M_T = 2, and 3, respectively, when CSI is available at the transmitter. **Table 3** presents a numerical results for the achieved capacities by using different numbers of transmit antennas at SNR = 18 dB for both, known and unknown CSI.

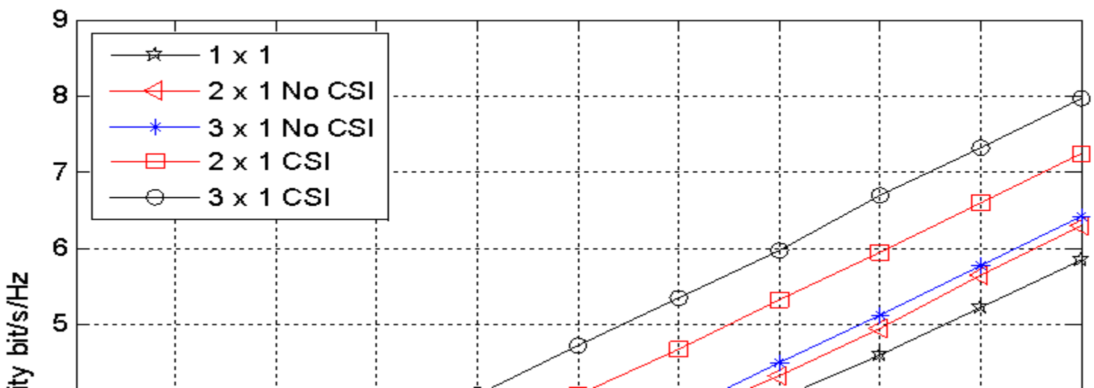


Table 3 Numerical results for the achieved capacity of MISO system with different numbers of transmit antennas

Transmission type \ Channel capacity	For unknown CSI	For known CSI
1×1	5.245	5.245
2×1	5.7	6.631
3×1	5.85	7.295
4×1	5.85	7.809

4.3.3. MIMO Capacity with No CSI at the Transmitter

By using multiple transmit and receive antennas, the channel capacity can be much better than the earlier examined systems. From **Figure 35**, at SNR = 18 dB, the MIMO channel capacities are about, 10.11 bit/s/Hz, 11.17 bit/s/Hz, 13.15 bit/s/Hz, and 19.63 bit/s/Hz for transmission schemes of 2×2, 4×2, 2×4, and 4×4 respectively. The maximum capacity improvement over SISO system is about 14.385 bit/s/Hz for 4×4 transmission, at SNR = 18 dB.

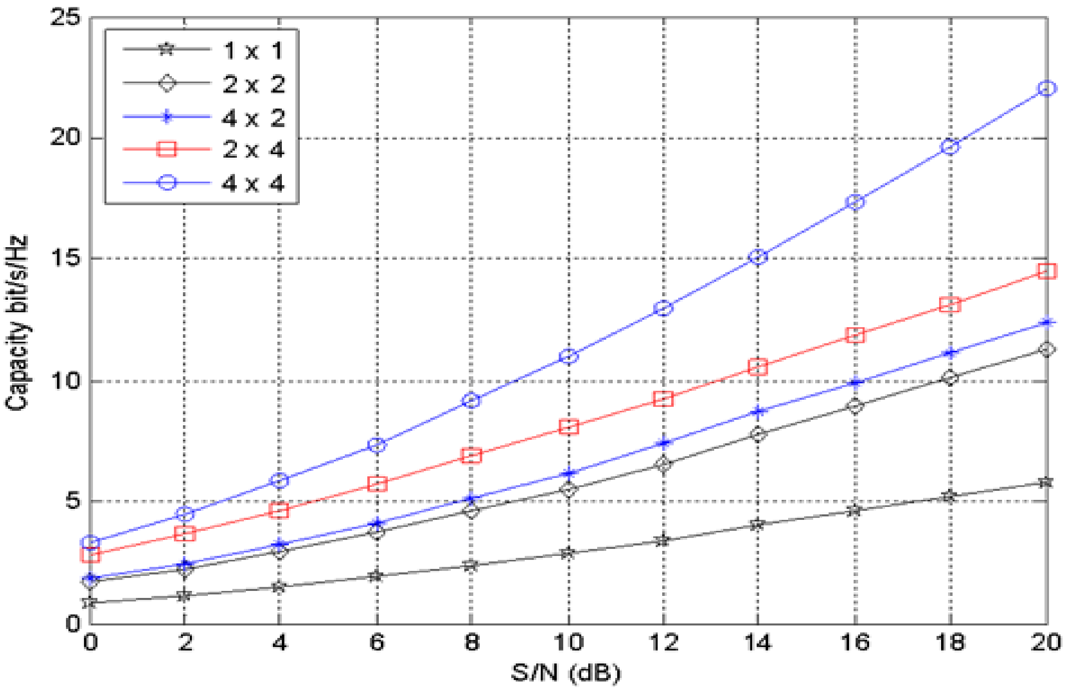
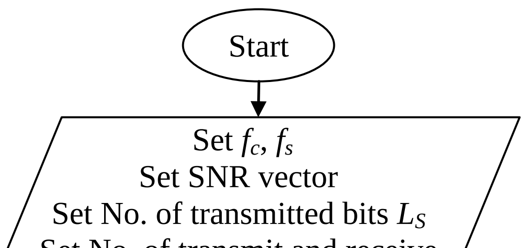


Figure 35 MIMO channel capacity with no CSI at the transmitter

4.3.4. MIMO Capacity with CSI at the Transmitter (Water-Filling (WF) Method)

When CSI is available at the transmitter, the MIMO channel capacity could be further increased by optimally allocating power to each transmit antenna using Water-Filling (WF) principle. **Figure 36** shows the program flow chart of WF Method.



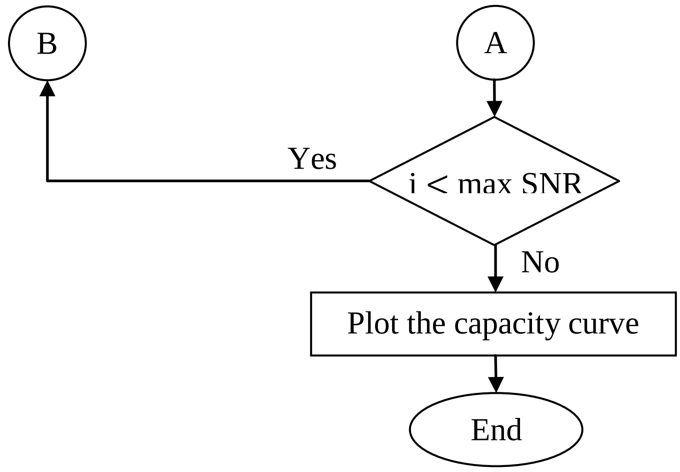


Figure 36 Continued

The comparison of MIMO system capacities for known and unknown CSI at the transmitter is shown in **Figure 37**, for 4×2, and 4×4 transmission cases. From Fig. (4.19), it can be seen that, there is a clear difference in channel capacity between unknown and known CSI at the transmitter for 4×2 transmission cases. The difference is decreased for 4×4 transmission cases. This is because that, for 4×2 transmission cases, the number of transmit antennas is more than the number of receive antennas($M_T = 2M_R$), and hence, the almost channel capacity will depend on the transmitter, thus, the existence of CSI at the transmitter for 4×2 transmission will has an important role in increasing the MIMO channel capacity and vice versa. For 4×4 transmission cases, the number of transmit antennas not exceeds the number of receive antennas and hence, the MIMO channel capacity will not be of high dependence on the transmitter. For more details, **Table 4** provides a numerical results comparison of MIMO channel capacities for unknown and known CSI at the transmitter, with different transmission cases.

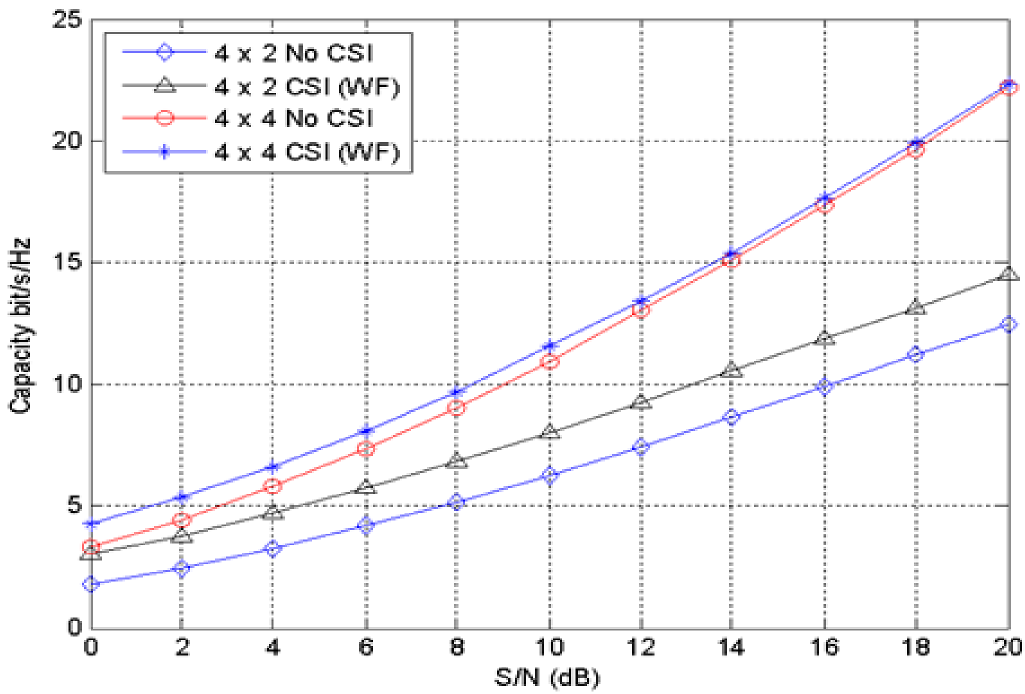


Figure 37 MIMO channel capacity comparison with CSI (water filling) and without CSI at the transmitter

Table 4 Numerical results for the achieved capacity of MIMO system with different numbers of transmit and receive antennas

Channel capacity / Transmission type	For unknown CSI	For known CSI
1×1	5.241	5.245
2×2	10.10	10.14
2×3	11.15	12.07
2×4	13.15	13.2
4×2	11.16	13.14
4×4	19.62	20.05

CHAPTER 5

CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORK

5.1. Conclusion

The effect of Rayleigh fading channel humiliates the performance of SISO system and causes a significantly low error rate performance. In addition to that, SISO system has a very limited channel capacity. The presented work in this thesis shows the enhancement gained from using multiple antenna systems.

The conclusions obtained from the results of using diversity in MIMO systems are summarized below, this system includes its own types of diversity techniques. Here also the new implementation and characteristic of self-designed Band Pass Filter (BPF) is reported, which are used to reject image bands. This provides higher harmonics suppression in out of band region which is very interesting in MIMO communication system .The proposed filter has obvious lower insertion loss as compared to reported microstripbandpass filter for MIMO wireless system indicated in [7].

By the way ,STBC has very good error rate performance, since it provides a diversity gain through coding across space and time to achieve a reliable transmission.Also, MIMO antenna configurations have better BER as compared to SIMO and MISO cases. It should be mentioned that the new proposed MIMO-OFDM model has higher data rate and lower bit error rate as compared to [45].

The proposed MIMO wireless system has better channel capacity enhancement as compared to SIMO and MISO cases. Its capacity increases linearly with increasing number of transmit and receive antennas. The MIMO capacity can become optimal, if the transmitter has a full CSI knowledge. In this case, Water-Filling (WF) theorem is used to allocate the desired power in each subchannel.

The following conclusions have been obtained from channel capacity results of multiple antennas systems:

1. SIMO system provides a slight channel capacity enhancement over SISO system, and its increases with the number of receive antennas. Furthermore, Since CSI is often easy to obtain at the receiver, SIMO system usually has a higher channel capacity than MISO system.

2. MISO system has lower channel capacity than SIMO system, when the transmitter has no CSI, which is not easy to obtain as in SIMO system, because it requires a feedback from the receiver to inform the transmitter. If the transmitter has a full CSI, MISO system has the same channel capacity of SIMO system.

3. MIMO system has best channel capacity enhancement. Its capacity increases linearly with increasing number of transmit and receive antennas. The MIMO capacity can become optimal, if the transmitter has a full CSI knowledge. In this case, Water-Filling (WF) theorem is used to allocate the desired power in each subchannel.

5.2. Suggestions for Future Work

MIMO systems can offer new means to attain both superior bit rates and minor error rates with no necessitating additional bandwidth or additional transmission power . Whilst spatial diversity protects the communication system from the effects of multipath propagation when multiple antennas are used at either the transmitter or receiver, significant capacity increases can be achieved by using multiple antennas at both ends of the link.For future work, there are few possible extensions to the presented work, which are listed below:

1. The presented results are based on numerical techniques carried out by the adopted softwares; however, practical confirmation throughout measurements is still needed.

2. MIMO channel models adopted in this work suppose a flat fading surroundings. Nevertheless, in mobile channel, the signals frequently suffer frequency selective fading and a variety of multipath factors can be determined. It would be positive to enlarge the analysis on MIMO models to report various cases of frequency selective fading.

3. The MIMO-OFDM and MIMO-OFDMA systems are hopeful techniques in high data rate wireless communications.

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