TRIBHUVAN UNIVERSITY
INSTITUTE OF ENGINEERING

PULCHOWK CAMPUS

THESIS NO: 070/MSI/611

MIMO CHANNEL SIMULATION AND ANALYSIS FOR MOBILE AD HOC WIRELESS NETWORKS

BY

Rajendra Upadhyay

A THESIS

SUBMITTED TO THE DEPARTMENT OF ELECTRONICS AND COMPUTER ENGINEERING IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN INFORMATION AND COMMUNICATION ENGINEERING

DEPARTMENT OF ELECTRONICS AND COMPUTER ENGINEERING

November, 2015

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A thesis submitted in partial fulfilment of the requirements for the degree of Master of Science in Information and Communication Engineering

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November, 2015

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The undersigned certify that they have read and recommended to the Department of Electronics and Computer Engineering for acceptance, a thesis entitled **"MIMO Channel Simulation and Analysis for Mobile Ad Hoc Wireless Networks**", submitted by **Rajendra Upadhyay** in partial fulfilment of the requirement for the award of the degree of "**Master of Science in Information and Communication Engineering**".

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DEPARTMENTAL ACCEPTANCE

The thesis entitled **"MIMO Channel Simulation and Analysis for Mobile Ad Hoc Wireless Networks**", submitted by **Rajendra Upadhyay** in partial fulfilment of the requirement for the award of the degree of "**Master of Science in Information and Communication Engineering**" has been accepted as a bonafide record of work independently carried out by him in the department.

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ACKNOWLEDGEMENT

I have taken effort in this thesis. However, it would not have possible without the kind support and help of many individuals and **Institute of Engineering, Pulchowk Campus**. I would like to extend my sincere thanks to all of them. I am very much thankful to the Department of Electronics and Computer Engineering, Institute of Engineering for accepting my thesis on **“MIMO Channel Simulation and Analysis for Mobile Ad-Hoc Wireless Networks”**. Furthermore I would like to acknowledge with much appreciation the crucial role of our Master’s degree program coordinator, **Dr. Surendra Shrestha**.

I would like to express my special gratitude and thanks to my supervisor **Prof. Dr. Shashidhar Ram Joshi** for his support over the whole thesis. His advices on technical matters are invaluable, and his guidance is very critical for the successful of my thesis.

Also I would like to express my special gratitude and thanks to **Er. Krishna Prasad Bhandari** for his invaluable suggestions.

Finally, I’d like to express my heartfelt thanks to my family and my friends who have always encouraged and supported me.

ABSTRACT

The radio channel has very significant characteristics specially in Mobile Ad Hoc Wireless Networks because of its dynamic configuration, mobility, type of terrains in which the networks operates and fading and multipath propagation. The integration of Multiple Input Multiple Output (MIMO) elements for either diversity or spatial multiplexing makes the channel more complex for study and analysis. This thesis work implements the MIMO channel simulation for Mobile Ad Hoc Wireless Networks and studies and examines the effects of important characteristics on the channel. The characteristics like Doppler shift due to mobile devices, Doppler power spectrum, type of terrains, spatial correlation have been introduced in the channel and examined the channel behaviour. The MIMO channel simulation is implemented based on power delay profile, Doppler power spectrum and spatial correlation at the transmitter and receiver. The spatial correlation present at the transmitter and receiver has seen to have great effect on fading envelopes at the channel output. The simulation results obtained for 1*2 MIMO diversity indicate that the Gaussian spectrum is more suitable for signal estimation in low mobile velocity both in urban and hilly areas. But in high mobile velocity, Flat spectrum is suitable for signal estimation in urban areas and Flat and Jakes spectrum both are suitable for signal estimation in hilly areas.

.

Keywords: Ad Hoc, MIMO, Doppler shift, Doppler power spectrum, spatial correlation, fading envelope

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List of Abbreviations

WLAN	Wireless Local Area Network
MANET	Mobile Ad Hoc Network
MIMO	Multiple Input Multiple Output
LOS	Line of Sight
IEEE	Institute of Electrical and Electronics Engineering
TDL	Tapped Delay Line
QPSK	Quadrature Phase Shift Keying
SNR	Signal to Noise Ratio
CSI	Channel State Information
PAS	Power Azimuth Spectrum
Tx	Transmitter
Rx	Receiver
ISM	Instrumentation, Scientific and Medical
PDP	Power Delay Profile
ITU	International Telecommunication Authority

Chapter 1: INTRODUCTION

1.1 Background

The trend of communication is going from wired to wireless. Almost all of the communication systems are being deployed wirelessly keeping wired network for backup and highly reliable communication. There are different kinds of wireless communication system being realized till date and many more are yet to come. Majority of wireless communication system is based on some form of fixed infrastructure networks be it either a satellite communication, mobile communication and wireless local area networks (WLAN). Today, many people carry numerous portable devices, such as laptops, smartphones, tablets etc, for use in their professional and private lives. Increasing trend of such portable devices is indicating the need of emergence of some form of dynamic network that need not always be relying on the pre-existing infrastructure. And there is no doubt that today the whole world is faced with natural disasters like tsunami, volcanic eruptions, earthquakes, floods, landslides and other. All of these catastrophic events can lead to human, financial and environmental losses. During a disaster saving of the human life is priceless, so the time of reaction of the rescue teams in a rescue mission is critical and it depends on time needed to determine the exact location of the survivors in order to give them the necessary assistance. Usually in this case, the places that are affected from a disaster are destroyed and do not support centralized networking [1]. In this kind of situations Mobile Ad Hoc networking (MANET) plays key role in the process of enabling communication with the outside world.

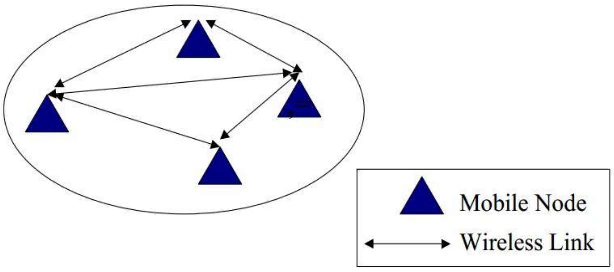

Figure 1: Mobile Ad Hoc Network

Figure 1. shows a mobile ad hoc network. While in principle, the communications among the nodes is on a peer to peer basis, one of the nodes may be elected to become

a gateway for coordination of external connectivity. Ad hoc networks self-organize by adjusting themselves as users join, leave, or move. Such a network is formed without requiring pre-existing infrastructure or centralized administration. Nodes within transmission range can communicate directly with each other, but those out of range must rely on other nodes to forward along packets to their final destination[2]. Because they can be deployed quickly and require no extra planning, ad-hoc networks are often useful for establishing temporary communication in classroom settings, business meetings, or disaster relief situations. They are extensively used in military communication. In general, in a mobile ad hoc network, there are no fixed points of failure like base stations that can be disabled by a strike.

Multiple Input Multiple Output (MIMO) systems have recently become one of the most active research topics in the field of wireless communications. MIMO systems basically use multiple antenna elements at both the transmitter and the receiver. They utilize independent multipath propagation and channel fading to increase the capacity [3]. MIMO systems can be used to either send the same bit stream from all the transmit antennas and use the Diversity gain [4] for very reliable communication or by sending independent bit streams from the transmit antennas (as in Spatial Multiplexing) to increase the data transmission rate, without using extra Bandwidth. This study simulates the MIMO based mobile ad hoc wireless networks and explores the effects of varying the various radio channel parameters

1.2 Problem Statement

Ad hoc networking enables its users to roam about freely, but its radio channel presents a hostile environment to a transmitted signal as compared to transmission on a fixed wireless link.. The transmission path between the receiver and the transmitter can be altered from simple line-of-sight (LOS) to one that is drastically obstructed by buildings, foliage and mountains. Even the speed of the mobile impacts how rapidly the signal level fades. Similarly, as radio waves propagate through space, multiple corruptions due to morphology, temperature and humidity of the environment through which they are travelling can occur. As a consequence, mobile radio transmissions usually suffer large fluctuations in both time and space. Modelling the wireless channel has historically been one of the most difficult parts of the communication system design. Enough research have been done in infrastructure based wireless networks developing various channel model. But there is not sufficient study regarding radio channel of the mobile ad hoc wireless network. All the study related to mobile ad hoc network are carried in data link layer and above considering various routing protocols.

1.3 Objective and Technical Approach

The objective of this thesis study is to implement a MIMO radio channel model and examine the effects of various parameters on the channel behaviour that represents the environments in which mobile ad hoc wireless networks operate with multiple antenna elements both at the transmitter and receiver. The various physical phenomena and parameters considered in this modelling are outdoor environments, fading and multipath propagation, type of terrains, mobility (Doppler shift).

In order to meet the objective of the thesis, a MIMO channel model incorporating the doppler shift and power delay profile and spatial correlation will be implemented in the MATLAB and results of the simulation will be analyzed and presented.

Chapter 2: LITERATURE REVIEW

Mobile Ad hoc Wireless Networks is a new and interesting topic to research for research enthusiastic. There are various aspects of study going on around about the topic. Ad hoc mode of communication is also supported by various contemporary communication systems like IEEE 802.11 WLAN and IEEE 802.11 PAN. IEEE 802.11 WLAN is infrastructure based communication system standard but it has been evolving continuously in the name of different versions to support different communication mode and data rate. One of the standard IEEE 802.11/b supports single-hop communication for ad hoc capability.

R. Wang and D.Cox have attempted to model channel for Ad hoc mobile wireless networks based on fading models used in cellular networks[5]. This paper shows a way to simulate small-scale and large-scale fading on links in an ad hoc network and present simulation results for a multipath shadowed outdoor environment. It further studies fundamental discrepancies between ad hoc and cellular network and finds that link performance is worse for the ad hoc case. But the performance gap shrinks with increased mobility. The model assumes that the two communicating nodes are heavily shadowed from each other (no dominant path) and that signal energy arrives equally divided in angles uniformly distributed in the horizontal plane. It is based on flat Rayleigh fading and utilizes Line Spectrum method.

D.C. Karia, B.K. Lande and R.D. Daruwala have studied about characterization of radio channel for mobile ad hoc wireless networks[6]. This paper propose a suitable mobile radio channel model based on a Tapped Delay Line (TDL) structure that not only examines the effect of various parameters on channel behavior, but also represent the environment in which the mobile ad hoc wireless networks operates. The mobile ad hoc network assumed in the study is based on IEEE 802.11 b/g. The performance of the time-varying nature of the radio channel is studied and simulated by plotting the signal constellations using QPSK modulation Technique.

K.K. Praveen and Dr. K. Kalaiarasi have surveyed on IEEE standards for Mobile Ad hoc Networks [7].This paper attempts to provide an overview of this dynamic field. It explains the important role that mobile ad hoc networks play in the evolution of future wireless technologies, its characteristics, capabilities and the architecture of MANET. It also explains the IEEE standard 802.11 for Wireless LANs (WLANs) and all the circumventing design issues and how it can be used to enable ad hoc networking.

Dr.I. khider, Prof.W. Furong, A. Saad used the simulation model to study some general characteristics of urban environments and their impact on MANET performance[8]. They investigated some important issues related to the simulation and use of MANETs in urban environments supported with base stations. They have presented a radio wave propagation models which showed how these models affect the performance of Mobile Ad Hoc Networks in urban area.

M. E. Khan [9] presents a study of various papers on Multiple Input Multiple Output (MIMO) capacity in Rayleigh fading channel. Reference papers are evaluated with the intent to simulating spatially correlated Rayleigh fading channel model and its associated parameters. It is argued that an implementable model isn’t readily available in the evaluated reference papers. As such a model is developed for simulating spatially correlated MIMO system in Rayleigh fading channel. Capacity of MIMO systems is also evaluated based on references and it is shown that the references provide a thorough description which is then utilized in developing the simulation code. To verify the developed model, a Matlab code is devised to simulate the capacity of MIMO system which is compared with the results presented in references.

E. Mohamed and A.M. Abdulsattar [10] evaluate the MIMO system capacity over Rayleigh fading channel. Correlated and uncorrelated channels MIMO system was considered in this paper for different number of antennas and different SNR over Rayleigh fading channel. At the transmitter both CSI(channel state information) technique and Water filling power allocation principle was also considered in this paper.

Chapter 3: RELATED THEORY

3.1 Typical Propagation Environments

Two models of propagation environments that are widely used in system performance evaluation [11] are urban areas and hilly terrain. In urban areas, typical values of multipath spread range from 1 to 10 µs and is governed by the following equation:

$$\mathrm{P}(\tau) = \begin{cases} \exp(-\tau) & \text{for } 0 < \tau < 7\mu\mathrm{s} \\ 0 & \text{elsewhere} \end{cases} \tag{1}$$

where $P(\tau)$ is the received power as a function of the delay τ.

In rural mountainous areas, the multipath spreads are much greater, with typical values in the range of 10 to 30 µs as given by

$$\mathrm{P}(\tau) = \begin{cases} \exp(-3.5\tau) & \text{for } 0 < \tau < 2\mu s \\ 0.1\exp(15-\tau) & \text{for } 15 < \tau < 20\mu s \\ 0 & \text{elsewhere} \end{cases} \tag{2}$$

3.2 Multipath Propagation

For most practical channels, where signal propagation takes place in the atmosphere and near the ground, the free-space propagation model is inadequate to describe the channel [12]. In a wireless mobile communications system, a signal can travel from the transmitter to the receiver over multiple reflective paths; this phenomenon is known as multipath propagation. This effect can cause fluctuations in the received signal's amplitude, phase, and angle of arrival, known as multipath fading. there are two main types of fading effects that characterize mobile communications, large-scale fading and small-scale fading. A mobile radio roaming over a large area must process signals that experience both types of fading, small-scale fading superimposed on large-scale fading. An overview of the fading channel manifestations [13] is as shown in Figure 2. It shows that there are two main types of fading effects that characterize mobile communications, large-scale fading and small-scale fading. A mobile radio roaming over a large area must process signals that experience both types of fading, small-scale fading superimposed on large-scale fading.

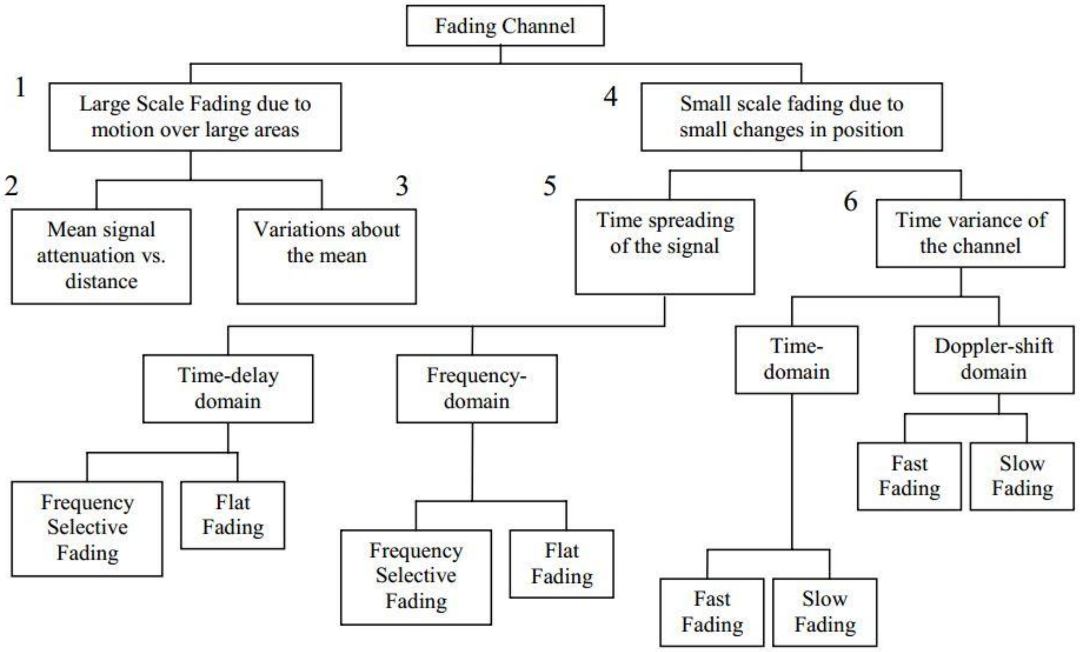

Figure 2: Fading Channel Illustration

3.2.1 Large-Scale and Small-Scale Fading

Large-scale fading is affected by prominent terrain contours (e.g., hills, forests, clumps of buildings, etc.) between the transmitter and the receiver [13]. Small-scale fading refers to the rapid fluctuations in signal amplitude and phase that can be experienced as a result of small changes in the spatial separation between a receiver and a transmitter. Small-scale fading manifests itself in two mechanisms, namely, time-spreading of the signal and time-variation of the channel. For mobile radio applications, the channel is time-varying because motion between the transmitter and the receiver results in propagation path changes.

3.2.2 Delay Spread

The reflected paths are usually longer than the direct path, which means that these signals reach the receiver later than those from the direct path [13]. As a consequence, the signals from different paths can arrive at the receiver with different delays and at different times as shown in Figure 3. The delay spread is thus defined as the maximum time difference between the arrival of the first and last multipath signal seen by the receiver and is a function of the transmission environment.

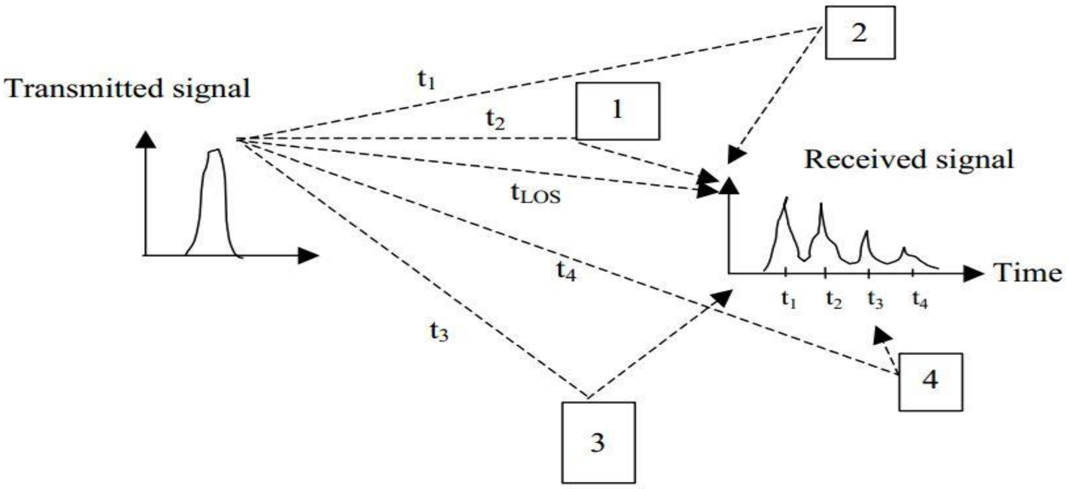

Figure 3: Illustration of Multipath Delay Spread

3.2.3 Rayleigh and Ricean Fading

Small-scale fading is also known as Rayleigh fading [13] when the multiple reflective paths are large in number and there is no LOS signal component. The signal from the transmitter reaches the receiver via other paths that could be a result of reflection, diffraction or scattering from an obstacle. There is no direct LOS path from the transmitter to the receiver. The envelope of the received signal is statistically described by a Rayleigh probability density function (PDF), given by

$$\mathrm{Pd(rl)} = \begin{cases} \dfrac{\mathrm{r}}{\sigma^2 \exp\left(-\frac{\mathrm{r}^2}{2\sigma^2}\right)}, & r \geq 0 \\ 0, & r < 0 \end{cases} \tag{3}$$

where r is the envelope amplitude of the received signal and σ is the rms value of the received voltage signal before envelope detection.

Rayleigh fading [13] is not the only consequence of the multipath phenomenon. In addition to a number of random paths taken by the signal, it is possible to have a LOS signal from the transmitter to the receiver. This LOS signal adds a deterministic component to the multipath signal and has a PDF given by

$$\mathrm{Pd(ri)} = \begin{cases} \dfrac{\mathrm{r}}{\sigma^2 \exp\left(-(\mathrm{r}^2+\mathrm{A}^2)\right)} / 2\sigma^2 \mathrm{I}(\mathrm{Ar}/\sigma^2), & A \geq 0, r \geq 0 \\ 0, & r < 0 \end{cases} \tag{4}$$

where A is the peak amplitude of the dominant signal and I is the modified Bessel function of the first kind and zero-order.

3.3 Mobility

For mobile radio applications, the channel is time-varying because motion between the transmitter and receiver results in propagation path changes. The Doppler effect is a phenomenon caused by the relative velocity between the receiver and the transmitter [14]. When a wave source and a mobile are moving relative to one another, the motion leads to a frequency variation, f, of the received signal known as Doppler shift and can be written as

$$f = {}^{v}\!/_{\lambda} \sin\theta \tag{5}$$

where v is the mobile unit velocity, λ is the wavelength of the incident wave, and θ is the angle of incidence.

3.4 MIMO Channel Models

Single Input Single Output (SISO) channel models provide information on the distributions of signal power level and Doppler shifts of received signals. MIMO channel models, which are based on the classical understanding of multi-path fading and Doppler spread, incorporate additional concepts such as Angular Spread, Angle of Arrival, Power Azimuth Spectrum (PAS), and the antenna array correlation matrices for the transmitter (Tx) and receiver (Rx) combinations[15]. Figure 4. shows the multipath signals in an uniform linear array for MIMO channel.

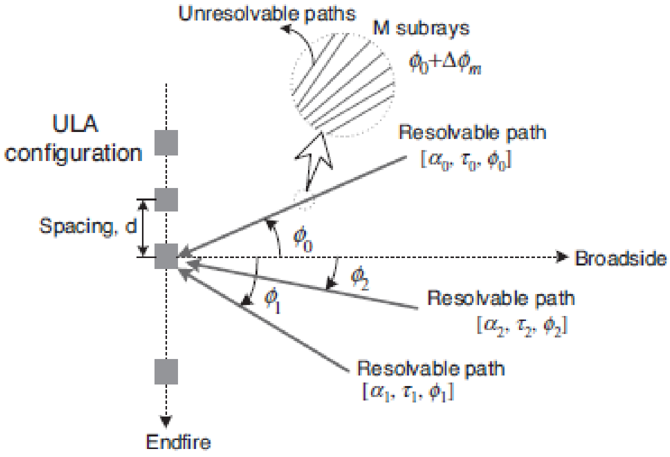

Figure 4: Multipath signals in a uniform linear array

The incredible versatility and performance gains of MIMO systems have produced many MIMO channel models in the last years. Such MIMO channel models can be classified into 2 main groups: physical models and analytical models.

- Physical models characterize the double-directional impulse responses $h(t,\tau,\Omega_t\Omega_r)$, based on physical wave propagation: deterministic (ray-tracing), stochastic, geometry-based, geometry-stochastic based, etc.
- Analytical models describe the MIMO channel matrix $H(t,\tau)$ in function of spatial and time correlations properties.

Both approaches have advantages and disadvantages. In one hand physical models have a sophisticated approach to the propagation between multiple antennas and their surroundings. However, they do not have analytical expressions that allow a physical design (space-time coding, beamforming, signal processing for instance), besides of being very computationally intensive. On the other hand, analytical models are relatively simple to use for design and to implement for simulations at the physical level. However, they are a formal and they do not give propagation quantitative information.

3.5 MIMO Channel Model Classification

There are three main approaches to MIMO channel modeling: the correlation model, the ray-tracing model, and the scattering model[15]. The properties of these models are briefly described as follows:

1. **Correlation Model**: This model characterizes spatial correlation by a linear combination of independent complex channel matrices at the transmitter and receiver.
2. **Ray-Tracing Model**: In this approach, exact location of the primary scatterers, their physical characteristics, as well as the exact location of the transmitter and receiver are assumed known. The resulting channel characteristics are then predicted by summing the contributions from a large number of the propagation paths from each transmit antenna to each receive antenna. This technique provides fairly accurate channel prediction by using site-specific information, such as database of terrain and buildings. For modeling outdoor environments this approach requires detailed terrain and building databases.
3. **Scattering Model**: This model assumes a particular statistical distribution of scatterers. Using this distribution, channel models are generated through simulated interaction of scatterers and planar wave-fronts. This model requires a large number of parameters.

3.6 Power Delay Profile

Power delay profile provides an indication of distribution or dispersion of the signal in a multipath propagation[15]. A typical plot of the power delay profile is shown if Figure 5.

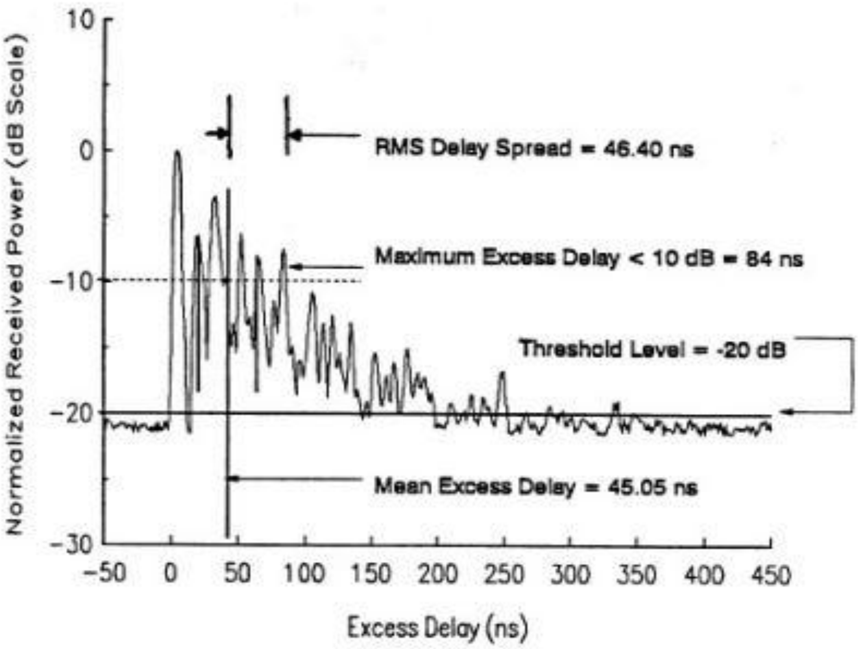

Figure 5: Typical Power delay profile

Multipath propagation causes severe dispersion of the transmitted signal. The expected degree of dispersion is determined through the measurement of the power-delay profile of the channel. Time dispersion varies widely in a mobile radio channel, due to the fact that reflections and scattering occur at seemingly random locations, and the resulting multipath channel response appears random, as well. Time dispersion is dependent on the geometrical position relationships among the transmitter, the receiver, and the surrounding physical environment.

Chapter 4: METHODOLOGY

This chapter discusses the simulation model used to represent the MIMO channel in mobile ad hoc wireless networks. The aim of the simulation was to study the system behaviour under different channel conditions. A simulation of MIMO channel was performed in MATLAB.

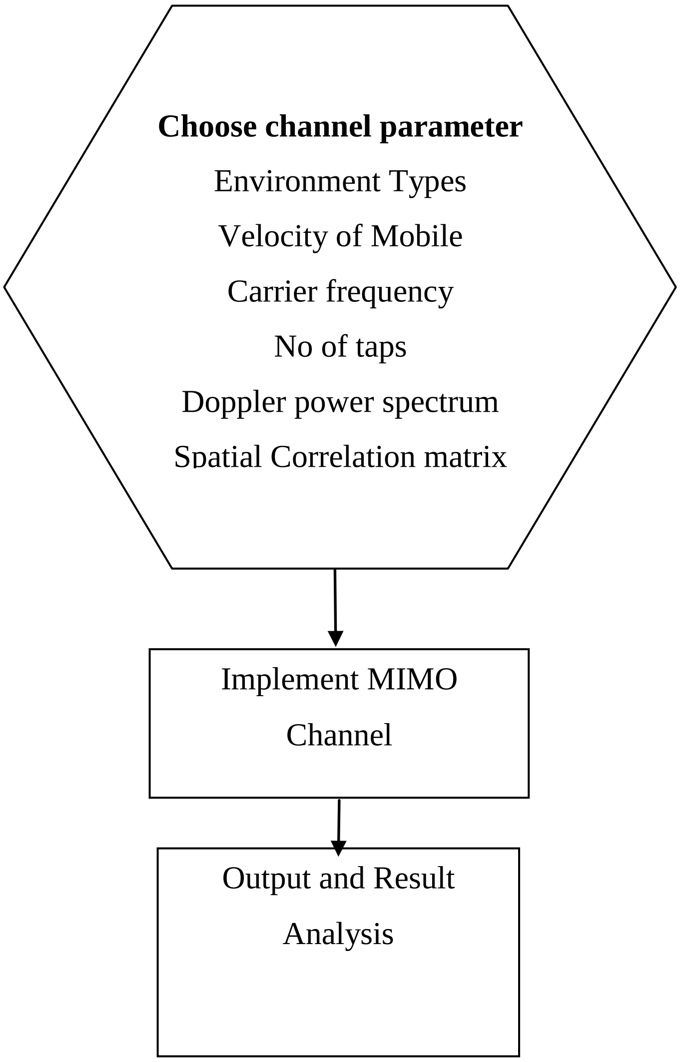

Figure 6: Overall approach of channel simulation

Figure 6. shows the overall procedure of the simulation approach from setting initial parameters of the simulation model to the output and result analysis. First of all, the initial parameters like environment types, velocity of mobile, carrier frequency, no of taps, power spectrum model, spatial correlation matrix are given to represent the scenario in which the channel operates. The environment types could be either urban

and suburban or hilly terrain, velocity of mobile devices can take a range of values, carrier frequency can take values in the ISM bands, number of tap of channel can take range of values to account for multipath propagation, Doppler power spectrum could be either Jakes, Flat or Gaussian, spatial correlation matrix can take the range of values depending upon the spatial configuration of multiple antenna elements at the transmitter and receiver.

4.1 MIMO Channel Simulation

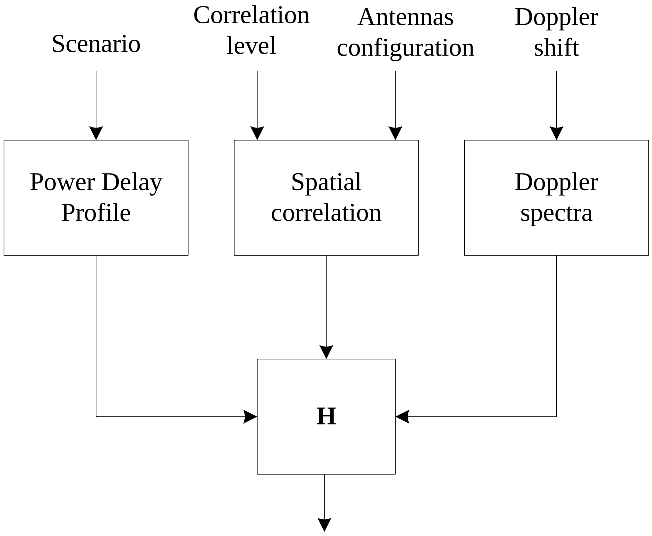

Figure 7: MIMO channel simulation methodology

Figure 7. shows how three types of characteristics namely temporal characteristics, frequency characteristics and spatial characteristics are used to implement the MIMO channel. Mobile ad hoc radio channel is a challenging environment, in which the high mobility causes rapid variations across the time-dimension, multi-path delay spread causes severe frequency-selective fading, and angular spread causes significant variations in the spatial channel responses. For best performance, the Rx & Tx algorithms must accurately track all dimensions of the channel responses (space, time, and frequency). Therefore, a MIMO channel model must capture all the essential channel characteristics, including

- Spatial characteristics (Angle Spread, Power Azimuth Spectrum, Spatial correlations),
- Temporal characteristics (Power Delay Profile),

- Frequency-domain characteristics (Doppler spectrum).

In MIMO systems, the spatial (or angular) distribution of the multipath components is important in determining system behaviour. System capacity can be significantly increased by exploiting rich multi-path scattering environments.

4.2 Correlated MIMO fading channel

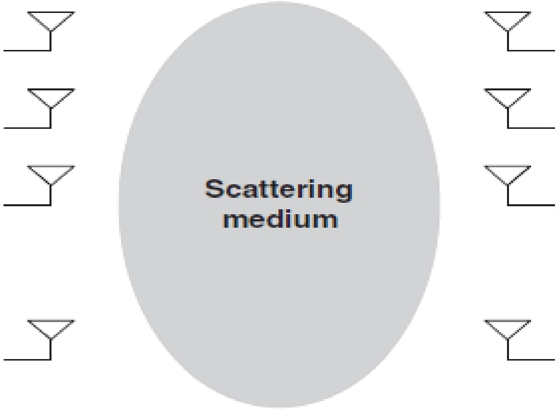

Figure 8: Schematic diagram of the MIMO correlation model

A typical analytical model describes the MIMO channel matrix as a function of a random Gaussian fading matrix shaped by spatial and temporal correlations. Such correlation values depend on the antenna array structure, environment, power delay profile (PDP), power azimuth spectrum (PAS) and Doppler spectrum. Those values are obtained after intense characterization of measurement campaigns. Figure 8. shows the schematic diagram of the MIMO correlation model.
The spatial correlation matrix is defined as

$$\mathrm{R} = \mathrm{E}\left[vec(\mathrm{H})^{H} vec(\mathrm{H}^{H})^{H}\right] \tag{6}$$

where R is a N_tN_r x N_tN_r positive semi-definite Hermitian matrix that describes the correlation between all pairs of transmit-receive channels, N_t is the number of antennas at transmitter, N_r is the number of antennas at receiver.

Considering the channel between antenna pairs as a sum of a large number of contributions with random and independent phases, directions of departure and directions of arrival, each individual channel is modelled as a zero-mean complex circularly symmetric Gaussian variable.

Consequently, the correlation matrix R constitutes a sufficient description of the stochastic behavior of the MIMO channel. A channel realization is given by

$$vec(\mathrm{H}'^{H}) = \sqrt{\mathrm{R}}\, vec(\mathrm{H}_w^{H}) \qquad (7)$$

where H_w is one realization of identically and independently distributed complex circularly symmetric Gaussian matrix.

Furthermore, Equation.(7) is simplified by the so-called Kronecker model or correlation separability:

$$\mathrm{R} = \mathrm{R}_r \otimes \mathrm{R}_t \qquad (8)$$

where $\mathrm{R}_t = \mathrm{E}[\mathrm{H}^H\mathrm{H}]$ and $\mathrm{R}_r = \mathrm{E}[(\mathrm{H}^H\mathrm{H})^T]$ are the transmit and receive correlation matrices, respectively. This model is valid when the transmit and receive correlation values are independent of the considered receive and transmit antenna respectively.

Finally, under the Kronecker model, the MIMO channel matrix can be expressed as

$$\mathrm{H}' = \sqrt{\mathrm{R}_\mathrm{r}}\, \mathrm{H}_\mathrm{w} \sqrt{\mathrm{R}_\mathrm{t}} \qquad (9)$$

This greatly simplifies expressions like mutual information, error probability, etc., besides it allows for separate transmit and receive optimizations.

Correlation matrices R_t and R_r are provided by typical scenarios and antenna configurations targeted for practical applications found. The correlation matrix and correlation values according to ITU guidelines for advanced radio technologies are given in Table 1, Table 2 and Table 3.

Table 1. Transmit correlation matrix

	One antenna	Two antennas	Four antennas
Tx correlation	$\mathrm{R}_t = 1$	$\mathrm{R}_t = \begin{bmatrix} 1 & \alpha \\ \alpha^* & 1 \end{bmatrix}$	$\mathrm{R}_t = \begin{bmatrix} 1 & \alpha^{1/9} & \alpha^{4/9} & \alpha \\ \alpha^{*(1/9)} & 1 & \alpha^{1/9} & \alpha^{4/9} \\ \alpha^{*(4/9)} & \alpha^{*(1/9)} & 1 & \alpha^{1/9} \\ \alpha^{*} & \alpha^{*(4/9)} & \alpha^{*(1/9)} & 1 \end{bmatrix}$

Table 2. Receive correlation matrix

	One antenna	Two antennas	Four antennas
Rx correlation	$\mathrm{R}_r = 1$	$\mathrm{R}_r = \begin{bmatrix} 1 & \beta \\ \beta^* & 1 \end{bmatrix}$	$\mathrm{R}_r = \begin{bmatrix} 1 & \beta^{1/9} & \beta^{4/9} & \beta \\ \beta^{*(1/9)} & 1 & \beta^{1/9} & \beta^{4/9} \\ \beta^{*(4/9)} & \beta^{*(1/9)} & 1 & \beta^{1/9} \\ \beta^* & \beta^{*(4/9)} & \beta^{*(1/9)} & 1 \end{bmatrix}$

Table 3. Correlation values

Low correlation		Medium correlation		High correlation	
α	β	α	β	α	β
0	**0**	**0.3**	**0.9**	**0.9**	**0.9**

4.3 Kronecker Model

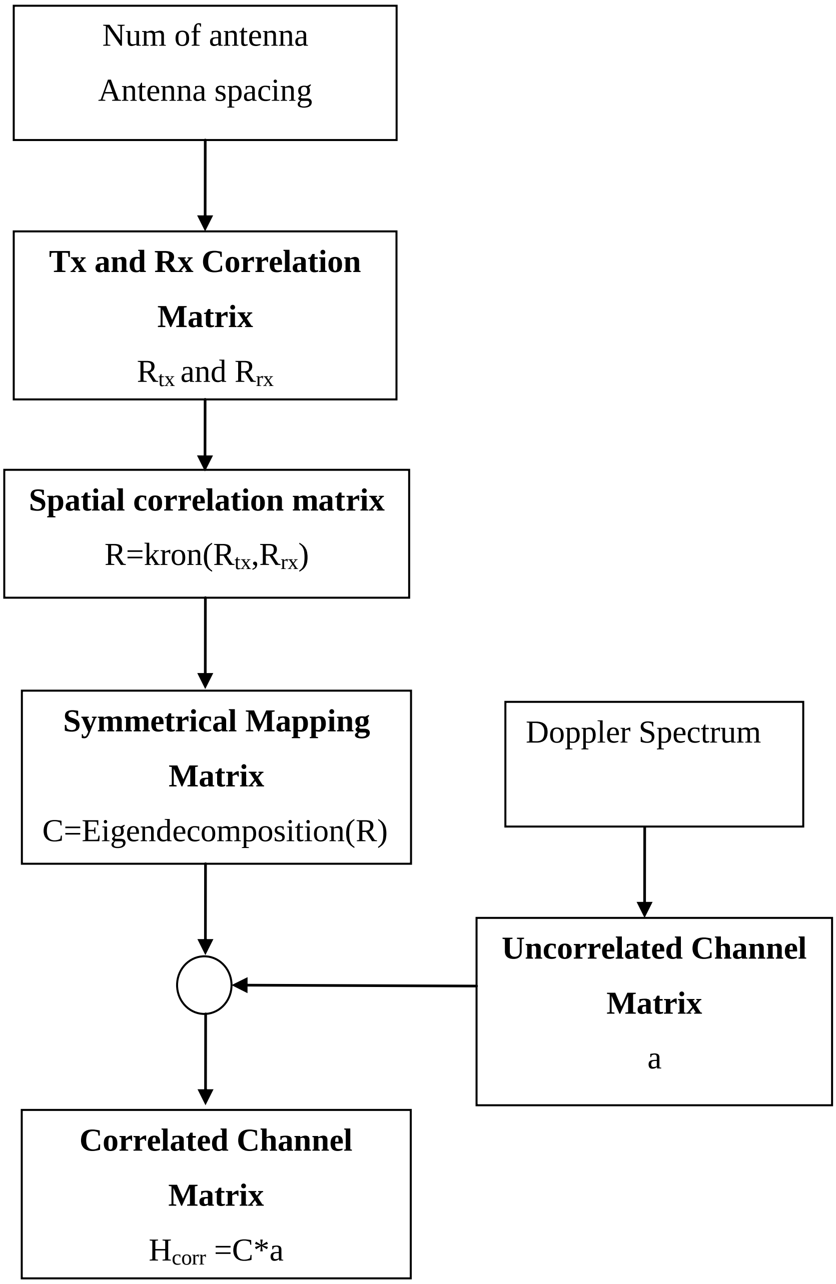

Figure 9: Schematic flow of simulation for the Kronecker model

Figure 9. shows the schematic flow of simulation for the kronecker model. The procedure is divided into two major phases. In the first phase, a correlation matrix is generated for each transmitter station (TX) and receiver station (RX) based on the number of antennas, antenna spacing, number of clusters, power azimuth spectrum (PAS), azimuth spread (AS), and angle of arrival (AoA). These two correlation matrices are combined to create a spatial correlation matrix using the Kronecker

product. In the second phase, a correlated signal matrix is created using fading signals derived from various Doppler spectra and power delay profiles, and a symmetrical mapping matrix based on the spatial correlation matrix.

4.4 Doppler Power Spectrum

To generate the temporally correlated fading signal, various Doppler spectrum with their respective power spectral densities are used. Three types of spectrum used in this thesis are:

- Flat Spectrum:

  The flat spectrum has a rectangular shape as shown in figure 10. The flat spectrum is described by

$$S_F(f) = \begin{cases} {\sigma^2}/{f_d} & -f_d < f < f_d \\ 0 & otherwise \end{cases} \tag{10}$$

  where σ^2 is the total signal power and f_d is the maximum Doppler frequency.

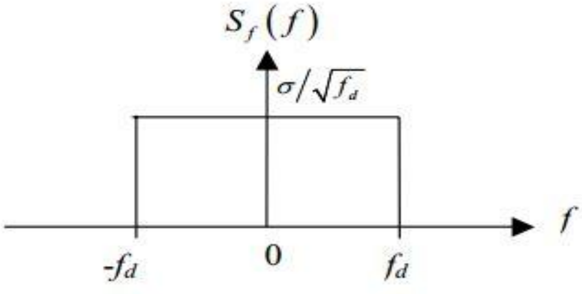

Figure 10: Flat power spectrum

- Gaussian Spectrum:

  The Gaussian spectrum is illustrated in figure 11. and is mathematically described by

$$S_G(f) = \left({2\sigma^2}/{\sqrt{\pi (f_d)^2}} \right) exp \left\{ -\left({f}/{f_d} \right)^2 \right\} \tag{11}$$

  where σ^2 is the total signal power and f_d is the maximum Doppler frequency.

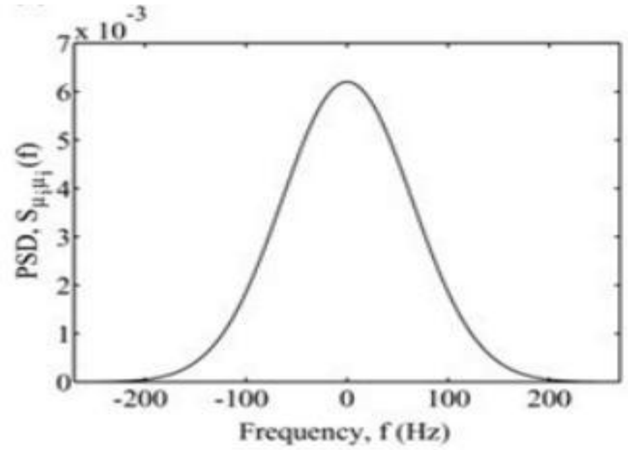

Figure 11: Gaussian power spectrum

- Jakes Spectrum:

The Jakes spectrum that characterizes a mobile radio channel is described by

$$S_J(f) = \begin{cases} 1/\pi f_d\sqrt{1-(f/f_d)^2}, & |f| \le f_d \\ 0, & otherwise \end{cases} \quad (12)$$

where f_d is maximum Doppler frequency.

A plot of Jakes power spectrum is shown in figure 12.

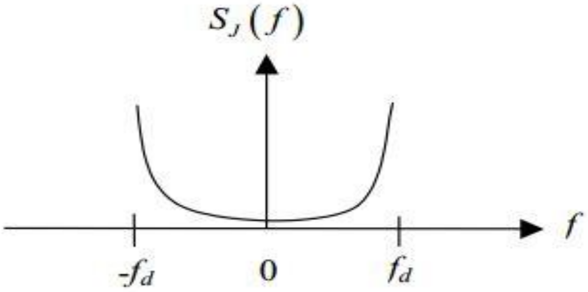

Figure 12: Jakes power spectrum

Chapter 5: SIMULATION RESULT AND ANALYSIS

5.1 Simulation Parameters

Simulations were conducted for different sets of parameters consisting of terrain types, number of taps, velocity of mobile devices, carrier frequency, correlation level, MIMO configuration and Doppler power spectrum. Each of these parameter can take their values considered for simulation.

The terrain types considered in the thesis work are urban and hilly areas which represent the propagation environment. Wireless networks mostly operate in the unlicensed portions of the radio spectrum which are collectively known as an ISM (Instrumentation, Scientific and Medical) bands. These include 902-928 MHz, 2.4-2.483 GHz and 5.725-5.875 GHz. So the carrier frequencies considered for simulation are the ones specified in the ISM band. The choice of number of taps in the simulation is dictated by the amount of multipath propagation in the specified environments. The velocity of mobile devices can take the different values to simulate the high mobility and low mobility scenario in the operating environments. The Doppler frequency shifts due to the motion of transmitter and receiver introduce the time varying characteristics in the channel. The Doppler spectrum is thus used to simulate the time varying nature of the channel. The Doppler power spectrum considered in this work are Jakes, Gaussian and Flat Doppler spectrum. The spatial correlation present due to the incorporation of more than one antenna elements both at the transmitter and receiver in MIMO configuration has great impact on the fading envelopes of the different links among transmitter and receiver. The level of spatial correlation used here are the ones defined by ITU guidelines for Advanced Radio Technologies, i.e. values defined for low, medium and high level of correlation. The number of transmitter is 2 and number of receiver is 2 i.e. 2*2 MIMO configuration is used for simulation.

The simulation results include the plots of the power delay profile, theoretical and estimated Doppler power spectral density, constellation diagram and fading envelope of the different links and paths of MIMO channel.

Power Delay Profile illustrates how power is distributed along time in the environments. It also shows the delay spread due to multipath propagation in the environments. Doppler power spectrum are introduced in the channel where there is relative motion between transmitter and receiver. It shows how a power spectrum is spread across the frequency. Constellation diagram shows the signal as a two-dimensional X-Y plane scatter diagram in the complex plane at symbol sampling instants. In this thesis work, constellation diagram is used as a channel performance evaluation tool based on mapping of input symbol and channel output symbols.

5.2 Simulation Results

First and Second set of simulation parameters for urban terrain is given in Table 4.

Table 4. First and Second Set of simulation parameters for urban terrain

Set	Area	No. of tap	Velocity (mph)	Frequency (MHz)	correlation	configuration	Doppler spectrum
I	urban	6	50	2500	medium	2*2	Jakes
II	urban	6	30	2500	medium	2*2	Jakes

For these simulation parameters, the results are obtained for typical power delay profile, Doppler power spectrum according to link and path, fading envelopes for the different link and paths.

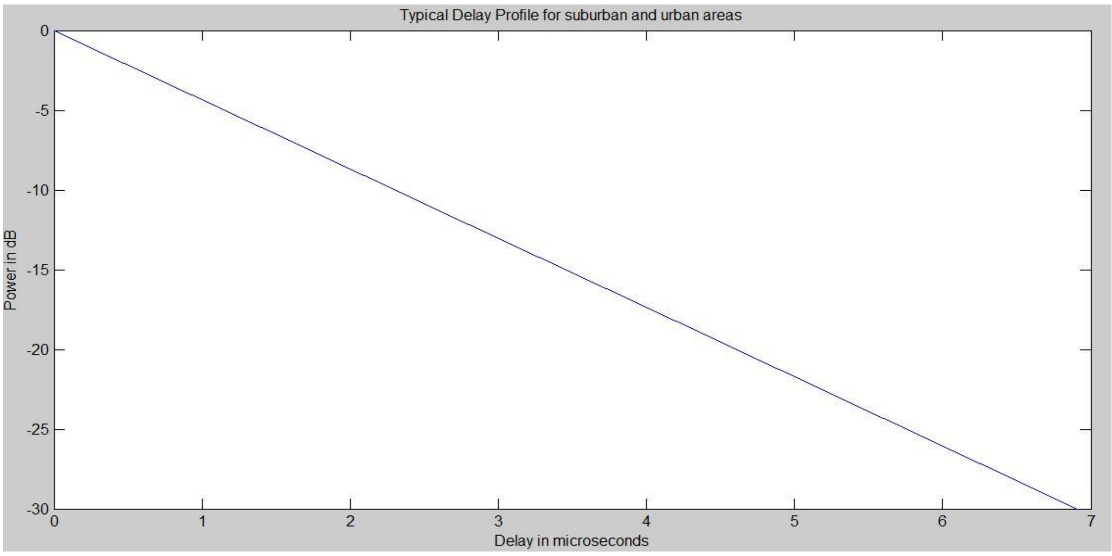

Figure 13: Power delay profile for urban area

Figure 13. shows the power delay profile for urban area with the excess delay spread of 7 micro second.

Results for first set of parameters are given below:

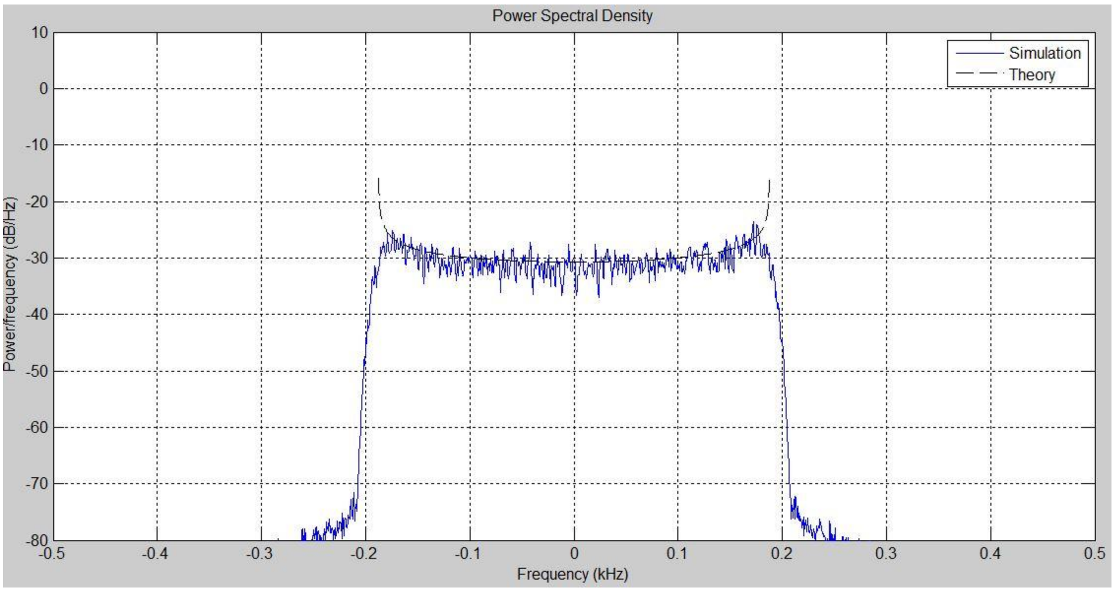

Figure 14: Jakes doppler spectrum of Tx1-Rx1 link of first path

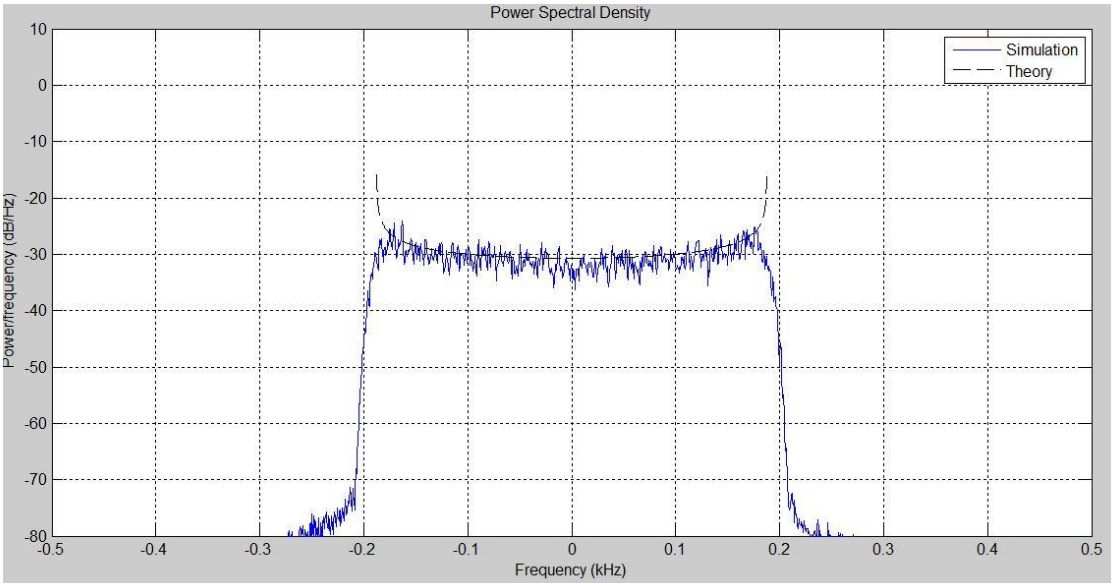

Figure 15: Jakes doppler spectrum of Tx1-Rx2 link of first path

The estimated jakes doppler spectrum as obtained in figure 14. and figure 15. has a good match with the theoretical doppler spectrum. For the mobile velocity of 50 miles per hour and carrier frequency of 2.5 GHz, the maximum doppler shift of 187.5 Hz is obtained. All of the path is assumed to have Jakes Doppler power spectrum in the implemented channel and hence the same result will be obtained for every path.

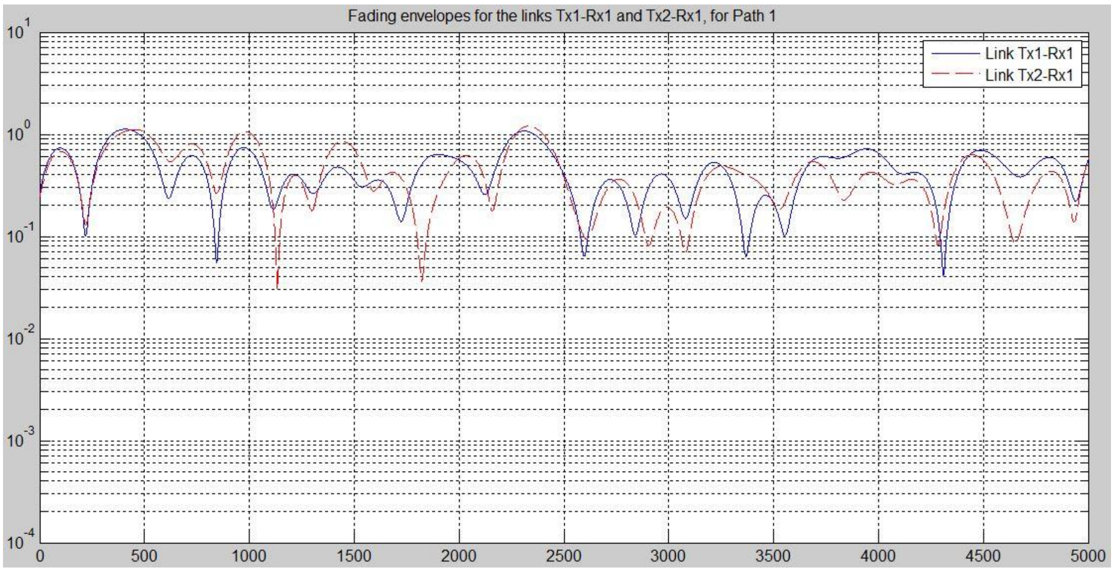

Figure 16: Fading envelopes for the links Tx1-Rx1 and Tx2-Rx1, for Path 1

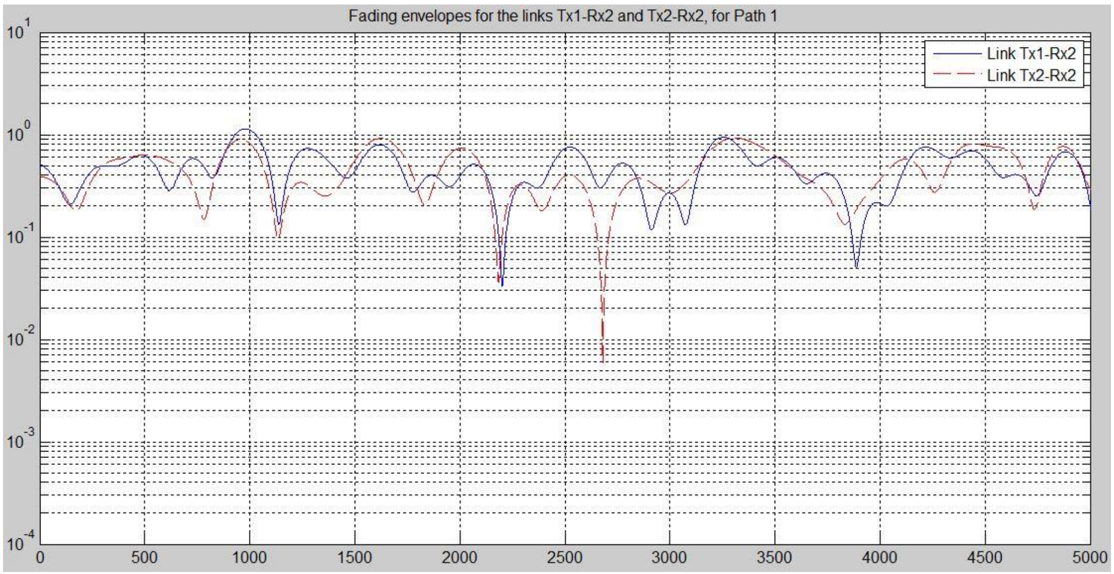

Figure 17: Fading envelopes for the links Tx1-Rx2 and Tx2-Rx2, for Path 1

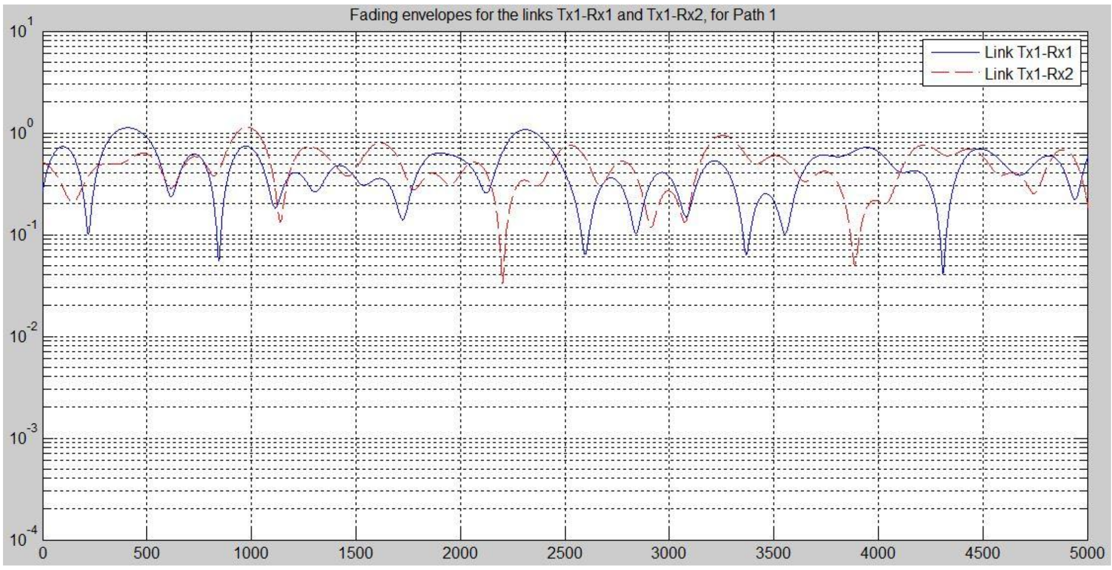

Figure 18: Fading envelopes for the links Tx1-Rx1 and Tx1-Rx2, for Path 1

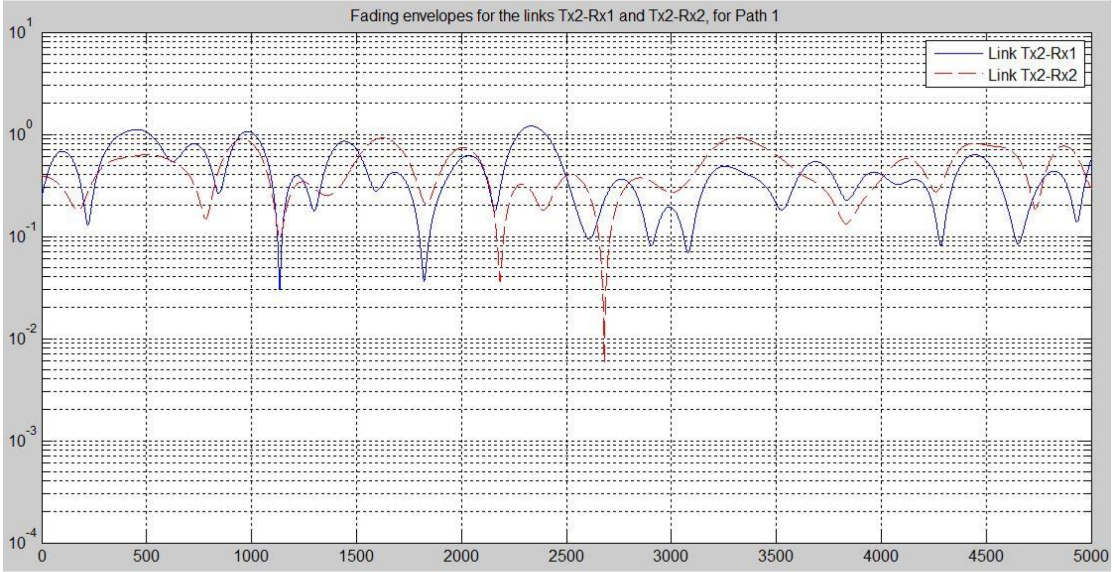

Figure 19: Fading envelopes for the links Tx2-Rx1 and Tx2-Rx2, for Path 1

Table 5. Transmit and Receive Correlation Values for first set of parameters

Correlation Values	
α (Rt at Rx1)	0.8982
α (Rt at Rx2)	0.8973
β (Rr at Rx1)	0.2843
β (Rr at Rx2)	0.2812

From the results of first set of parameters, the simulated jakes Doppler spectrum has a good fit with the theoretical spectrum for path 1. The same will be the result for other paths. Similarly, the transmit and receive correlation values obtained in table 5. from fading envelope for different link of first path is found to have good match with the specified correlation matrix of medium level.

Results Obtained for second set of parameter are given below:

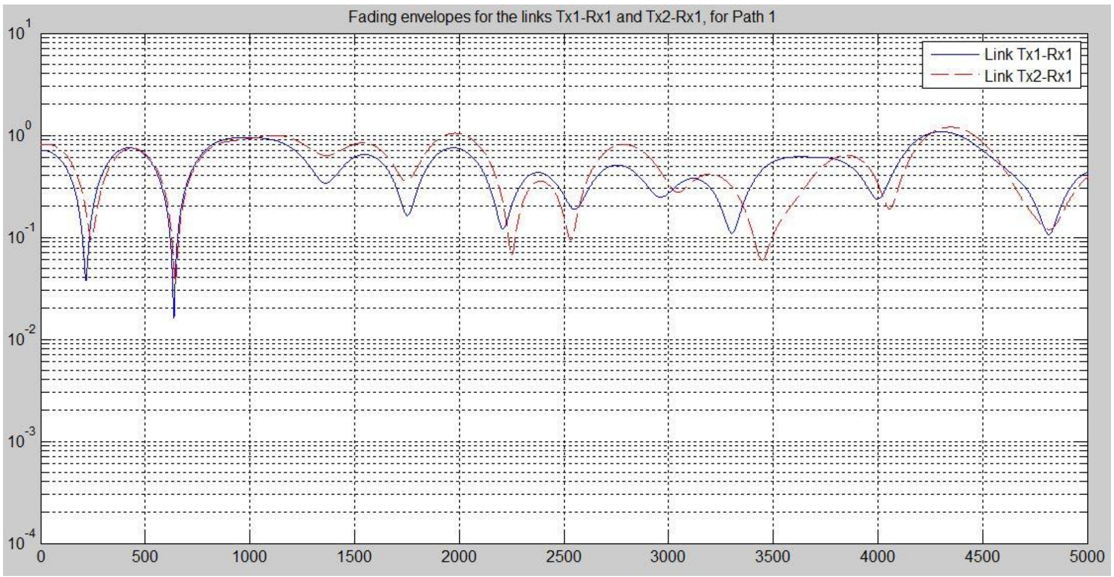

Figure 20: Fading envelopes for the links Tx1-Rx1 and Tx2-Rx1, for Path 1

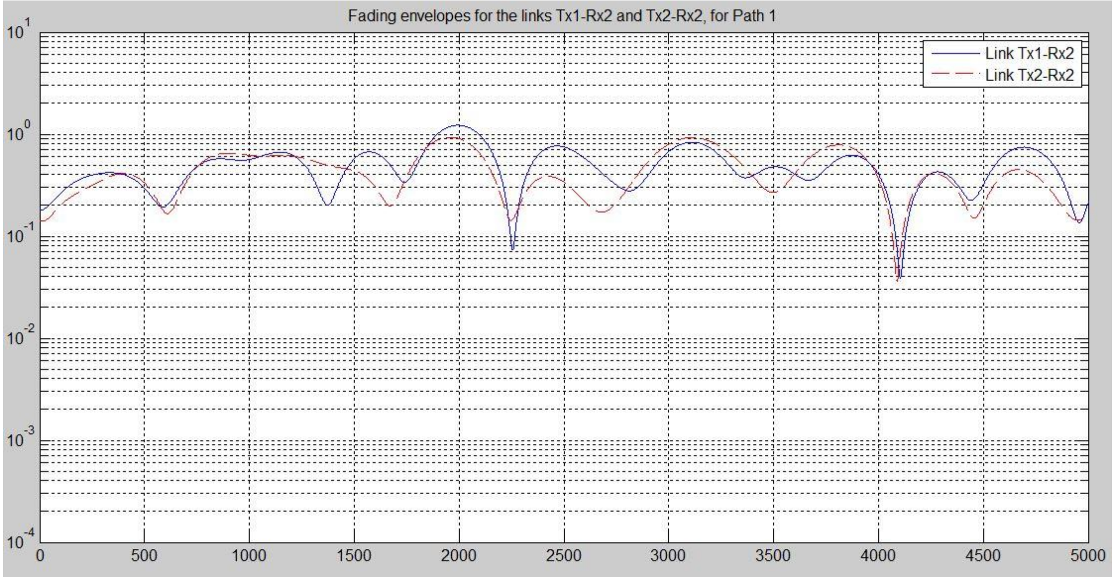

Figure 21: Fading envelopes for the links Tx1-Rx2 and Tx2-Rx2, for Path 1

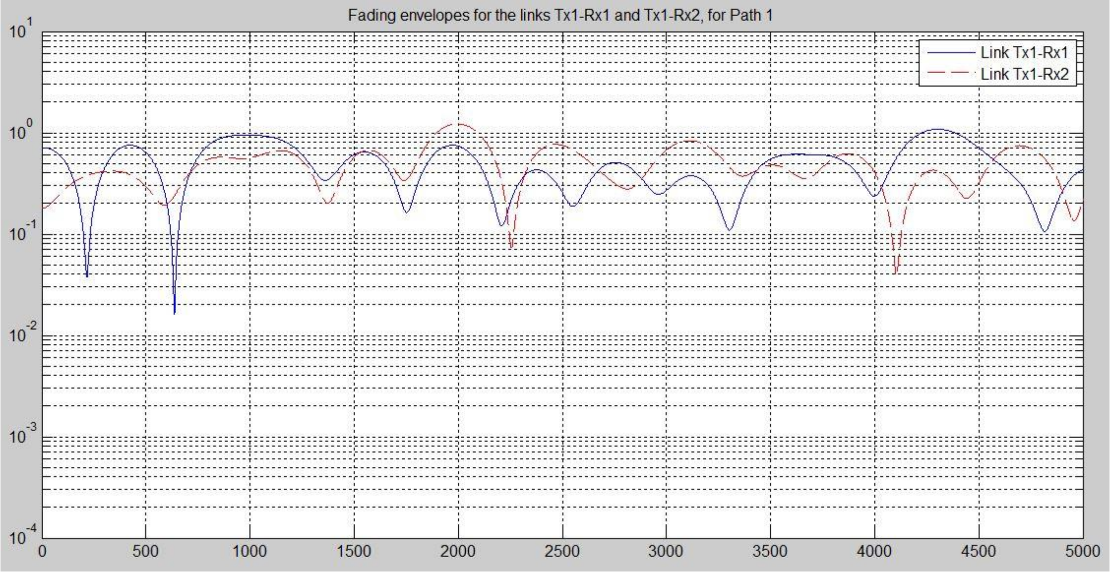

Figure 22: Fading envelopes for the links Tx1-Rx1 and Tx1-Rx2, for Path 1

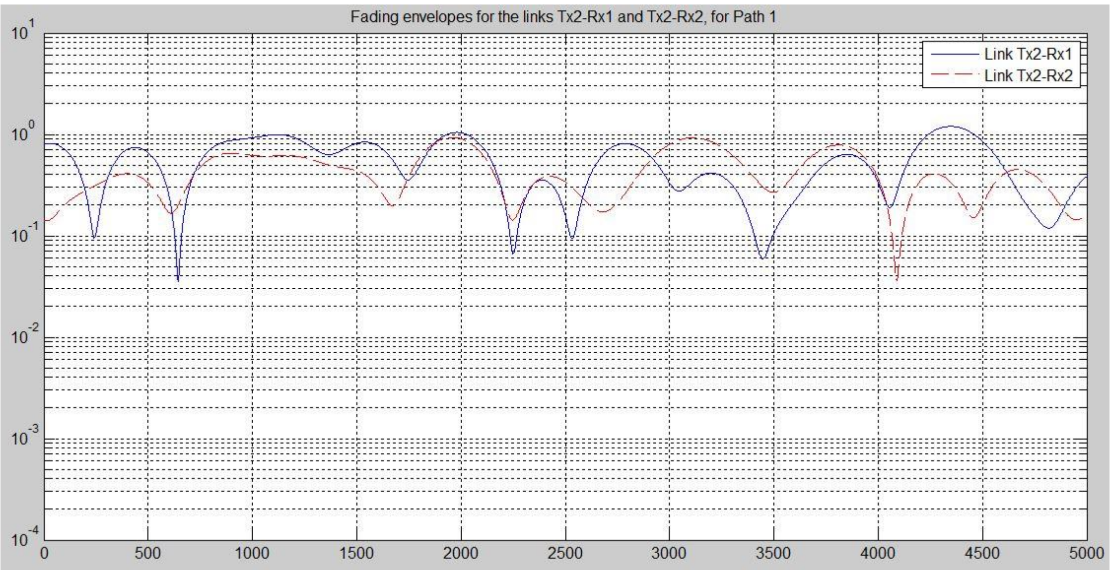

Figure 23: Fading envelopes for the links Tx2-Rx1 and Tx2-Rx2, for Path 1

Table 6. below shows the correlation values obtained based on the fading envelope of different link of first path in the simulation.

Table 6. Transmit and Receive Correlation Values for second set of parameters

Correlation Values	
α (Rt at Rx1)	0.9005
α (Rt at Rx2)	0.8985
β (Rr at Rx1)	0.3184
β (Rr at Rx2)	0.3058

From the results in figures 20, 21, 22 and 23, the simulated jakes Doppler spectrum has a good fit with the theoretical spectrum for path 1 and the fading envelopes are slowly varying compared to fading envelopes in figures 16, 17, 18 and 19. The same will be the result for other paths. Similarly, the transmit and receive correlation values obtained from fading envelope for different link of first path is found to have good match with the correlation matrix specified (based on ITU guideline) in the initial parameter.

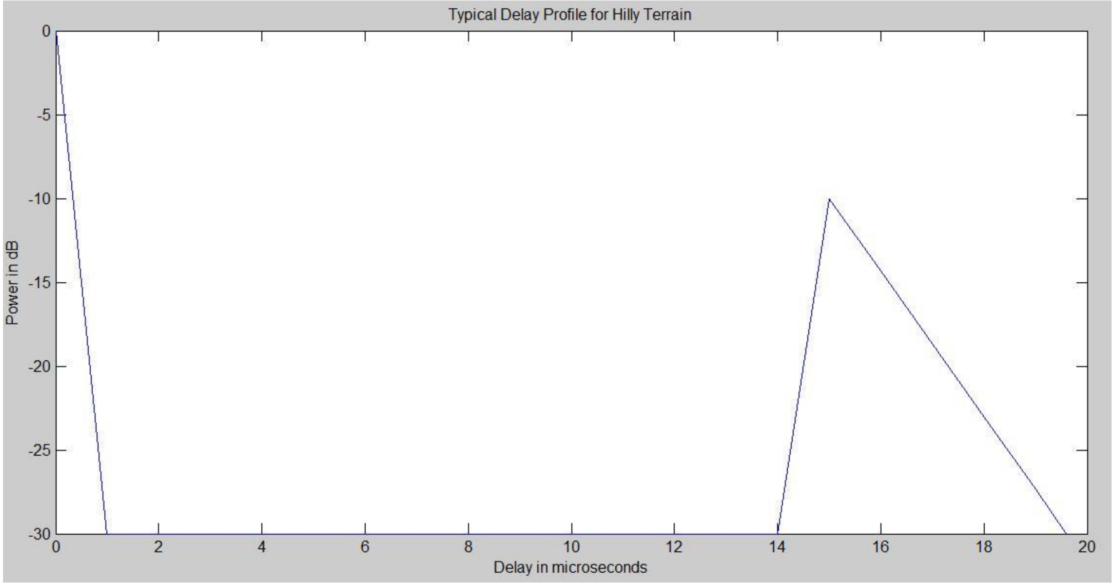

Figure 24: Typical power delay profile for hilly terrain

Figure 24. shows the power delay profile for hilly terrain. For hilly terrain, there are two regions over which the power is spread. The delay spread is about 20 microsecond and is longer than that of urban region.

Table 7. Third and Fourth Set of simulation parameters for hilly terrain

Set	Area	No. of tap	Velocity (mph)	Frequency (MHz)	correlation	configuration	Doppler spectrum
III	hilly	6	50	2500	medium	2*2	Jakes
IV	hilly	6	30	2500	medium	2*2	Jakes

Table 7. shows the third and fourth set of values of simulation parameters for hilly terrain and jakes Doppler power spectrum. On changing the terrain from urban to hilly and keeping the other parameters same, correlation between fading envelope of different link of the path remains same. So, the transmit and receive correlation is independent of terrain types.

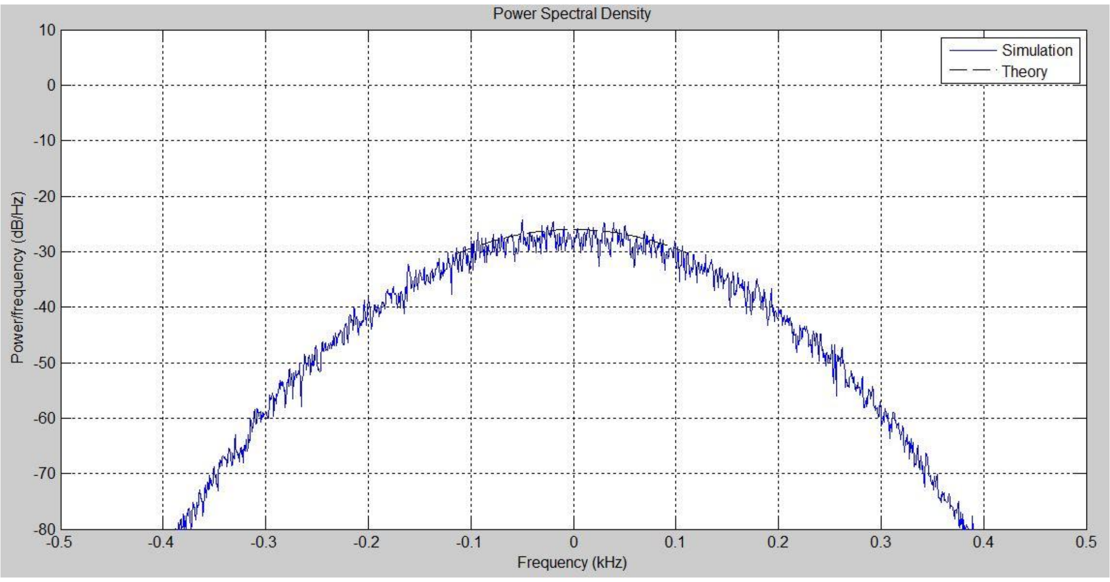

Figure 25: Gaussian Doppler spectrum of a link in MIMO with velocity of 30 mph and 2.5 GHz carrier frequency.

For the mobile velocity of 30 miles per hour, carrier frequency of 2.5 GHz, figure 25. shows the Gaussian Doppler spectrum. The estimated power spectral density is found to have good match with the theoretical Gaussian spectrum.

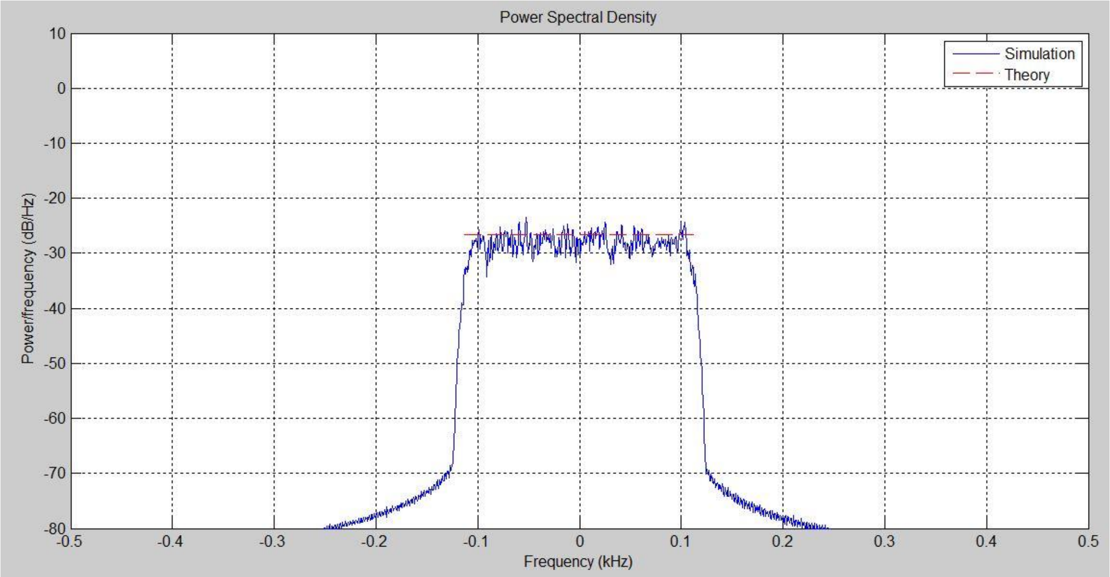

Figure 26: Flat Doppler spectrum of a link in MIMO with velocity of 30 mph and 2.5 GHz carrier frequency.

For the mobile velocity of 30 miles per hour, carrier frequency of 2.5 GHz, figure 26. shows the Flat Doppler spectrum. The estimated power spectral density is found to have good match with the theoretical Flat spectrum.

5.2.1 Relation between Velocity and Doppler Spectrum in Urban Area

To see how the mobile velocity is related to Doppler spectrum, simulation is carried out with parameter settings of 2.5 GHz carrier frequency, varying mobile velocity, urban area, 1*2 MIMO configuration, medium level of correlation and varying Doppler spectrum viz. Jakes, Gaussian and Flat spectrum. For each scenario, signal constellation including the transmitted symbol and received symbol at the two receiver is presented and system performance is evaluated.

I. Low Velocity Case

With the velocity of 5 mph, signal constellation plots are obtained for Jakes, Gaussian and Flat Doppler spectrum. For a transmitted symbol in 1*2 MIMO channel, two symbols are obtained as channel outputs for two receivers. The distortion introduced by the channel is measured based on the Euclidean distance from the transmitted symbol.

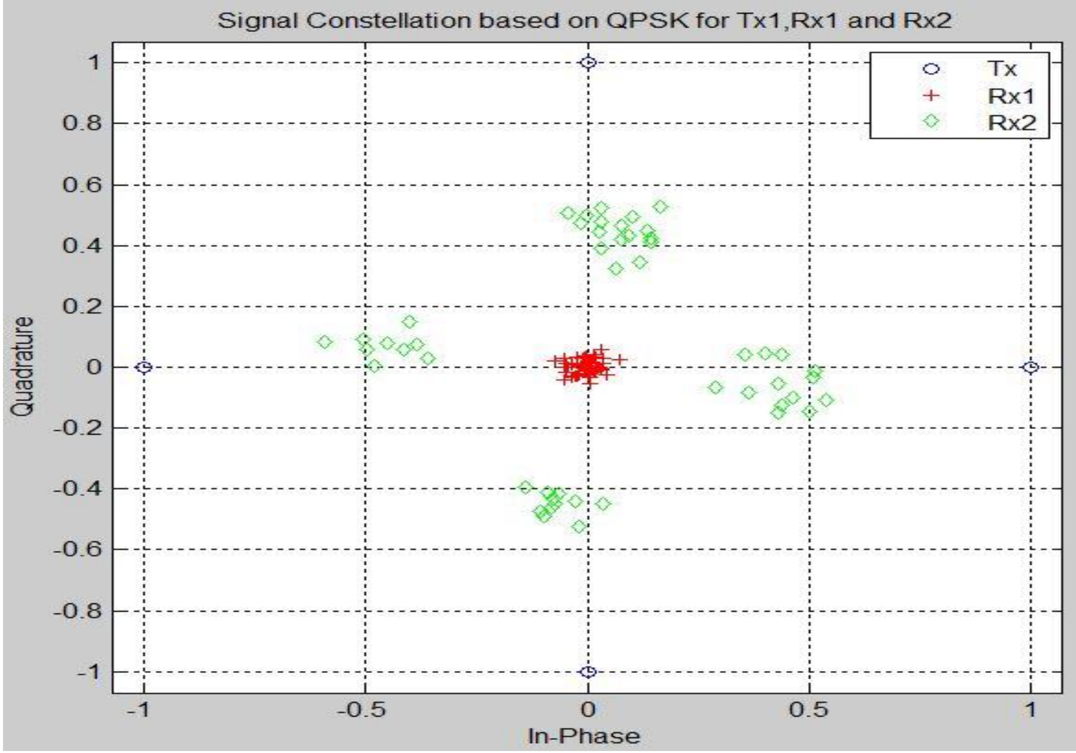

Figure 27: Constellation diagram for 5 mph, Flat spectrum and urban area.

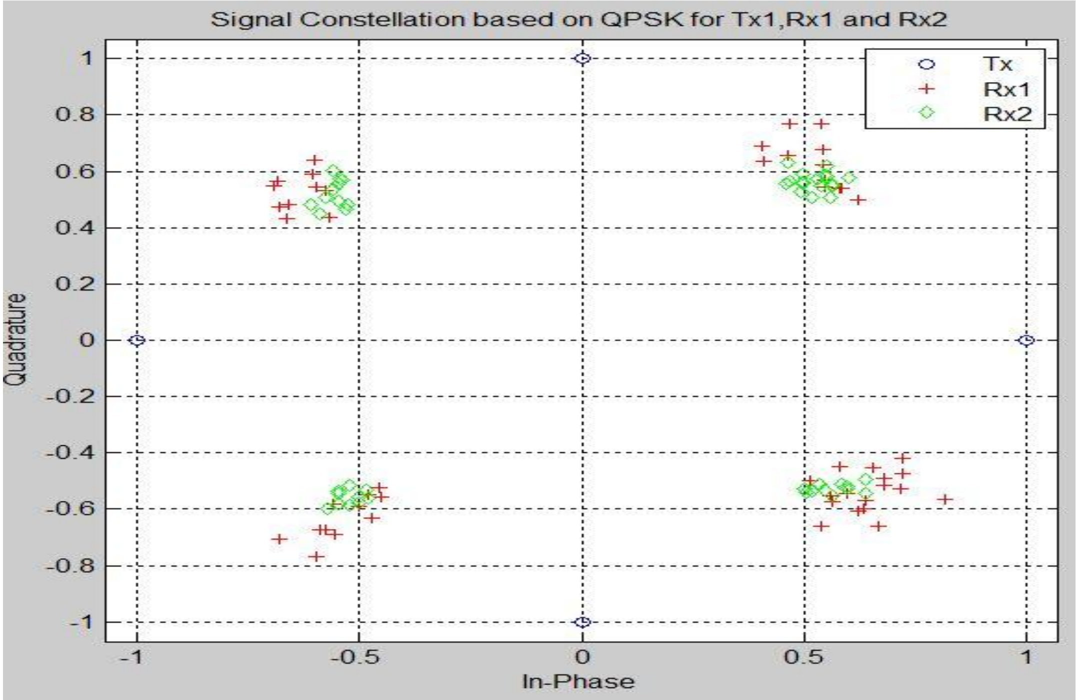

Figure 28: Constellation diagram for 5 mph, Gaussian spectrum and urban area.

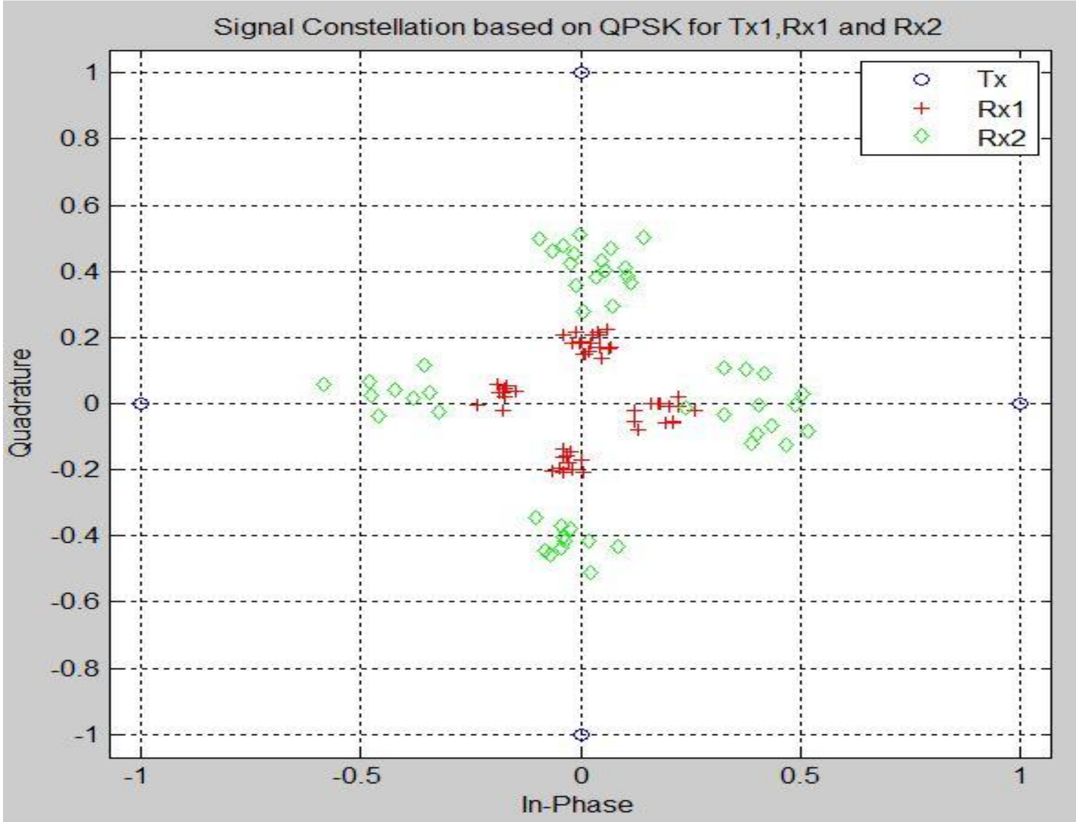

Figure 29: Constellation diagram for 5 mph, Jakes spectrum and urban area.

From the figures 27, 28 and 29, important remarks can be drawn regarding the relation of various Doppler spectrum in low velocity. In the constellation diagram for Flat Doppler spectrum in figure 27, symbols in Rx1 are centered around zero which shows the high distortion by the channel. Figure 28. for Gaussian Doppler spectrum has the received symbols less scattered and closer to the transmitted symbols than in figure 30. for Jakes Doppler spectrum. Thus, it is noted that Flat spectrum has worst signal estimation and Gaussian spectrum has better signal estimation among three spectrums in the case of mobility.

II. High Velocity Case

With the velocity increased to 60 mph, signal constellation plots are obtained for Jakes, Gaussian and Flat Doppler spectrum. Figure 30, 31 and 32 shows the signal constellation diagram for Flat, Gaussian and Jakes Doppler spectrum respectively for 60 mph velocity, urban area and 1*2 MIMO configuration.

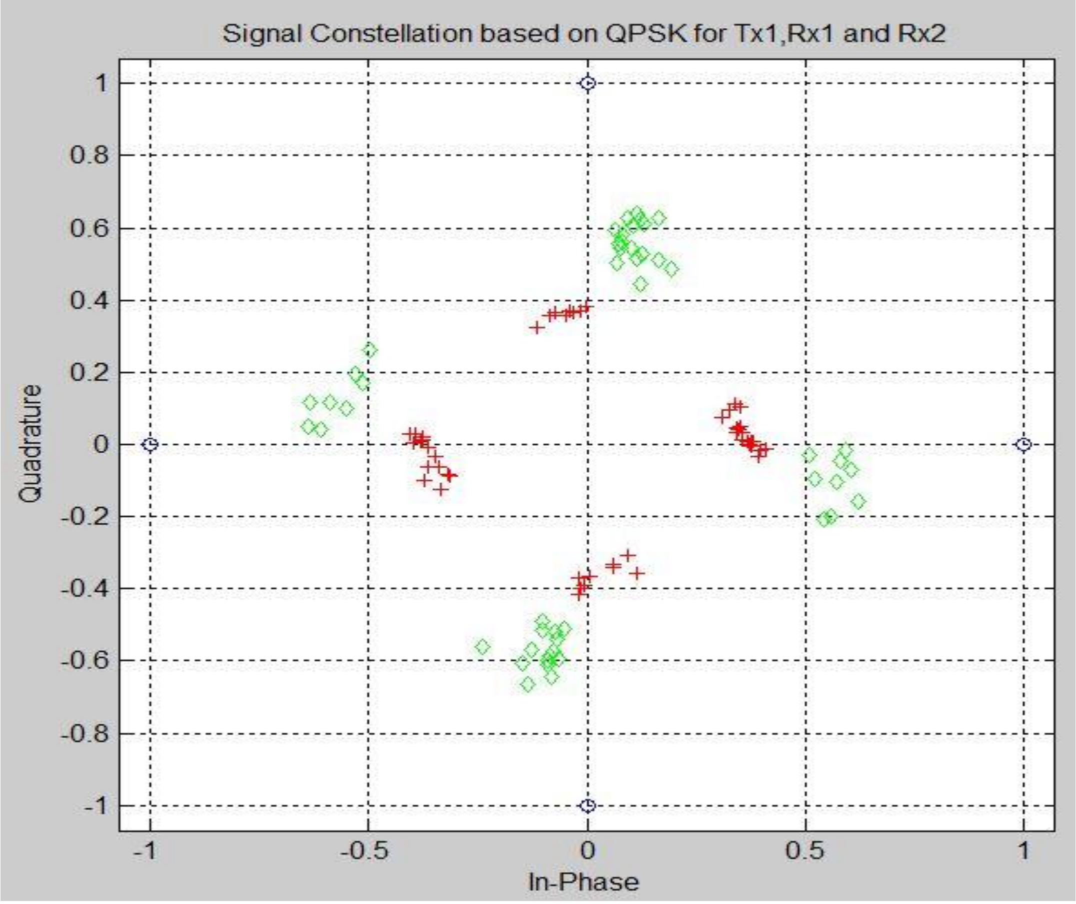

Figure 30: Constellation diagram for 60 mph, Flat spectrum and urban area.

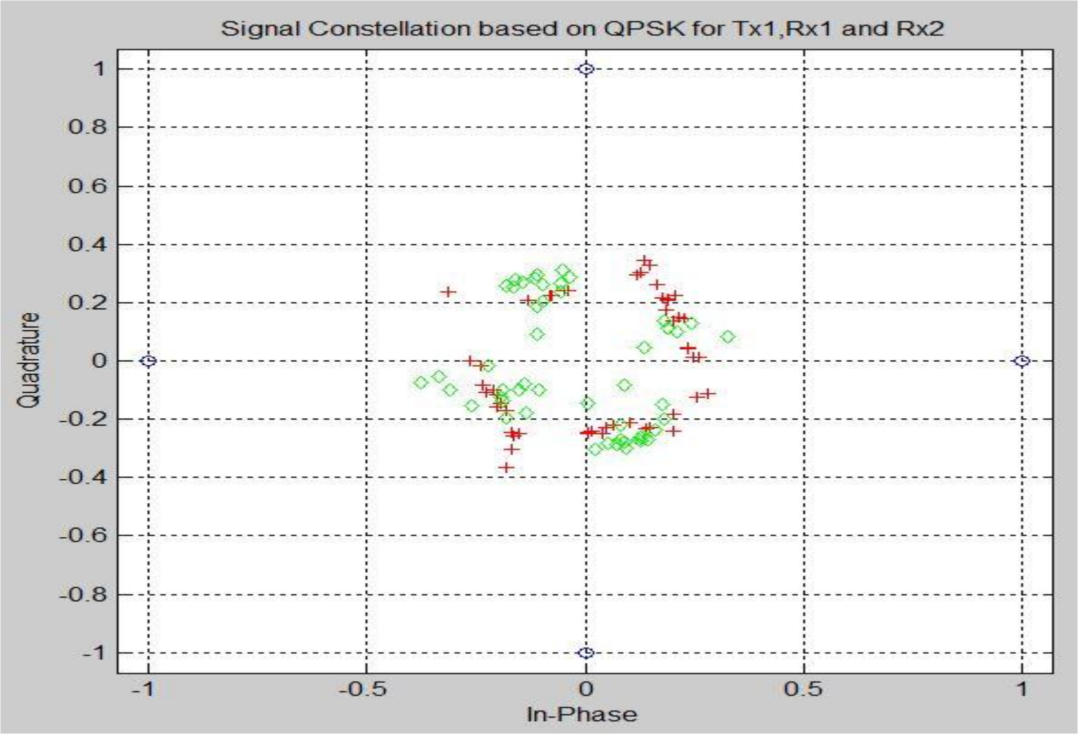

Figure 31: Constellation diagram for 60 mph, Gaussian spectrum and urban area.

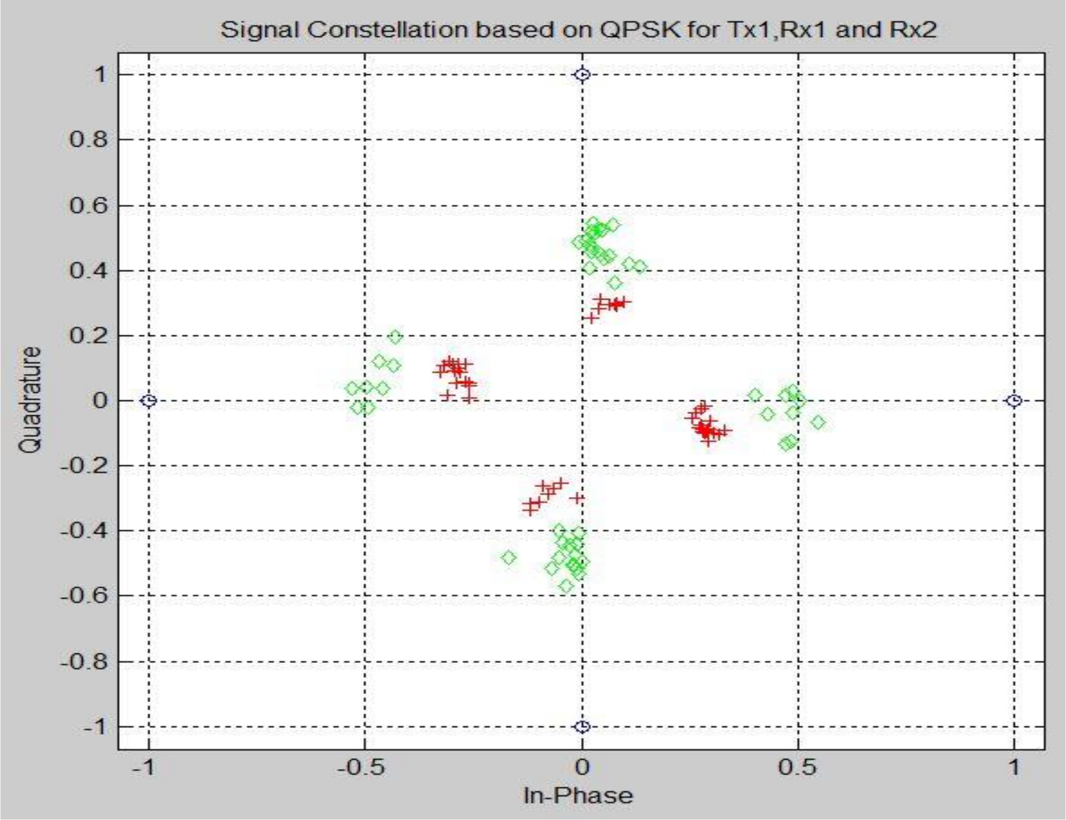

Figure 32: Constellation diagram for 60 mph, Jakes spectrum and urban area.

Based on the Euclidean distance criteria, it can be seen from results in figures above that the Gaussian spectrum is not suitable for signal estimation in high velocity case. Among Jakes and Flat spectrum, it can be noted that Flat spectrum provides relatively better signal estimation in urban area for high mobility.

5.2.2 Relation between Velocity and Doppler Spectrum in Hilly Area

I. Low Velocity Case

With the terrain changed to hilly type and performing simulation for low mobility, results in constellation diagram are obtained for three Doppler spectrum as in figures 33, 34 and 35.

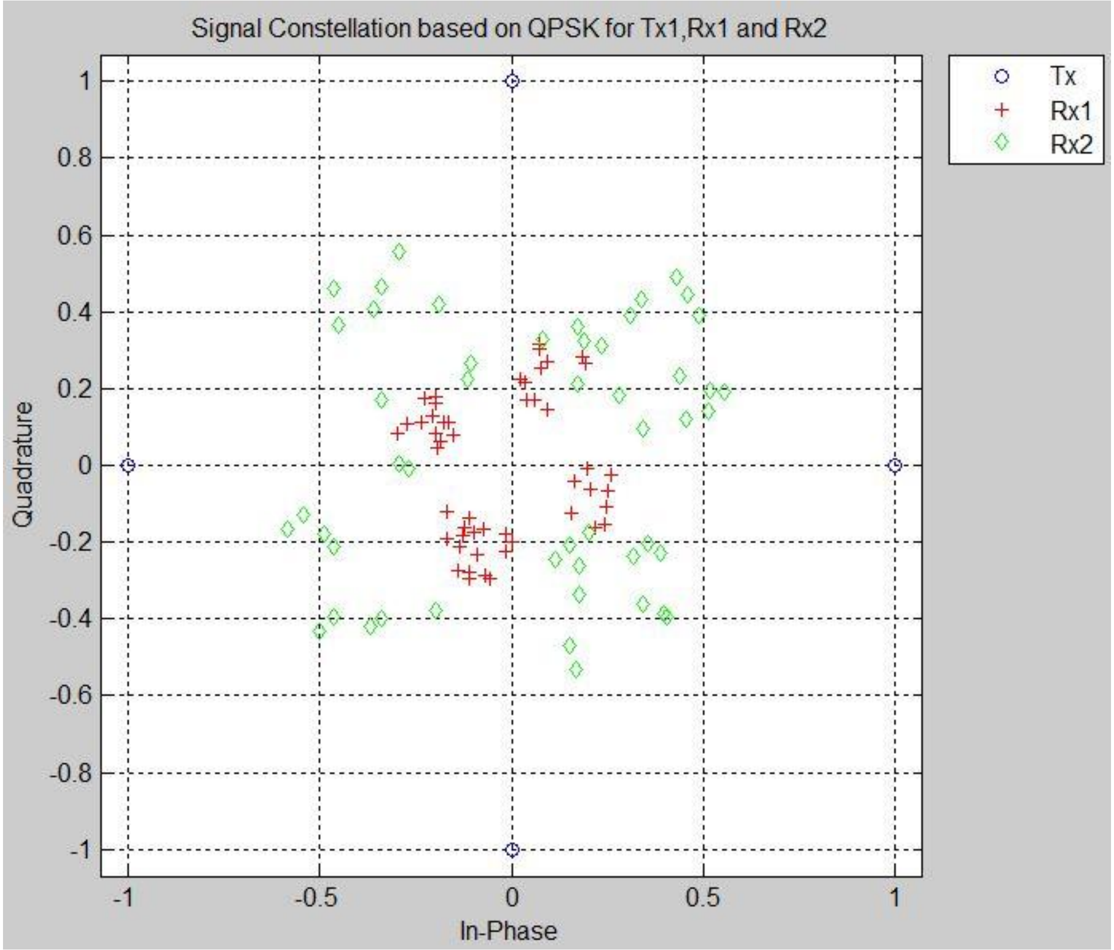

Figure 33: Constellation diagram for 5 mph, Flat spectrum and hilly area.

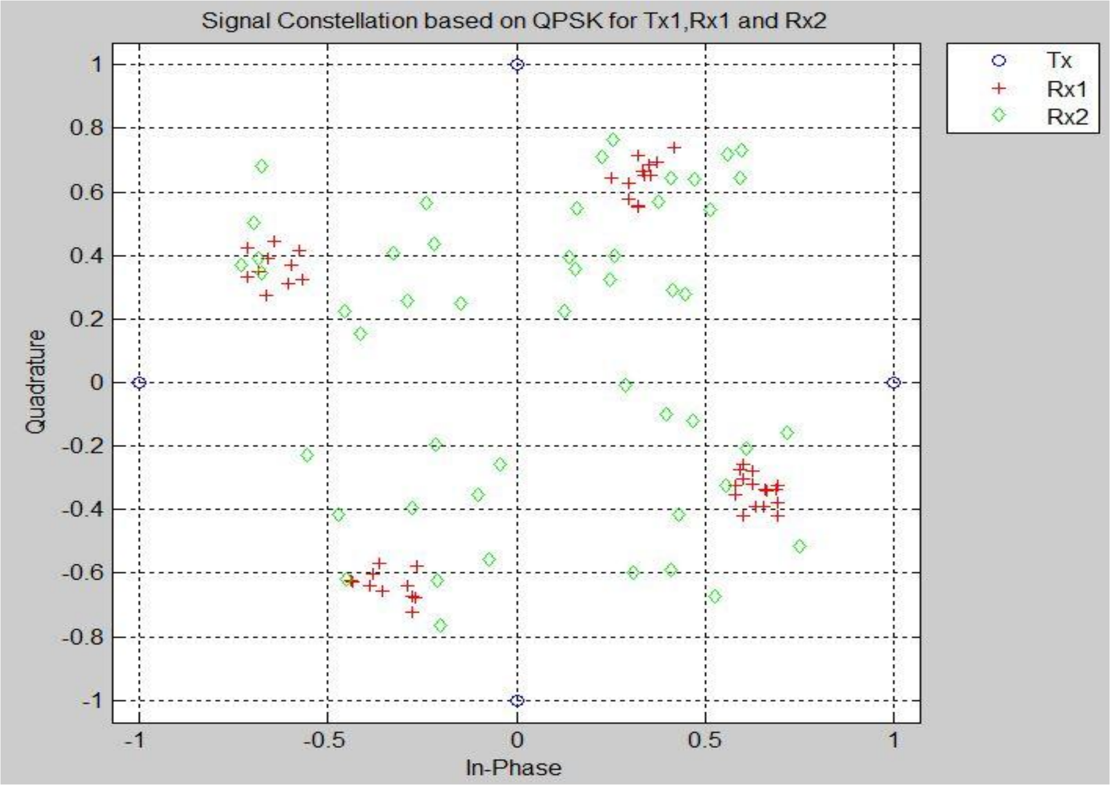

Figure 34: Constellation diagram for 5 mph, Gaussian spectrum and hilly area.

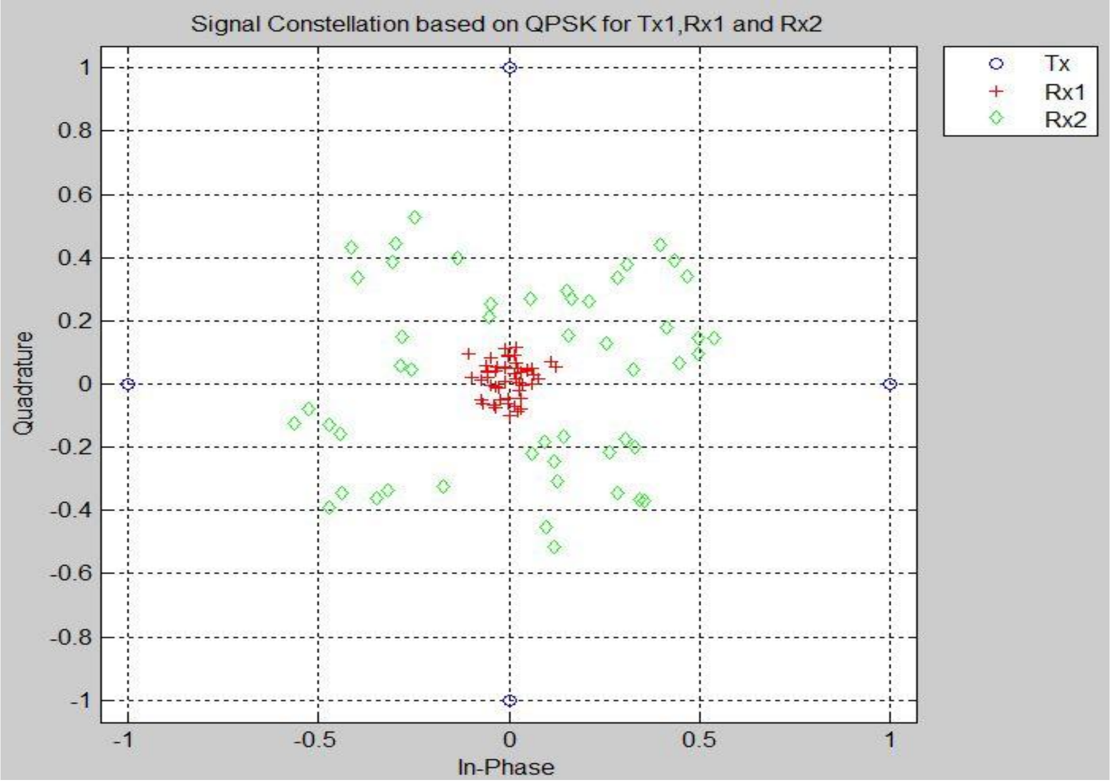

Figure 35: Constellation diagram for 5 mph, Jakes spectrum and hilly area

In the results obtained above, received symbols at Rx1 are closely centered around zero and received symbols at Rx2 are highly scattered. So, signal estimation by Jakes spectrum in this case is worst. Based on Euclidean distance criteria, Gaussian spectrum provides the better signal estimation for hilly terrain with low velocity mobile devices.

II. High Velocity Case

When velocity of mobile devices is increased to 60 mph, Doppler shift increases and hence the fading rate of the channel. The simulation results for 1*2 MIMO configuration in hilly terrain are given in figures 36, 37 and 38.

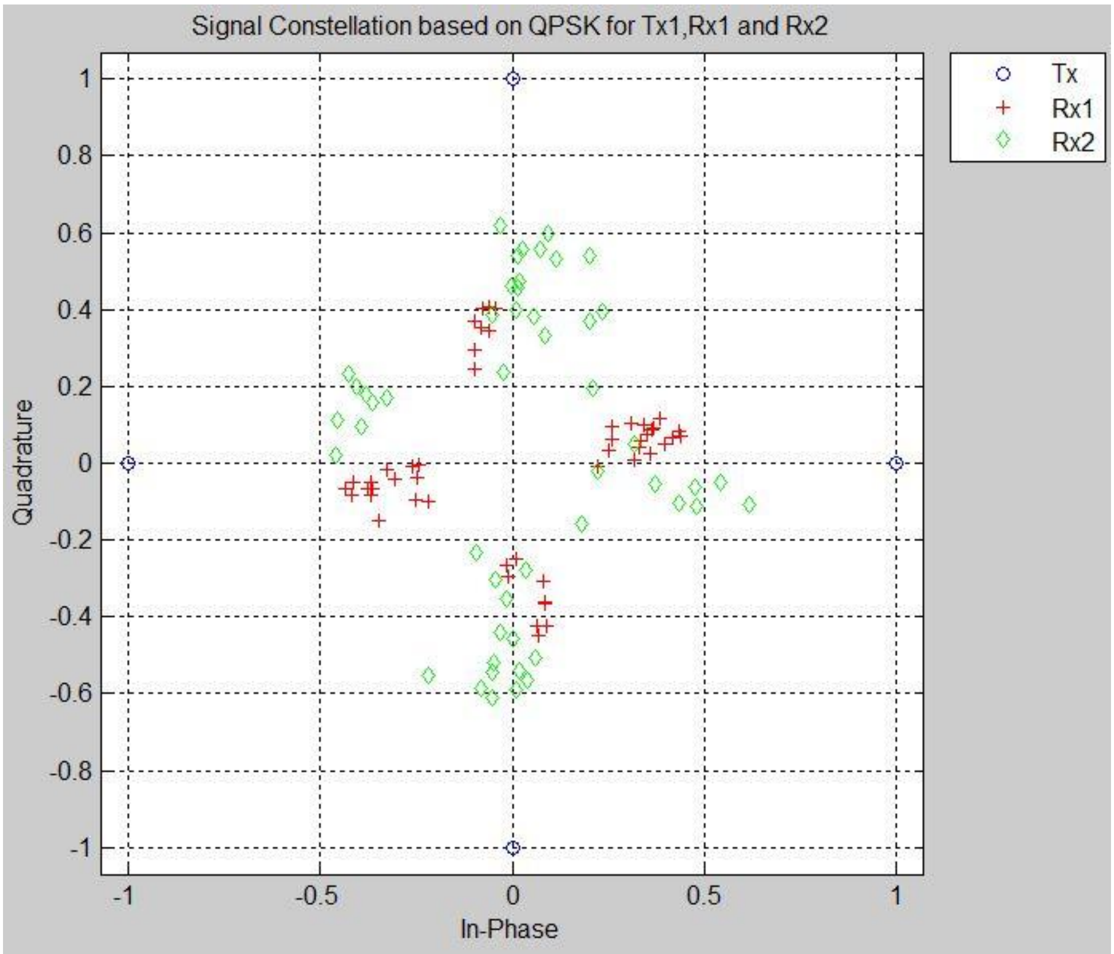

Figure 36: Constellation diagram for 60 mph, Flat spectrum and hilly area

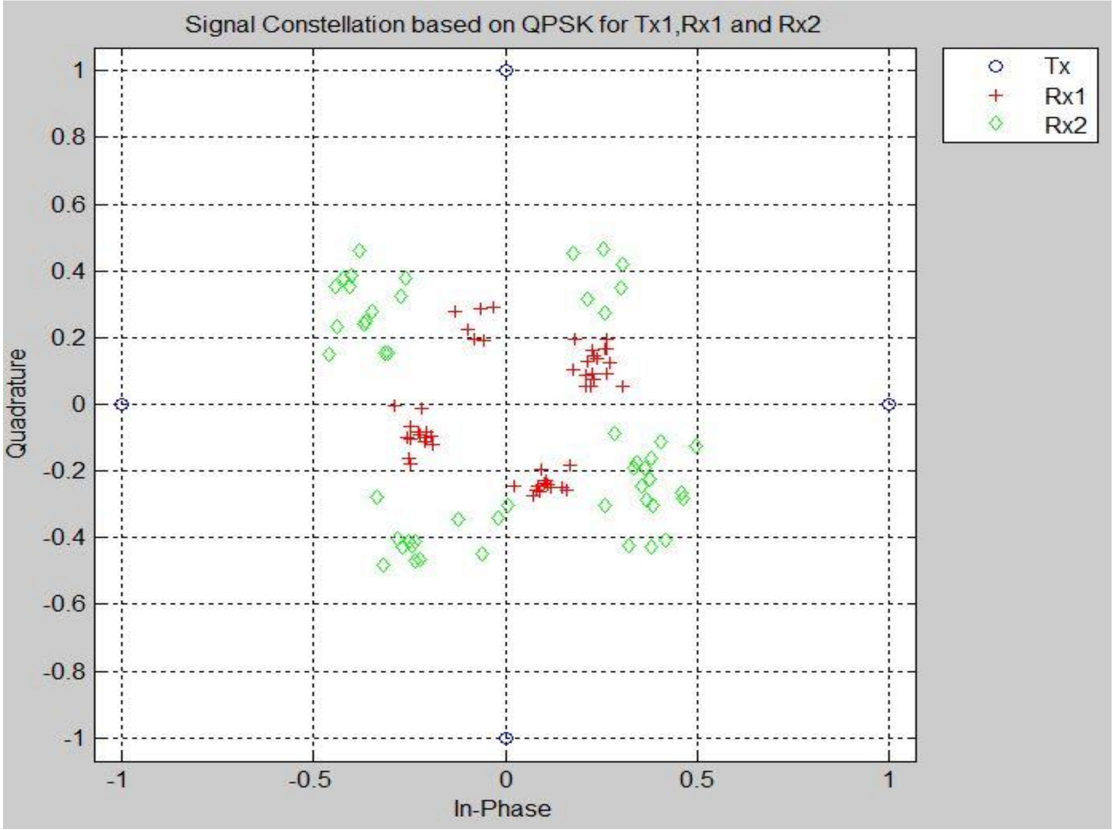

Figure 37: Constellation diagram for 60 mph, Gaussian spectrum and hilly area

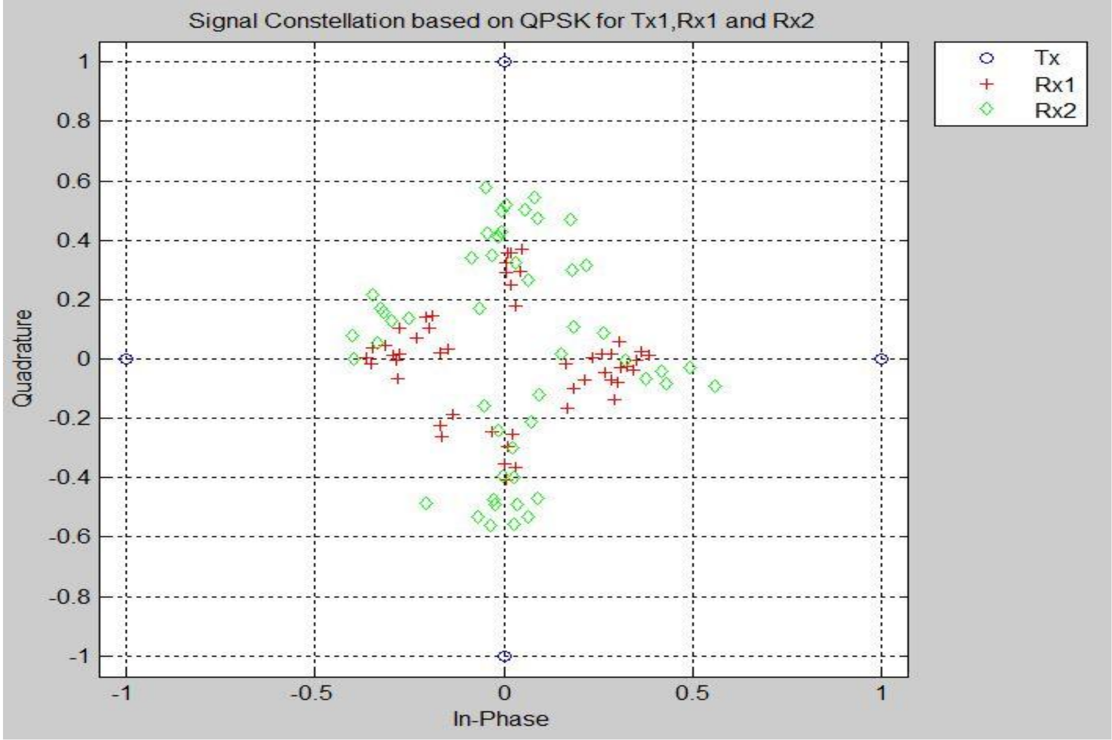

Figure 38: Constellation diagram for 60 mph, Jakes spectrum and hilly area

Simulation results for three spectrum in the case of high velocity mobile shows that Flat spectrum and Jakes spectrum has better signal estimation than Gaussian spectrum.

From the simulation results obtained regarding the better choice of Doppler spectrum for urban and hilly areas for high velocity and low velocity mobile devices, it is noted that Gaussian spectrum is more suitable for signal estimation in low velocity mobile devices in both urban and hilly areas. Flat spectrum provides better signal estimation in high velocity mobile devices both in urban and hilly areas. Jakes spectrum is suitable for high velocity mobile devices in hilly areas. On the other hand, Flat spectrum has worst signal estimation in low velocity mobile devices in urban areas whereas Jakes spectrum has worst signal estimation in low velocity mobile devices in hilly areas.

Chapter 6: EPILOGUE

6.1 Conclusions

The channel scenario described and utilized in this work include the concept of multipath propagation, types of terrain, Doppler shift and spatial correlation at the transmitter and receiver elements. The type of fading used was Rayleigh fading for NLOS scenario. The power delay profile for two terrain types urban and hilly areas were investigated and used for generation of multipath propagation. Three Doppler power spectral densities, namely, Jakes, Flat and Gaussian, were also used to quantify the mobility in the channel. The modulation scheme used was QPSK.

Simulation results include the plots of power delay profile, Doppler power spectral densities, fading envelopes of different link of 2*2 MIMO channel and signal constellation for 1*2 MIMO channel. Estimated Doppler power spectral densities is found to have good match with the theoretically obtained spectral densities. Spatial correlation are observed and verified through the correlation obtained from the fading envelopes of different links of 2*2 MIMO channel. Signal constellation were used to see the relation of velocities with the Doppler spectrum and operating environments. Gaussian spectrum was found to be more suitable for using as a shaping filter for low velocity mobile devices in urban and hilly areas. For high velocity mobile devices, Flat spectrum was better for using as a shaping filter in urban areas whereas both Flat and Jakes spectrum were better for signal estimation in hilly areas.

6.1 Recommendations

The simulation implemented in this thesis works stands out on the certain assumptions and conditions. The simulation presented do not considers all of the dimensions and details of the real scenario channel. Thus there are some limitations in simulation and analysis of MIMO channel for Mobile Ad Hoc Wireless Networks in this thesis work which has left space for future enhancements.

The transmitter and receiver both are allowed to have motion in Mobile Ad Hoc Wireless Networks in any direction. Thus there is always associated degree of mobility for such mobile devices moving with different velocities. In this thesis works, simulation is carried out based on the relative velocity of mobile devices which neglects the degree of mobility. So, there is a way for incorporating the degree of mobility concept based on the two different velocities of transmitter and receiver.

For examining the spatial characteristics of the MIMO channel, the spatial correlation at the transmitter and receiver are based on the values recommended by the ITU in its Advanced Radio Technologies. The spatial characteristics can be observed and verified through the correlation of fading envelopes of different links of MIMO channel. It is recommended to calculate the spatial correlation values based on the spatial orientation of antenna elements at the transmitter and receiver.

Constellation diagram has been used as a system performance evaluation tool for making important remarks on the relation of mobile velocity with the Doppler spectrum and terrain types. It is recommended to use MIMO channel capacity value as a evaluation criteria in the future enhancement of this thesis work.

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