



ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
INSTITUTE OF TECHNOLOGY
ELECTRICAL AND COMPUTER ENGINEERING DEPARTMENT

Statistical Modeling and Simulation of Small Scale Fast Fading Wireless Channel

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*Dedicated to
My family*

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ABBREVIATIONS

AWGN	Additive White Gaussian Noise
AFD	Average Fade Duration
BER	Bit Error Rate
BPSK	Binary Phase Shift Key
BPSK	Binary Phase Shift Key
CSI	Channel State Information
Db	Deci Bell
EMW	Electro-Magnetic Wave
IEEE	Institute of Electrical and Electronic Engineering
FCF	Frequency Correlation Function
FFH-SS	Fast Frequency Hopping Spread Spectrum
FSFC	Frequency Selective Fading Channel
FWA	Fixed Wireless Access
IFFT	Inverse Fast Fourier Transform
GSM	Global System for Mobile Communication
ISI	Inter Symbol Interference
LCR	Level Crossing Rate
LOS	Line Of Sight
LPNM	L P Norm Method
MCM	Monte Carlo Method
MEA	Method Of Equal Area
MED	Method Of Equal Distance
MMSE	Minimum Mean Square Error
MQAM	M-ary Quadrature Amplitude Modulation
MPSK	M-ary Pulse Shift Keying
MSEM	Mean Square Error Method
PAM	Pulse Amplitude Modulation

PDF	Probability Density Function
PSD	Power Spectral Density
PSK	Phase Shift Keying
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Key
SNR	Signal to Noise Ratio
SOS	Sum of Sinusoid
SUI	Stanford University Interim
TU	Typical Urban

ABSTRACT

Communication system performance is eventually determined by the medium through which the message signal passes. Wireless channels differ from wired channels, e.g., due to their unreliable behavior. Communication over wireless channel becomes very difficult due to the randomness of the wireless channel. Though it is so difficult to analyse, it puts fundamental limitation on the communication performance.

Performance Measurement of wireless fading channel is done by mathematical modeling and simulation of the parameters of the channel. Since the channel is random, statistical modeling is preferred to evaluate using the 1st and 2nd order statistics of the channel transfer function. The sum of sinusoid (SOS) model and the impulse response model work for a terminal moving with a constant speed. But real world communication terminals may be at rest, in motion with constant speed, varying speed both in magnitude and direction. So, the model which represents all states of motion and comparison of this model with pre-existing SOS model is to be presented in this thesis. After the mathematical modeling is made, the performance of fast fading and frequency selective fading channel are to be measured. The main parameters used to measure the small scale fading channel are fading probability, fading rate (level crossing rate), fading duration and BER.

The effect of the multipath parameters (number of path, delay spread and power delay profile) on the BER of the frequency selective channel are presented. Besides to this, the effects of the speed of the mobile terminal and the bit period on the fading rate, fading duration and the BER of the fast fading channel is presented. Finally, for large values of the multipath parameters, channel performance is low and for constant bit period if the speed of mobile terminal is large, channel variation is large so that BER, fading rate and fading duration of fast fading channel increases.

Key words: statistical modeling, small scale fading channel, fast fading channel, performance of fading channel

CHAPTER ONE: INTRODUCTION

1.1. Background information

The performance of any communication system is eventually determined by the medium through which the message signal passes through. This medium which may be an optical fiber, a hard disk drive of a computer or a wireless link, is referred to as communication channel. There exists a large variety of channels that may be divided into two groups. If a solid connection exists between transmitter and receiver, the channel is called a wired channel. If this solid connection is missing, this connection is called a wireless channel. In wireless channels the state of the channel may change within a very short time span. This random behavior of wireless channels turns communication over such channels into a difficult task. There are several different classifications regarding the wireless channels. Wireless channels may be distinguished by the propagation environment encountered, such as urban, suburban, indoor, underwater or orbital propagation environments, which differ in various ways as in [10, 12, 14]. The transmission path between the receiver and the transmitter can be altered from a simple line-of-sight to one that is drastically obstructed by buildings, foliage and mountains which produce multipath propagation. In addition to propagation environment, the speed of the mobile terminal impacts on how rapidly the signal level changes.

The term fading, in the context of wireless communications, refers to the interference caused by the reception of numerous reflected, diffracted, scattered copies of a given signal at an antenna. Small scale fading is the propagation model that characterizes the rapid fluctuations of the received signal strength over very short travel distances (a few wavelength) or short time durations (on the order of seconds) [8, 9, 10].

The most important effects of the small scale fading are:

- Rapid changes in signal strength over a small travel distance or time interval,
- Random frequency modulation due to varying Doppler shifts on different multi-path signal components and
- Time dispersion (echoes) caused by multi-path propagation delays.

The wireless systems are expected to provide multimedia services with transmission capabilities that are able to handle higher data rates and higher mobility. The reliability of the channel depends on the understanding of its analytic model and how it behaves given a specific environment [8].

1.1.1 The Communication system

A communication system contains three main subsystems as shown in Fig (1.1): the *transmitter*, the *channel* and the *receiver* [8]. The main concern of this work is the second subsystem, the channel. During transmission the signal is affected by the channel's environment. If the channel characteristics are known, then it is possible to predict the effects on the transmitted signal at the receiver.

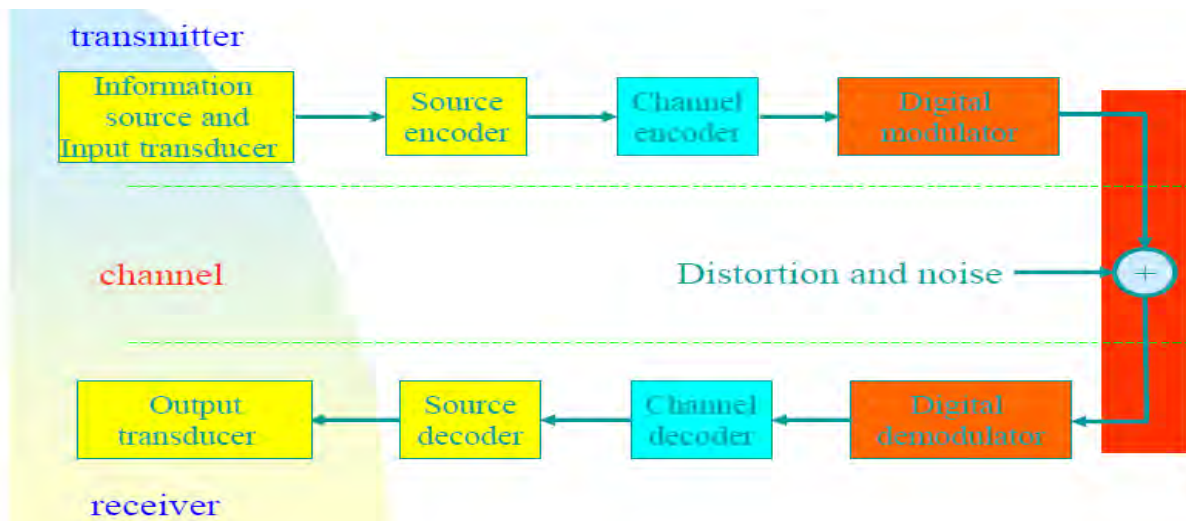


Fig 1.1 Communication system

To determine a channel model, mathematical descriptions of the propagation effect between the transmitter and receiver must be known. If the channel characteristics are known, it helps to study and understand the performance of different communication systems. Digital communication over wireless channel has made digital transceivers much cheaper, faster, and more power-efficient due to the different digital modulation/demodulation techniques used. Digital modulation and detection consist of transferring information in the form of bits over a communications channel. Detection consists of determining the original bit sequence based on the signal received over the channel.

The main modulation techniques used in wireless fading channel are Pulse Amplitude Modulation (MPAM), Phase Shift Keying (MPSK) and Quadrature Amplitude Modulation (MQAM)

1.1.2 Wireless channel models

Empirical models: - Empirical models are channel models that depend on observation and measurement data of a particular location [24]. These models are mainly used to predict the path loss, but models that predict rain-fade and multipath have also been proposed [37]. Although the empirical model is highly accurate, it is also mostly unavailable.

Deterministic model: - This model Makes use of the laws governing electromagnetic wave propagation to determine the received signal power at a particular location [9, 24]. Deterministic models often require a complete 3-D map of the propagation environment. An example of a deterministic model is a ray tracing model.

Stochastic models: - Stochastic models use the first and second order statistical properties of the channels impulse response to characterize the channel behavior. Stochastic models model the variability of the channel property using a series of random variables [24]. Stochastic models are the least accurate but require the least information about the environment and use much less processing power to generate predictions so that it is the least expensive.

1.1.3 Types of fading

Fading is the random fluctuation and reduction in quality of the communication signal which is because of multi-path propagation, Shadowing and path loss. The main categories of fading in general are

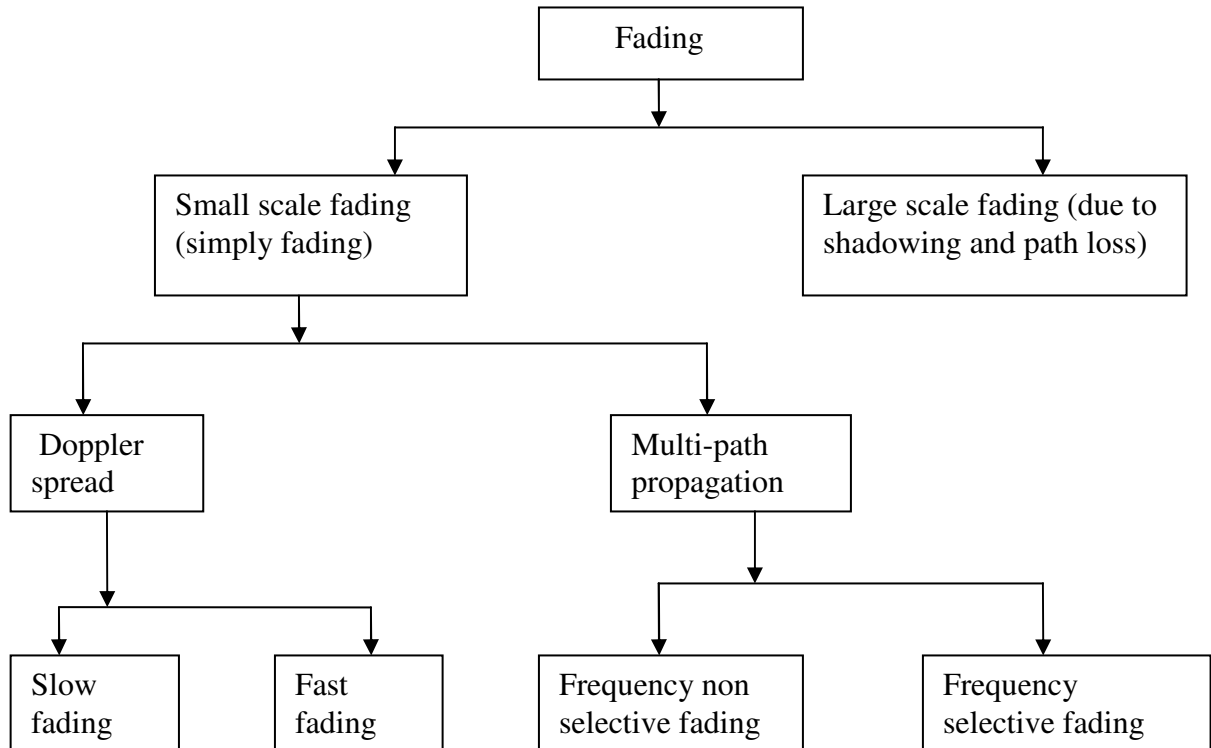


Fig 1.2 Fading categories

Multi-path propagation and Doppler spread due to the motion of the mobile terminal produces small scale fading which leads to rapid fluctuations of the phase and amplitude of the signal if the mobile terminal moves over a distance in the order of a wave length or more. Shadowing and path loss effect produce reduction of the strength of the power level which occur if the antenna is displaced over distances larger than a few tens or hundreds of meters.

1.2.Motivation

In recent years, radio-engineering requirements have become more stringent and necessitate not only more detailed information on signal level, but also much more exact knowledge on fading statistics in both ionospheric and tropospheric modes of propagation. Such circumstances

demanded a large number of experiments and number of theoretical investigations to be performed. Field tests in a mobile environment are considerably more expensive and may require permission of regulatory authorities. It is difficult to generate repeatable field test results due to random, uncontrollable nature of the mobile communication path. Atmospheric conditions and cost also play a key role in field test measurements. These limitations can be overcome by means of simulation.

Modeling the wireless channel has historically been one of the most difficult parts of the communication system design and is typically done in a statistical manner, based on measurements made specifically for a designated communication system or spectrum allocation [14]. Generally, the fading, which is caused due to multi-path propagation and moving terminal in a communication channel, challenges the wireless communication engineer who tries to establish a reliable communication path between transmitter and receiver. Indeed, a first step towards reducing the challenges is to understand the nature and characteristics of these effects through producing models of and simulating this phenomenon

So the motivation behind this work is to model the wireless channel when the mobile terminal is moving in a time varying speed and simulating the parameters (BER, fading rate, fading duration and the fading probability) of the channel so that the performance at the receiver is easily determined and reduce the challenges. Sum of sinusoid model and the impulse response model are simple models based on the constant speed of the mobile terminal. But real world communication terminals may be either at rest, moving in a constant speed, moving in a time varying speed both in magnitude as well as direction, i.e in accelerating motion. This work primarily seeks to model and simulate the wireless channel considering the parameters like:

- ✓ Motion information of the transmitter and receiver(magnitude of the speed as well as direction and channel fluctuation)
- ✓ Type of scenario(communication environment type indoor, suburban and urban)
- ✓ Signal and channel parameters (channel bandwidth, bit rate and rms delay spread)

1.3. Thesis objective

1.3.1. General objective

The main objective of this thesis is to study and gain better understanding and knowledge of the wireless channel especially modeling and simulation of the small scale fast fading wireless channel

1.3.2. Specific objective

Specifically the main objectives of this thesis are:

- ✓ To model the impulse response of small scale fast fading wireless channel i.e. to derive the attenuation factor, the phase, multi-path delay spread and Doppler spread, number of multi-paths)
- ✓ The second order statistics of the typical system (power spectrum, autocorrelation, level crossing rate, covariance and their relation with velocity of mobile) or spectral characteristics.
- ✓ To model the channel for the time varying speed of the terminal(change in both magnitude and direction at different instances)
- ✓ To study and evaluate the effect of multi-path on the channel performance
- ✓ To study and evaluate the effect of motion of the mobile on the performance of the channel
- ✓ To measure the performance of the small scale fading channel: FSFC as well as fast fading channel and to compare them with frequency flat and slow fading channel respectively

1.4. Review of Literatures on small scale fading channel modeling and simulation

Radio waves propagate from a transmitting antenna, and travel through free space undergoing absorption, reflection, refraction, diffraction, and scattering. They are greatly affected by the ground terrain, the atmosphere, and the objects in their path, like buildings, bridges, hills, trees, etc. These multiple physical phenomena are responsible for most of the characteristic features of the received signal. The height of the mobile antenna, in most cases, is smaller than the surrounding structures and makes the *line-of-sight* path between the transmitter and the receiver

highly unlikely [8]. So, in practice, the transmitted signal arrives at the receiver via several paths with different time delays creating a multipath situation.

At the receiver, these multipath waves with randomly distributed amplitudes and phases combine to give a resultant signal that fluctuates in time and space. Therefore, a receiver at one location may have a signal that is much different from the signal at another location, only a short distance away, because of the change in the phase relationship among the incoming radio waves. This causes significant fluctuations in the signal amplitude. This phenomenon of random fluctuations in the received signal level is termed as *fading* [8, 10, 14].

Fading can produce significant random variations of signal power, amplitude, and phase and hence the quality of the information carried by the signal. Therefore, in order to achieve reliable mobile communications, provisions must be considered to counter the effects of fading. In studying and evaluating the small scale fast fading channel, much attention has been paid to the

- ✓ Effects of the scattering environment
- ✓ Effect of the movement of terminals
- ✓ Effect of both signal and channel parameters
- ✓ Effect of the number of paths followed and the delay spreads that occur.
- ✓ Effects of the above factors on the performance of the channel in terms of fading rate, fading probability and bit error rate.

In this section we will see some of the literatures about small scale fading channel

In [3], the author reviewed the most peculiar and interesting information-theoretic and communications features of fading channels. This paper, first describes the statistical models of fading channels which are frequently used in the analysis and design of communication systems. Next, focus is given on the information theory of fading channels, by emphasizing capacity as the most important performance measure. In the modeling of the channel, high concern is given to the doubly spread channel and is characterized by the scattering function and relating it to the Doppler power spectrum and delay power spectrum Or multi-path intensity profile. Parameters like delay spread, Doppler spread and the spread factor are also taken here to characterize the channel by power spectrum. In this paper, modeling of both frequency flat and frequency

selective channel is also presented. But the parameters of the channel like the attenuation factor, phase delay and time delay are not defined.

In [4], the performance of non-coherent reception in fast frequency hopped spread-spectrum (FFH-SS) communication systems operating through noisy, fading multi-path channels is investigated. Systems operating with binary frequency-shift keying (BFSK) modulation and non-coherent demodulation are examined under the assumption of very slow fading. These analyses demonstrate the frequency hopping benefits in selective channels. The performance of the channel under fast frequency hopped spread-spectrum is also measured. Performance is measured for the slow fading channel only so a means should be present to evaluate the performance of fast fading channel.

In [5], The Author reviewed and analyzed the statistical properties of Clarke's fading model with a finite number of sinusoids, and an improved reference model (Xiao's model) is proposed for the simulation of Rayleigh fading channels. A novel statistical simulation model for Rician fading channels is examined. The new Rician fading simulation model employs a zero-mean stochastic sinusoid as the specular(line-of sight) component, in contrast to existing Rician fading simulators that utilize a non-zero deterministic specular component. The statistical properties of the proposed Rician fading simulation model are analyzed in detail. It is shown that the probability density function of the Rician fading phase is not only independent of time but also uniformly distributed over $[-\pi, \pi)$. This property is different from that of existing Rician fading simulators. An explicit formula for the level-crossing rate is derived for general Rician fading when the specular component has non-zero Doppler frequency. In addition to this, [2] and [7] also dealt with the statistical channel modeling similar to that but mainly concerned with 2nd order statistics. SOS model is developed considering the speed of terminal as constant both in magnitude and direction. But it is necessary to have a means to model the channel for varying speed

In [8], the author of this thesis provides computer simulation of a physics-based channel model to define the essential channel parameters, and subsequently reproduce the characterized channel by appropriately utilizing the autoregressive process to remodel the attained channel data. The

principal method for this study is the use of Levinson-Durbin recursion to build a signal model for channel analysis. In this thesis comparison of amplitudes of the received signal and transmitted signal, the autocorrelation of the received with the transmitted signal, the power delay profiles are all realized and compared with the autoregressive model.

In [10], the author of this thesis has analysed the severity of the fading especially very severe when there is no line-of-sight component, which is the most frequent case in urban and suburban areas. Generally, the multipath fading amplitude distribution is modeled with Rayleigh distribution. But when the fading is very severe, the less efficient Rayleigh model is replaced by the powerful model, named so called Nakagami- m model. In this thesis report, efficient method is introduced which takes the advantage of product of two independent random processes, namely, a square root beta process and a complex Gaussian random process. But the performance of the Nakagami- m fading channel is evaluated by the probability density function by varying the m parameter. But other performance parameters like BER are also possible

In [13], in this paper, five fundamental methods are proposed to model the multipath power-delay profile of frequency-selective indoor and outdoor wireless channels. These five methods are labeled as MED, MSEM, MEA, MCM and LPNM All procedures are universally valid so that they can be applied to any specified or measured multipath power-delay profile. In this paper the main concern is to derive the power delay profile parameters, i.e. time delay and path gain given that there is no information about the environment except the measured and specified power delay profile is assumed to be given. The performance of the proposed methods is investigated with respect to important characteristic quantities such as the frequency correlation function (FCF), average delay, and delay spread. The method found to perform best is the so-called $-$ norm method (LPNM). This procedure is applied to measurement data of multipath power-delay profiles collected in different propagation environments. It is shown that the realization complexity of tapped-delay line-based simulation models for fading channels can be reduced considerably by using the LPNM. This is a great advantage for the development and specification of channel models for future wireless systems. Only Comparison of the methods is

presented here. But once the delay parameters like path attenuation and time delay are obtained, this power delay also should be used in the performance evaluation of the channel.

Based on the literature gathered from the above and other literatures mentioned in the reference section, we are going to model and simulate the small scale fast fading channel and measure the performance of the channel

1.5.Methodology

The methodology used in doing this thesis comprises the phases shown in the Fig 1.3. The first phase includes the reviews and gathering of various literatures on statistical modeling of small scale fading channel which help to understand the necessary theoretical background for the thesis work. The other four phases clarify how such major tasks as Modeling, simulating, and performance analysis and evaluation are carried out.

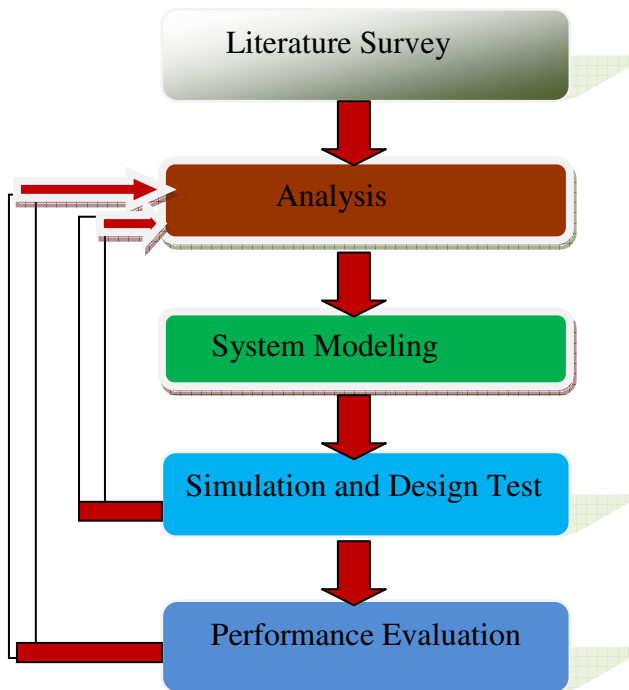


Fig 1.3 Methodology

Literature Survey: - This is accomplished by reviewing the literatures including books, articles, research publications, lecture notes, AAU previous thesis papers and other information from different related journals to the statistical modeling and simulation of small scale fading channel.

Analysis: - This phase involves the study different channel modeling mechanisms and then finally comparing the general model with pre-existing models.

System Modeling: - After an in-depth analysis of models and selection of the performance parameters, the general mathematical model which represents all states of motion is developed

Simulation:-Once the mathematical model of the channel is developed, comparison of this model with the preexisting model is done by simulation. In addition to this, performance of the small scale fast fading and frequency selective channel is simulated

Performance evaluation:-Finally, the performance of the developed system is evaluated and analyzed .performance the fast fading as well as the frequency selective channel is evaluated using the BER, fading rate, fading duration and fading probability.

1.6.Thesis organization

The remaining chapters will be organized as follows:

Chapter 2: introduces basic of wireless fading channel, basic propagation mechanism, types of fading channel, basic fading parameters and fading channel statistics.

Chapter 3: the different statistical models of small scale fading channel: impulse response model, SOS model, general fading channel model, comparison of the models, the performance measurement parameters of the small scale fading channel

Chapter 4: discusses about results and simulations. In this chapter comparison of the general model with the improved Xiao's model in terms of the autocorrelation function, fading probability, fading rate ,fading period and the Bit Error Rate are simulate and the results are discussed.

Chapter 5: Presents conclusion and recommendations for future work

CHAPTER TWO: FADING CHANNEL BASICS

2.1 EM wave propagation in wireless systems

Wireless channels differ from wired channels, due to their unreliable behavior compared to wired channels. In wireless channels the state of the channel may change within a very short time span. This random and severe variation of the wireless channels turns communication over such channels into a difficult task. There are several different classifications regarding the wireless channels. Wireless channels may be distinguished by the propagation environment encountered [14]. Many different propagation environments have been identified, such as urban, suburban, indoor, underwater or orbital propagation environments, which differ in various ways. Modeling the wireless channel has historically been one of the most difficult parts of the communication system design and is typically done in a statistical manner. In order to apply this statistical method, the propagation mechanisms play a major role. There are a lot of mechanisms behind the electromagnetic wave propagation, but they can be generally attributed to reflection, diffraction and scattering as shown in Fig 2.1 [8, 10 14, 25].

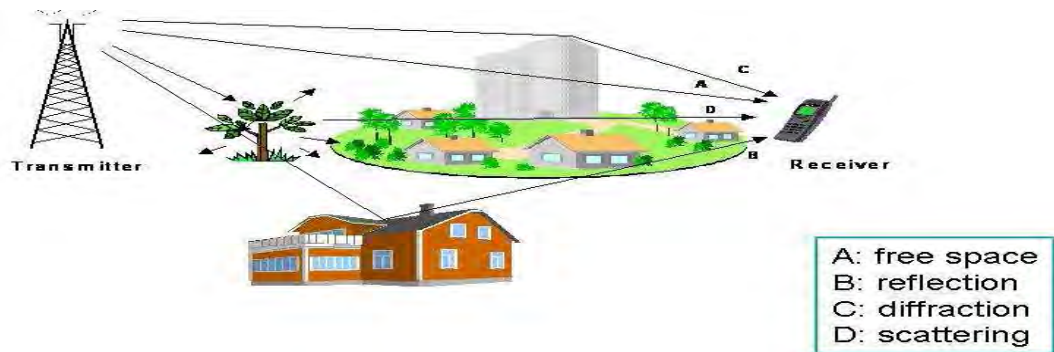


Fig 2.1 Propagation mechanism

Due to the aforementioned different propagation mechanisms, radio propagation can be roughly described by three nearly independent phenomenons; path loss variation with distance, shadowing and multi-path fading. Each of these phenomenons is caused by a different underlying physical principle and must be considered when designing and evaluating the performance of a wireless communication system.

Among the three independent phenomenons, only free space path loss is a deterministic effect which depends only on the distance between the transmitter and the receiver. It plays an important role on larger time scales like seconds or minutes, since the distance between the transmitter and the receiver in most situations does not change significantly on smaller time scales. On the other hand, shadowing and fading are not deterministic. They both have stochastic nature. Shadowing occurs due to the varying terrain conditions in suburban area and due to the obstacles such as buildings etc. Multipath Fading leads to significant attenuation changes within smaller time scales such as milliseconds or even microseconds. Fading is always caused by a multipath propagating environment, whereby in an environment reflecting the transmitted electromagnetic waves. Multiple copies of the received wave interfere at the receiving antenna.

2.2 Fading

The most troublesome and frustrating problem in receiving radio signals is variations in signal strength, most commonly known as fading. There are several conditions that can produce fading. When a radio wave is refracted by the ionosphere or reflected from the Earth's surface, random changes in the polarization of the wave may occur. Vertically and horizontally mounted receiving antennas are designed to receive vertically and horizontally polarized waves, respectively [10]. Therefore, changes in polarization cause changes in the received signal level because of the inability of the antenna to receive polarization changes. Fading also results from absorption of the RF energy in the ionosphere. Absorption fading occurs for a longer period than other types of fading, since absorption takes place slowly [9]. Usually, however, fading on ionospheric circuits is mainly a result of multi-path propagation.

2.2.1 Major categories of fading

Propagation models have traditionally focused on predicting the average received signal strength at a given distance from the transmitter, as well as the variability of the signal strength in close spatial proximity to a particular location. Depending upon it, the multi path fading is mainly classified into 2 types: large scale fading and small scale fading

2.2.1.1 Large-Scale Fading

Fading, that concentrates on the *mean* signal strength for an arbitrary transmitter-receiver (T-R) separation distance and is useful in estimating the radio coverage area of a transmitter and is called large scale fading. It is mainly due to the absorption of RF energy in the transmission medium and is calculated by keeping the transmitter and receiver in the fixed positions. That's why; it is also referred to as absorption fading. The absorption occurs due to 3 types of mechanisms. They are Reflection, Diffraction and Scattering. Different fading models are developed to estimate this large scale fading such as Longley-rice model, Durkin's model, Okumura model, Hata model, Ericsson multiple breakpoint models, Walfish and Bertoni model, etc.

2.2.1.2 Small - Scale Fading

Small-scale fading refers to the dramatic changes in signal amplitude and phase that can be experienced as a result of small changes (as small as half wavelength) in the spatial position between transmitter and receiver. The type of fading experienced by a signal propagating through a mobile radio channel depends on the nature of the transmitted signal with respect to the characteristics of the channel. The main factors influencing the small scale fading are as in [1, 8]

- ✓ Multi-path propagation
- ✓ Speed of mobile
- ✓ Speed of surrounding objects
- ✓ Transmission bandwidth of the channel as well as the bandwidth of the signal

2.2.1.2.1 Small scale fading channel parameters

In order to compare different multipath channels and to develop some design methods for mobile communication systems, different parameters which grossly quantify the channel are used. We can classify the parameters into 2 categories: time dispersion and frequency dispersion parameters

2.2.1.2.1.1 Time dispersion parameters

Mean excess delay: - It is the first moment of the power delay profile and is defined as

$$\bar{\tau} = \frac{\sum_n \alpha_n^2 \tau_n}{\sum_n \alpha_n^2} \quad (2.1)$$

Where α_n is the path attenuation factor, τ_n is the path delay

rms delay spread (σ_τ):-It is the square root of the second central moment of the power delay profile which is defined as

$$\sigma_\tau = \sqrt{\tau_n^2 - (\bar{\tau})^2} \quad (2.2)$$

These two parameters, the mean excess delay and the rms delay spread are measured relative to the first detectable signal arriving at the receiver at $\tau_0 = 0$. These are defined from a single power delay profile which is temporal or spatial average of consecutive impulse response measurements collected and averaged over a local area.

Maximum excess delay:-The maximum excess delay (X dB) of a power delay profile is defined to be the time delay during which multipath energy falls to X dB below the maximum. The maximum excess delay is defined as $\tau_x - \tau_0$, where τ_x is the maximum delay at which a multipath component is within X dB of the strongest arriving multipath signal.

Coherence bandwidth (B_c):- It is the statistical measure of the range of frequencies over which the channel can be considered flat. In other words, it is the range of frequencies over which two frequency components have a strong potential for amplitude correlation. The rms delay spread and coherence bandwidths are inversely proportional to each other, which mathematically is given as

$$B_c \propto \frac{1}{\sigma_\tau} \quad (2.3)$$

2.2.1.2.1.2 Frequency dispersion parameters

➤ **Doppler spread:** -It is a measure of the spectral broadening caused by the time rate of change of the mobile channel and is defined as the range of frequencies over which the received Doppler spectrum is essentially non-zero. When a pure sinusoidal tone of frequency

f_c is transmitted, the received signal spectrum, called the Doppler spectrum, will have components in the range $f_c - f_d$ to $f_c + f_d$, where f_d is the Doppler shift.

- **Coherence time:** - This is the time domain dual of Doppler spread and is used to characterize the time varying nature of the frequency depressiveness of the channel in the time domain. It is the time duration over which the channel impulse response is essentially invariant, and quantifies the channel response at different times.

2.2.1.2.2 Types of small scale fading

Small scale fading is categorized based on multipath delay spread and the Doppler spread due to the relative motion of the transmitter and receiver.

2.2.1.2.2.1 Small scale Fading due to time delay spread

Multipath time delay spread can affect radio communications channels and these effects can be Flat fading and Frequency selective fading

I. Flat fading

If the mobile radio channel has a constant gain and linear phase response over a bandwidth which is greater than the bandwidth of the transmitted signal, then the received signal will undergo *flat fading*. In flat fading, the Multipath structure of the channel is such that the spectral characteristics of the transmitted signal are preserved at the receiver. However the strength of the received signal changes with time, due to fluctuations in the gain of the channel caused by multipath. In a flat fading channel, the reciprocal of the bandwidth of the transmitted signal is much larger than the multipath time delay spread of the channel, and $h_b(t_\tau)$ which is the impulse response can be approximated as having no excess delay. Flat fading channels are also known as amplitude varying channels and are sometimes referred to as narrowband channels, since the bandwidth of the applied signal is narrow as compared to the channel flat fading bandwidth. Typically flat fading channels cause deep fades, and thus may require 20 or 30 dB more transmitter power to achieve low bit error rates during times of deep fades as compared to systems operating over non-fading channels. To summarize, a signal undergoes flat fading if

$$B_s \ll B_c \text{ and } T_s \gg \sigma_\tau$$

Where T_s is the reciprocal bandwidth (e.g., symbol period) and B_s is the signal bandwidth, respectively, of the transmitted modulation, and σ_τ and B_C are the rms delay spread and coherence bandwidth, respectively, of the channel.

II. Frequency Selective Fading

If the channel possesses a constant-gain and linear phase response over a bandwidth that is smaller than the bandwidth of transmitted signal, then the channel creates *frequency selective fading* on the received signal. Under such conditions, the channel impulse response has a multipath delay spread which is greater than the reciprocal bandwidth of the transmitted message waveform. Frequency selective fading channels are much more difficult to model than flat fading channels since each multipath signal must be modeled and the channel must be considered to be a linear filter.

For frequency selective fading, the spectrum $S(f)$ of the transmitted signal has a bandwidth which is greater than the coherence bandwidth B_c of the channel. Viewed in the frequency domain, the channel becomes frequency selective, where the gain is different for different frequency components. Frequency selective fading is caused by multipath delays which approach or exceed the symbol period of the transmitted symbol. Frequency selective fading channels are also known as *wideband channels* since the bandwidth of the signal $s(t)$ is wider than the bandwidth of the channel impulse response. To summarize, a signal undergoes frequency selective fading if: **$B_s > B_c$ and $T_s < \sigma_\tau$** .

A common rule of thumb is that a channel is flat fading if $T_s \geq 10 \sigma_\tau$ and a channel is frequency selective if $T_s < 10 \sigma_\tau$ although this is dependent on the specific type of modulation used.

2.2.1.2.2.2 Small scale Fading Due to Doppler Spread

There are a variety of reasons for this fading effect. The mobile station, user terminal and, many objects around are likely to be moving, and as a result the path lengths of all the signals being received are changing. Accordingly multi-path fading due to Doppler spread has a major bearing on cellular telecommunications. Accordingly fading can be classified as: Fast fading and slow fading.

I. Fast Fading

Depending on how rapidly the transmitted base band signal changes as compared to the rate of change of the channel, a channel may be classified either as a fast fading or slow fading channel. In a fast fading channel, the channel impulse response changes rapidly within the symbol duration. That is, the coherence time of the channel is smaller than the symbol period of the transmitted signal. This causes frequency dispersion (also called time selective fading) due to Doppler spreading, which leads to signal distortion. When viewed in the frequency domain, signal distortion due to fast fading increases with increasing Doppler spread relative to the bandwidth of the transmitted signal. Therefore, a signal undergoes fast fading if: $T_s > T_c$ and $B_s < B_b$

II. Slow fading

In a *slow fading channel*, the channel impulse response changes at a rate much slower than the transmitted base band signal. In this case, the channel may be assumed to be static over one or several reciprocal bandwidth intervals. In the frequency domain, this implies that the Doppler spread of the channel is much less than the bandwidth of the base band signals. Therefore, a signal undergoes slow fading if: $T_s \ll T_c$ and $B_s \gg B_b$

It should be clear that the velocity of the mobile (or velocity of objects in the channel) and the base band signaling determines whether a signal undergoes fast fading or slow fading.

The relation between the various multi-path parameters and the type of fading experienced by the signal are summarized in Figure 2.2 and 2.3 as in [1, 10, 24, 25]. It should to note that fast and slow fading deal with the relationship between the time rate of change in the channel and the transmitted signal, and not with propagation path loss models.

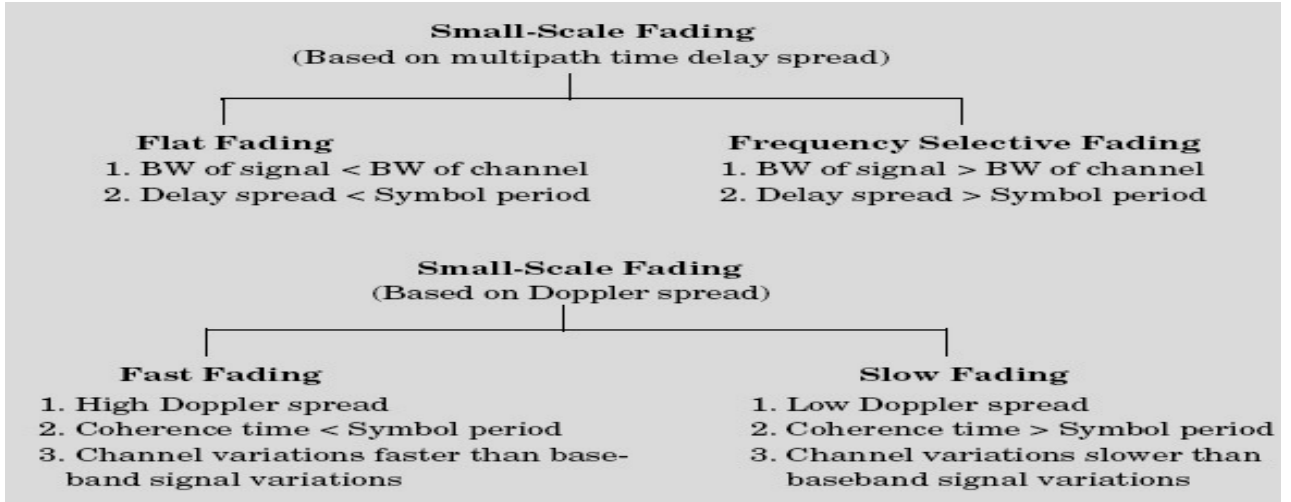


Fig 2.2a Types of small scale fading

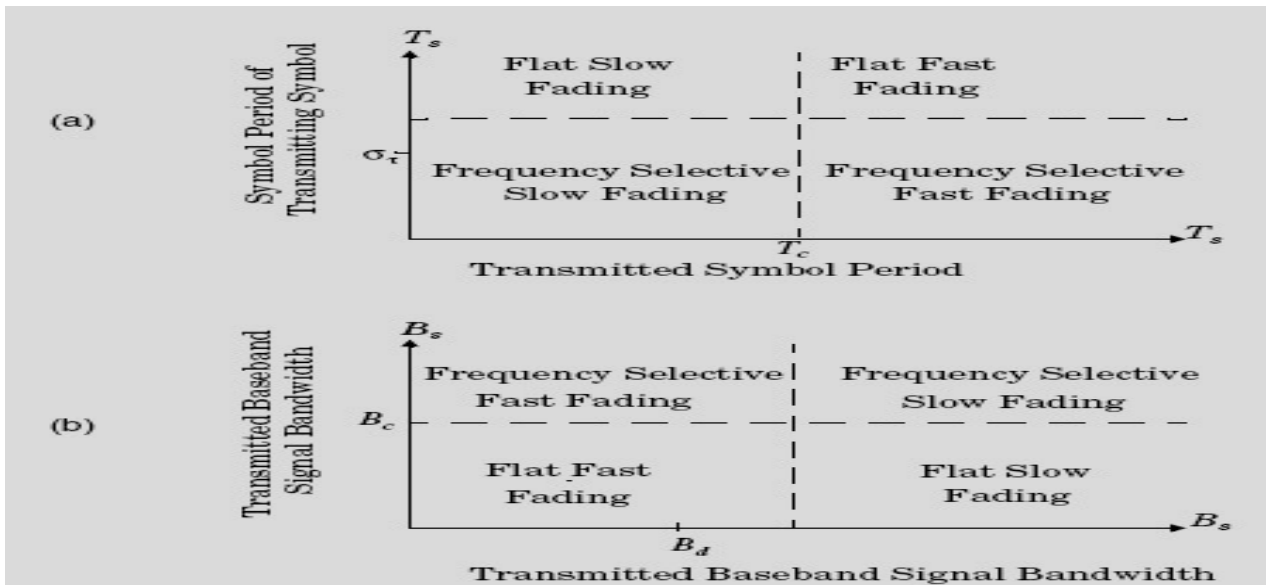


Fig 2.3b Types of small scale fading

2.2.1.2.3 First order statistics of fading

In general a received signal consists of a large number of signal copies which interfere at the receiver antenna. If all channel multipath gain were known at each time instance, the wireless channel could be seen as a deterministic channel in principle [14]. But due to the large number of reflection paths, this is not possible in practice. Therefore a statistical description is the only way to characterize at least some properties of the channel.

Since there is a high number of signal paths in a given propagation environment, the *central limit theorem* may be applied to the statistical behavior of the interfering signal copies at the receiver [14, 33]. If the number of paths tends to infinity, then the fading can be modeled by complex white Gaussian process.

Let us consider the complex channel gain: $h = x + jy$

As the number of the interfering signal copies approach to infinity, both x and y are each Gaussian distributed. The probability density function of the complex envelop \mathbf{h} is given by $|h| = \sqrt{(x^2 + y^2)}$ is Rayleigh distributed [1, 33]. The generation of Rayleigh fading is given in the diagram below.

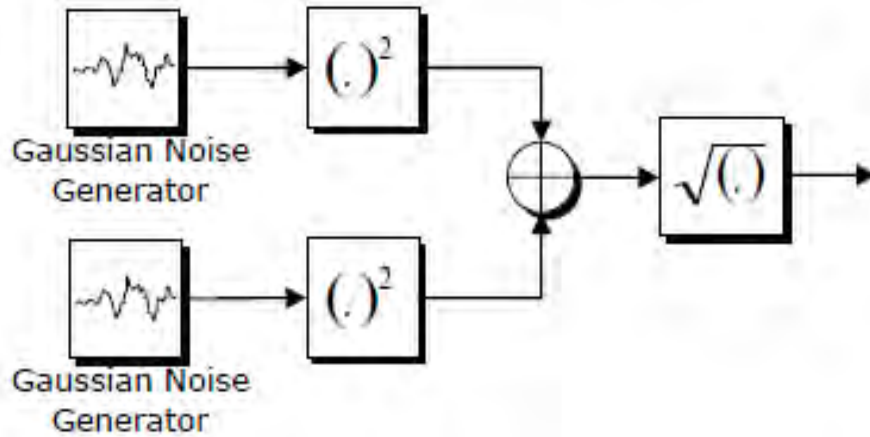


Fig 2.4 Rayleigh fading signal generation

The square of the envelope is exponentially distributed. The phase of the envelope is uniformly distributed. The expressions of the distribution of $|h|$ and $|h|^2$ are given in [24, 25, 33] by

$$p_h(h) = \frac{h}{\sigma^2} \exp\left[-\frac{h^2}{2\sigma^2}\right], \quad h \geq 0 \quad (2.4)$$

$$P_{h^2}(h) = \frac{1}{2\sigma^2} \exp\left(-\frac{h}{2\sigma^2}\right), \quad h \geq 0 \quad (2.5)$$

These expressions are valid only if there is no direct Line of Sight (LOS) path in the propagation environment. If there is a fixed LOS component in the channel, the components x and y are non-zero-mean Gaussian distributed. In this case the received signal equals the superposition of a

complex Gaussian component and a LOS component. The signal envelope in this case can be shown to have a Rician distribution which is given by

$$P_h(h) = \frac{2h(k+1)}{P_r} \exp\left[-k - \frac{(k+1)h^2}{P_r}\right] I_0\left(2h\sqrt{\frac{k(k+1)}{P_r}}\right), \quad h \geq 0 \quad (2.6)$$

Where P_r is the total power given by the expression

$$P_r = \int_0^\infty Z^2 P_z(z) dz = s^2 + 2\sigma^2 \quad (2.7)$$

$2\sigma^2 = \sum_{n,n \neq 0} E[\alpha_n^2]$ is the average power in the non-LOS multipath components and $s^2 = \alpha_0^2$ is

the power in the LOS component. The function I_0 is the modified Bessel function of 0th order; k is known as the Rician factor and completely specifies the Rician distribution. As the power of the LOS, $A \rightarrow 0$, $K \rightarrow -\infty$ dB, as the dominant path decreases in amplitude, the Rician distribution degenerates to a Rayleigh distribution. For small number of paths (< 5), the central limit theorem does not hold any more, so Gaussian process assumption does not fit adequately [10, 31]. In this case the amplitude of the received signal can be modeled by *Nakagami* distribution. The instantaneous power z of the signal has a gamma, Γ distribution. In Addition to this by varying a variable m of the Nakagami distribution can take into account the absence or presence of a LOS. Also the Nakagami distribution is more convenient for analytical work. For detailed derivation and discussion refer to [31].

2.2.1.2.4 Second order statistics of fading

In order to describe a random process it is sufficient to know its mean and its auto/cross correlation function, or *power spectrum* which is the Fourier transform of autocorrelation function when the process is wide sense stationary. We have already shown the mean implicitly in the previous Section in such a way that if the probability density function is known it is possible to easily define the mean. In this Section we are going to see the second order description of the process in case of the Doppler spread as well as in the case of delay spread.

In the case of Doppler spread only, where $s(t-\tau_i) \approx s(t)$, the received signal $r(t)$ is determined by the product of the transmitted signal $s(t)$ and the complex gain of the channel $C(t)$ where the complex gain of the channel is time variant.

$$R(t) = s(t) \times C(t) + n(t) \quad (2.7)$$

If a pure tone is transmitted through the channel then the received signal consists of multiple tones at frequencies in the vicinity of the carrier with a maximum shift by the Doppler frequency f_m . Let us consider a mobile receiver moving with the velocity v in a multipath environment. Each Doppler frequency f_d is given by.

$$f_d = f_m \times \cos(\theta) \quad (2.9)$$

Where f_m is the maximum Doppler frequency and θ is the angle of arrival. Generally f_d varies from $+f_m$, resulting from reflected paths in front of the receiver to $-f_m$ resulting from reflected paths behind the receiver (behind and in front relate to the direction of movement of the receiver). Assume that there is high number of scatterers; therefore the power received from differential angle $d\theta$ is given by the product of power density $P(\theta)$ and differential angle $d\theta$. Thus we can relate the received power, S_r to the Doppler shift frequency f_d and with this we obtain the received *power spectrum* $S_r(f)$ as in [14].

$$S_r(f) = \frac{P(\theta) + P[-\theta]}{f_d \sqrt{1 - \left(\frac{f_v}{f_d}\right)^2}} \quad (2.10)$$

In the above expression $f_v = f \cdot v/c$ which is the shift in frequency due to Doppler and it is, if we consider the special case of isotropic scattering, implying that the power received from different angles is equivalent ($P(\theta) = \sigma^2 / 2\pi$) and the angle of arrival is uniformly distributed. The auto/cross correlation can be derived in two ways. This can be either by taking the received signal and decomposing it in to the in phase and quadrature components and we can take the correlation from the components [33]. We can also easily derive the autocorrelation function of the complex channel gain by taking inverse Fourier transform of the power spectrum given in the above equation.

If we assume that the scatterers at different Doppler shifts f_d are uncorrelated, then $h(t)$ is in fact uncorrelated. This assumption is called the wide sense stationary (WSS) assumption and given as

$$E[h(t)h(t-\tau)] = r_h(\tau) \quad (2.11)$$

The coherence time which indicates the time span that channel roughly stays constant can be derived from the autocorrelation. One mathematical definition of the coherence time is determined by Equation below which gives an autocorrelation value of 0.98 [31].

$$T_c = \frac{1}{2\pi \times v_{rms}} = \frac{1}{(\sqrt{2})\pi f_d} \quad (2.12)$$

Other definitions of the coherent time can be found in literature [1], [31]. v_{rms} denotes the standard deviation of the power spectrum, $S_i(f)$, given by Equation equ 2.7. For the case of isotropic scattering the variance is

$$v_{rms} = \frac{f_d}{\sqrt{2}} \quad (2.13)$$

If the required bandwidth is not significantly smaller compared to the carrier frequency, the expected coherence time equals the coherence time of the highest frequency involved in the communication scheme [14].

CHAPTER THREE: SMALL SCALE FADING CHANNEL STATISTICAL MODELLING AND PERFORMANCE MEASUREMENTS

This chapter mainly concerned with the mathematical and diagrammatical modeling of the small scale fading channel. Starting from the sum of sinusoid (SOS) model, we will proceed to the modeling and derivation of the impulse response model of the channel and the main factors which determine the impulse response model. Once we have seen this, the general channel model which applies for all states of motion is presented. Finally the main fast fading wireless channel performance measurement parameters are analysed.

3.1 Propagation models

Propagation models are used extensively in network planning, particularly for conducting feasibility studies and during initial deployment. They are also very useful for performing interference studies as the deployment proceeds. These models can be broadly categorized into three types; empirical, deterministic and stochastic [33, 35].

Empirical modeling: - Empirical propagation models have found favor in both research and industrial communities owing to their speed of execution and their limited reliance on detailed knowledge of the terrain. Although the study of empirical propagation models for mobile channels has been exhaustive, their applicability for Fixed Wireless Access (FWA) systems is yet to be properly validated [33]. Among the most important empirical models are the Stanford University Interim (SUI) models [35] and the COST-231 Hata model [36].

Deterministic modeling:-Path loss and shadowing are two important aspects that should be analyzed by deterministic modeling. These variations, due to path loss and shadowing, occur over relatively large distances. This variation is sometimes referred to as large-scale propagation effects or local mean attenuation. An example of a deterministic model is a ray tracing model [36, 38]

Statistical modeling:-Stochastic models model the environment as a series of random variables [24]. Equivalently the system model might require that the variable in the system is a

random variable defined by a certain probability density function. The result of this simulation will no longer be a deterministic waveform, and samples of this waveform will yield a set of random variables. Models in which random quantities are present are referred to as stochastic simulation models. Stochastic models use the first and second order statistical properties of the channels impulse response to characterize the channel behavior [10].

Why statistical modeling is more preferable?

The main parameters used to compare one model from the other are accuracy, cost invested to gather information, processing power and speed.

Even though statistical model is the least accurate, it requires the least information about the environment in addition to this; this model uses much less processing power to generate predictions. Statistical models are less expensive because they don't need any field data and complicated experiments.

3.2 Simulation models of wireless channel

It is important to simulate communication systems in software for system design and verification. Simulation offers cost effective and time saving alternative to real time testing in the field. The prime requirement of the simulation set-up is to capture the fading effects created by a radio channel. As a result, efforts have been made to develop efficient models to simulate the actual radio propagation small scale fading environment in software and test various communications algorithms. Before we discuss our contributions in this area, it is necessary to understand different sum of sinusoid (SOS) simulation models commonly employed to simulate fading channels.

3.2.1 Sum of sinusoid model(SOS)

Mobile radio channel simulators are commonly used in the laboratory because they allow system tests and evaluations which are less expensive and more reproducible than field trials. Many different approaches have been used for the modeling and simulation of mobile radio channels [2]. Among them, the well-known sum of sinusoid is used for Rayleigh fading channels. SOS models are simpler to produce and more preferable to model the wireless channel by generating N complex sinusoids by considering the Doppler frequency, number of

path and the signal phase in to consideration. The main well known SOS models discussed in this work are Clark's model, Jack's model, Pop-Beaulieu model (improved jakes model) and the Xiao's model. In all SOS simulation models the received signal is given as in [2, 5, 7] by

$$g(t) = \frac{1}{\sqrt{N}} \sum_{n=1}^N \exp[j(\omega_d t \cos \alpha_n + \phi_n)] \quad (3.1)$$

$$g(t) = g_c(t) + jg_s(t) \quad \text{Where}$$

$$g_c(t) = \frac{1}{\sqrt{N}} \sum_{n=1}^N \cos[(\omega_d t \cos \alpha_n + \phi_n)] \quad (3.2)$$

$$g_s(t) = \frac{1}{\sqrt{N}} \sum_{n=1}^N \sin[(\omega_d t \cos \alpha_n + \phi_n)] \quad (3.3)$$

Where

N=the number of propagation paths,

ω_d = the maximum radian Doppler frequency,

α_n =the angle of arrival,

ϕ_n = initial phase of the nth propagation path.

These variables are the most important determining factors for each of the sum of sinusoid models. The parameters used to differentiate one SOS model from the other SOS model are Autocorrelation, Cross correlation and Variance of the autocorrelation /cross correlation between finite N and infinite N

➤ **Clarke's simulation Model:** - This model is sometimes called the reference mathematical model when N is very large. In this model the angle of arrival is uniformly distributed between 0 and $2*\pi$,i.e. $(0,2\pi)$ and the correlation functions are given in [5] as follows

$$R_{g_c g_c}(\tau) = R_{g_s g_s}(\tau) = \frac{1}{2} J_0(\omega_d \tau), \quad R_{g_s g_c}(\tau) = R_{g_c g_s}(\tau) = 0 \quad (3.4a)$$

$$R_{gg}(\tau) = E\{ \alpha, \phi [g^*(\tau) g(t + \tau)] \} = J_0(\omega_d \tau) \quad (3.4a)$$

$$R_{|g|^2 |g|^2}(\tau) = 1 + J_0^2(\omega_d \tau) - \frac{J_0^2(\omega_d \tau)}{N} \quad (3.4 \text{ b})$$

Where $E\{\alpha\phi[\cdot]\}$ is the expected value as a function of α and ϕ , and the above equation are for the reference model i.e., large N . For fixed N , the correlation statistics of the in phase is given as in [4]

$$R_{g_c g_c}(\tau) = \lim_{T \rightarrow \infty} \frac{1}{T} \int_0^T g_c(t) g_c(t + \tau) dt = \frac{1}{2N} \sum_{n=1}^N \cos(\omega_d \tau \cos \alpha_n) \quad (3.5)$$

The variance of the time averages between infinite N and fixed N Carries important information indicating the closeness between a single trial with finite N and the ideal case with $N = \infty$ as in [2, 4, 7], and is given as

$$\text{Var}\{R_{g_c g_c}(\tau)\} = E[R_{g_c g_c}(\tau) - 0.5 J_0(\omega_d \tau)]^2$$

For Clarke's simulation Model the variances are given by

$$\text{Var}\{R_{g_c g_c}(\tau)\} = \text{Var}\{R_{g_s g_s}(\tau)\} = \frac{1 - J_0(2\omega_d \tau) - 2J_0^2(\omega_d \tau)}{8N} \quad (3.6)$$

$$\text{Var}\{R_{g_c g_s}(\tau)\} = \text{Var}\{R_{g_s g_c}(\tau)\} = \frac{1 - J_0(2\omega_d \tau)}{8N} \quad (3.7)$$

$$\text{Var}\{R_{g g}(\tau)\} = \frac{1 - J_0^2(2\omega_d \tau)}{8N} \quad (3.8)$$

Plot of these expressions give the relationship of the auto/cross correlation of the reference with infinite N and with fixed N as a function N and speed of the mobile receiver. The plots below shows the autocorrelation for fixed N and infinite N

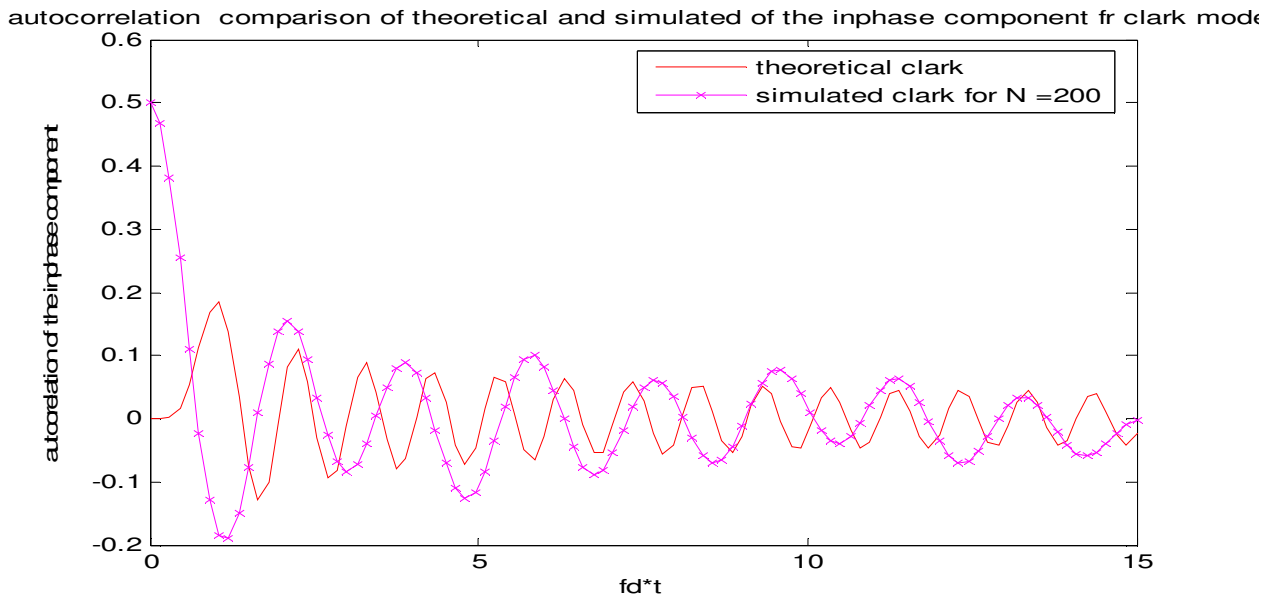
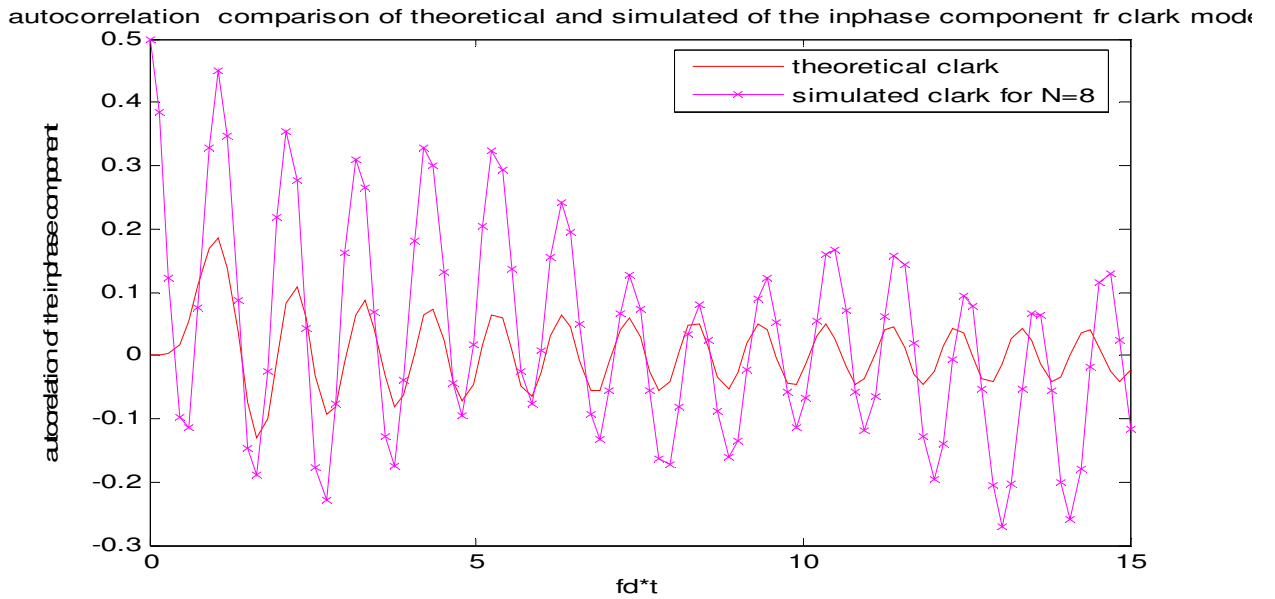


Fig 3.1 Autocorrelation vs. normalized time as a function of N

Fig 3.1 shows that as the number of simulators (paths) increase, the Clarks model for fixed N and the reference model approaches especially as time increases.

✓ **Jakes' simulation model**

The main difference of this model and the ideal Clark's reference model is, in the Clark's reference model the angle of arrival is uniformly distributed and the initial phase angle is not zero [16]. But in this model, i.e. in the Jake's model,

$$\alpha_n = \frac{2n\pi}{N}, \quad n = 1,2,3,\dots, N$$

$$\phi_n = 0, \quad n = 1,2,3,\dots, N \tag{3.9}$$

Using the symmetry of the 2-D isotropic scattering environment, Jakes reduced the number of sinusoidal components necessary for simulation from N to some $M = (N - 2)/4$ as in [16]. Here the main problem faced to this model is, the non-stationarity of the 2nd order statistics as well as the less convergence to the reference model, i.e., when M is finite, and all the second-order statistics of the newly improved simulation model do not match the desired ones of Clarke's reference model [17,16]. Even when M approaches infinity, the autocorrelations of the quadrature components, the cross-correlations of the quadrature components, and the autocorrelation of the squared envelope do not match the desired ones of Clarke's reference model.

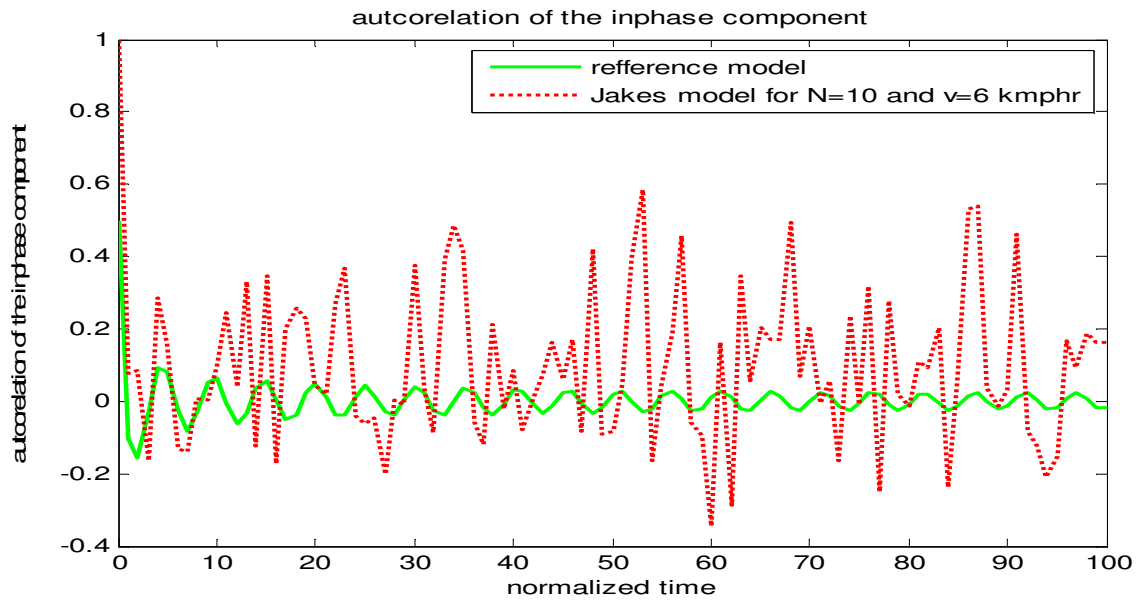


Fig 3.3a Jakes spectrum as function of normalized time

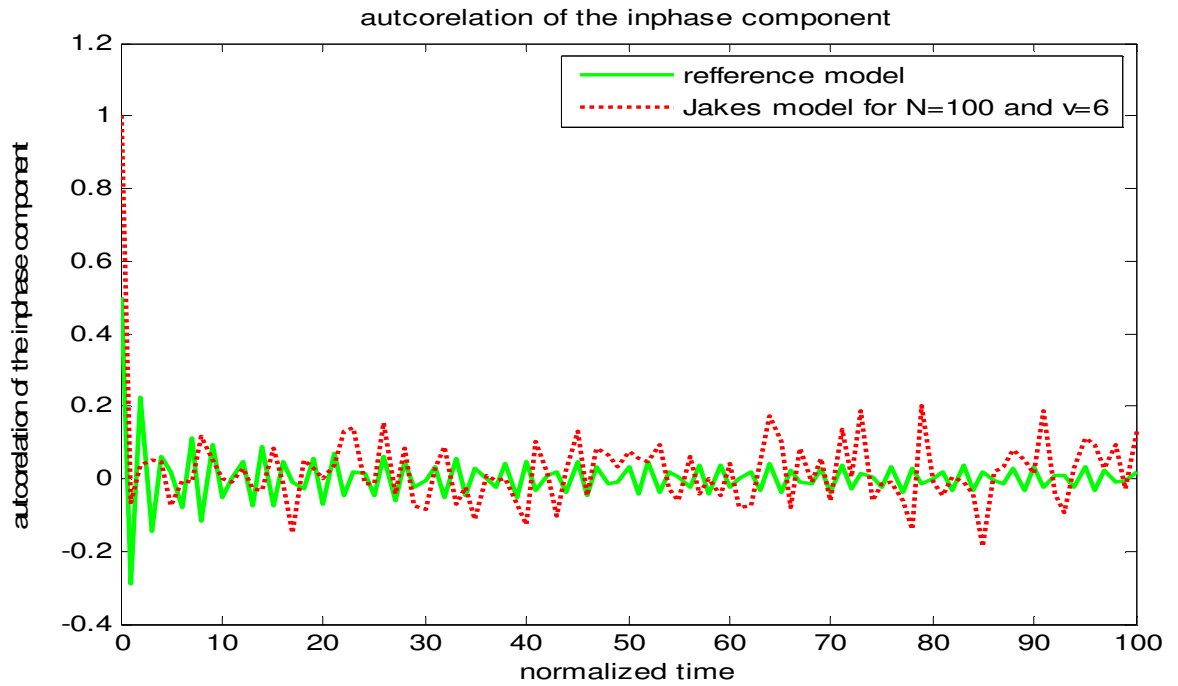


Fig 3.3b Jakes spectrum as function of normalized time

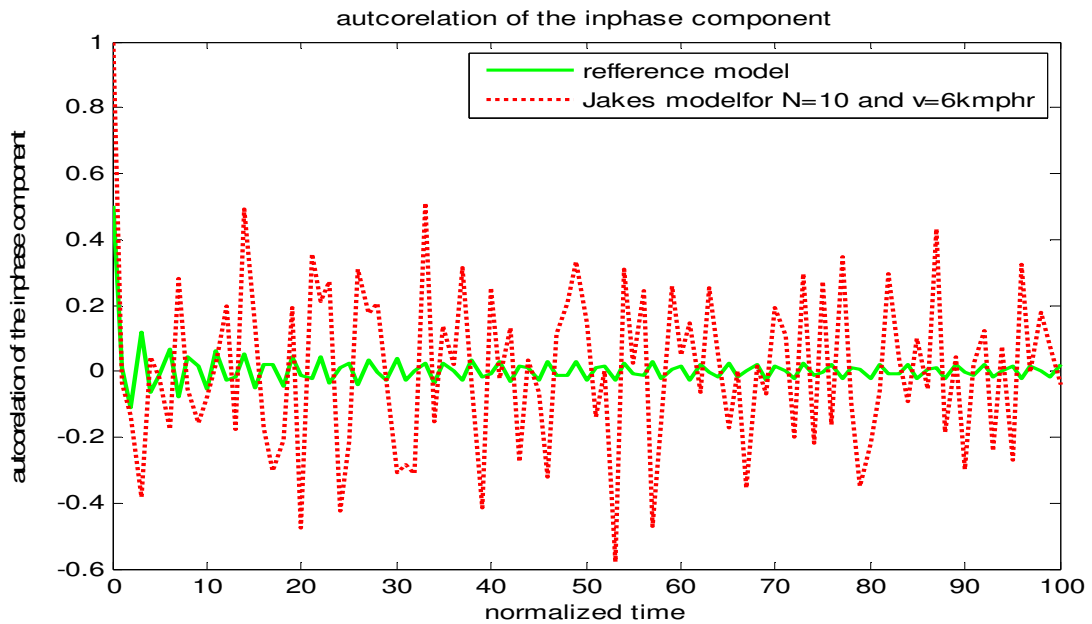


Fig 3.3c Jakes spectrum as function of normalized time

The above plots show that, for small N, the model is far from the mathematical reference model, and comparing fig 3.3a and 3.3c the effect of speed is almost negligible.

✓ **The Pop-Beaulieu Simulation model(improved jakes model)**

This model tried to improve the problem of the non stationarity of the original Jake's model [16] by changing the initial phase angel to be uniformly distributed in the interval of (0, 2π) and the angle of arrival to be

$$\alpha_n = \frac{2n\pi}{N}, \quad n = 1,2,3,\dots, N$$

The received signals which simulate the channel is similarly given by equ (3.4) But still the correlation statistics do not mach the desired reference model. This improved simulator is wide sense stationary (contrary to previous sum-of-sinusoids simulators, it may not model some higher-order statistical properties, for finite N [17]. The expressions of the 2nd order statistics are given as

$$R_{g_c g_d}(\tau) = R_{g_s g_d}(\tau) = \frac{1}{2N} \sum \cos\left(\varpi_d \tau \cos \frac{2\pi n}{N}\right) \quad (3.10)$$

$$R_{g_c g_s}(\tau) = R_{g_s g_c}(\tau) = \frac{1}{2N} \sum \sin\left(\varpi_d \tau \cos \frac{2\pi n}{N}\right) \quad (3.11)$$

$$R_{g_g}(\tau) = 2R_{g_c g_d}(\tau) + j2R_{g_c g_s}(\tau) \quad (3.12a)$$

$$R_{g^2 g^2}(\tau) = 1 + 4R_{g_c g_c}^2(\tau) + 4R_{g_s g_s}^2(\tau) - \frac{1}{N} \quad (3.12b)$$

Here as $N \rightarrow \infty$, these statistics approaches to the reference model.

✓ **Xiao's simulation model**

Based on the statistical analyses of Clarke's model and the Pop-Beaulieu simulator, the improved simulation model is proposed by C. **Xiao** [5] and for the received signal of equation (3.4), this model introduces another random angle Θ_n to the angle of arrival to improve the 2nd order statistics.

$$\alpha_n = \frac{2n\pi + \theta_n}{N}, \quad n = 1,2,\dots,N \quad (3.13)$$

Where φ_n and θ_n are statistically independent and uniformly distributed over $[-\pi, \pi)$ for all n . It is noted that the difference between this Xiao's model and the Pop-Beaulieu simulator model is the introduction of random variables θ_n to the angle of arrival. Randomizing θ_n slightly decreases the efficiency of the simulator, but significantly improves the statistical quality of the simulator. This model differs from Clarke's model in that it forces the angle of arrival, α_n , to have a value restricted to the interval as in [5] and given by

$$\left[\frac{(2n\pi - \pi)}{N}, \frac{(2n\pi + \pi)}{N} \right]$$

The angle of arrival is random and uniformly distributed inside this sector, in contrast to being fixed as it is in Jakes' model and in the Pop-Beaulieu simulator.

The autocorrelation and cross-correlation functions of the quadrature components and the autocorrelation functions of the complex envelope and the squared envelope of fading signal $g(t)$ are as in [16] is given by

$$R_{g_c g_c}(\tau) = R_{g_s g_s}(\tau) = \frac{1}{2} J_0(\omega_d \tau) \quad (3.14a)$$

$$R_{g_c g_s}(\tau) = R_{g_s g_c}(\tau) = 0 \quad (3.14a)$$

$$R_{g_g}(\tau) = J_0(\omega_d \tau) \quad (3.15a)$$

$$R_{|g|^2 |g|^2}(\tau) = 1 + J_0^2(\omega_d \tau) - f_c(\omega_d \tau, N) - f_s(\omega_d \tau, N) \quad (3.15b)$$

Where
$$f_c(\omega_d \tau, N) = \sum_{K=1}^N \left[\frac{1}{2\pi} \int_{\frac{2\pi K - \pi}{N}}^{\frac{2\pi K + \pi}{N}} \cos(\omega_d \cos \gamma) d\gamma \right]^2 \quad (3.16a)$$

$$f_s(\omega_d \tau, N) = \sum_{K=1}^N \left[\frac{1}{2\pi} \int_{\frac{2\pi K - \pi}{N}}^{\frac{2\pi K + \pi}{N}} \sin(\omega_d \cos \gamma) d\gamma \right]^2 \quad (3.16b)$$

But still as $N \rightarrow \infty$ this integrals have a minor effect on the correlation functions of the squared envelop autocorrelation [17] and can be approximated by $\frac{J_0^2(\omega_d \tau)}{N}$

The variance of the auto/cross correlation between the ideal value for $N = \infty$ and for finite N has also an important information about the difference between the correlation for large N and fixed N and is given by

$$\text{Var} \left\{ \hat{R}_{gcgc} \right\} = \text{Var} \left\{ \hat{R}_{gsgs} \right\} = \frac{1 + J_0(2\omega_d\tau)}{8N} - \frac{fc(\omega_d\tau, N)}{4} \quad (3.17a)$$

$$\text{Var} \left\{ \hat{R}_{gcgs} \right\} = \text{Var} \left\{ \hat{R}_{sgsc} \right\} = \frac{1 - J_0(2\omega_d\tau)}{8N} - \frac{fs(\omega_d\tau, N)}{4} \quad (3.17b)$$

$$\text{Var} \left\{ \hat{R}_{gg} \right\} = \frac{1}{N} - fc(\omega_d\tau, N) - fs(\omega_d\tau, N) \quad (3.17c)$$

Since the auto/cross correlation of the Clark's model directly converges, the only thing to compare this two simulation models is the squared envelop autocorrelation and the variance of the correlation statistics

Squared envelop comparison of Clark's and Xiao's model

From the plots in Fig 3.4a and 3.4b, it is possible to conclude that, as N increase the squared envelopes correlation spectrum decreases, and as N increases the two models almost approaches each other.

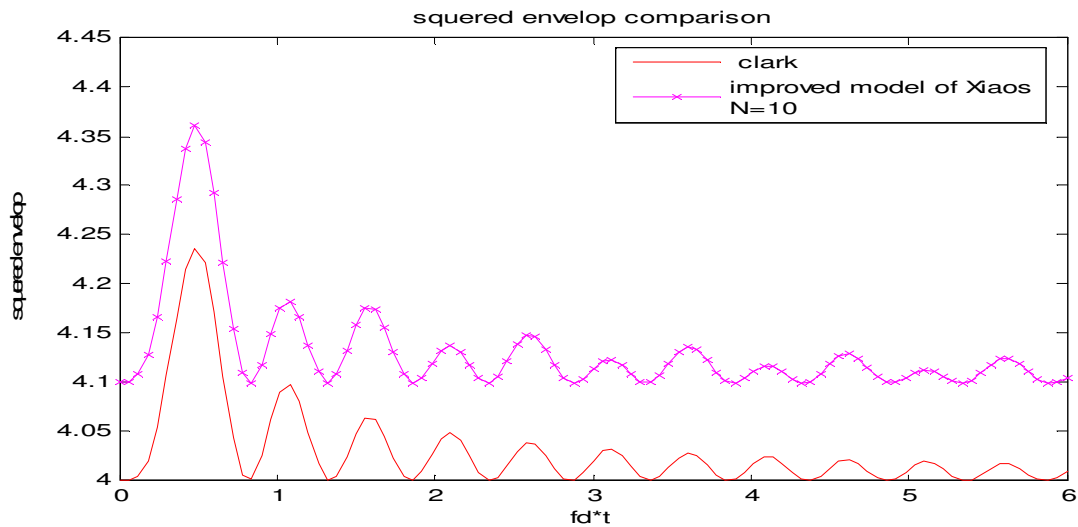


Fig 3.4a correlation of the Squared envelop comparison for different N

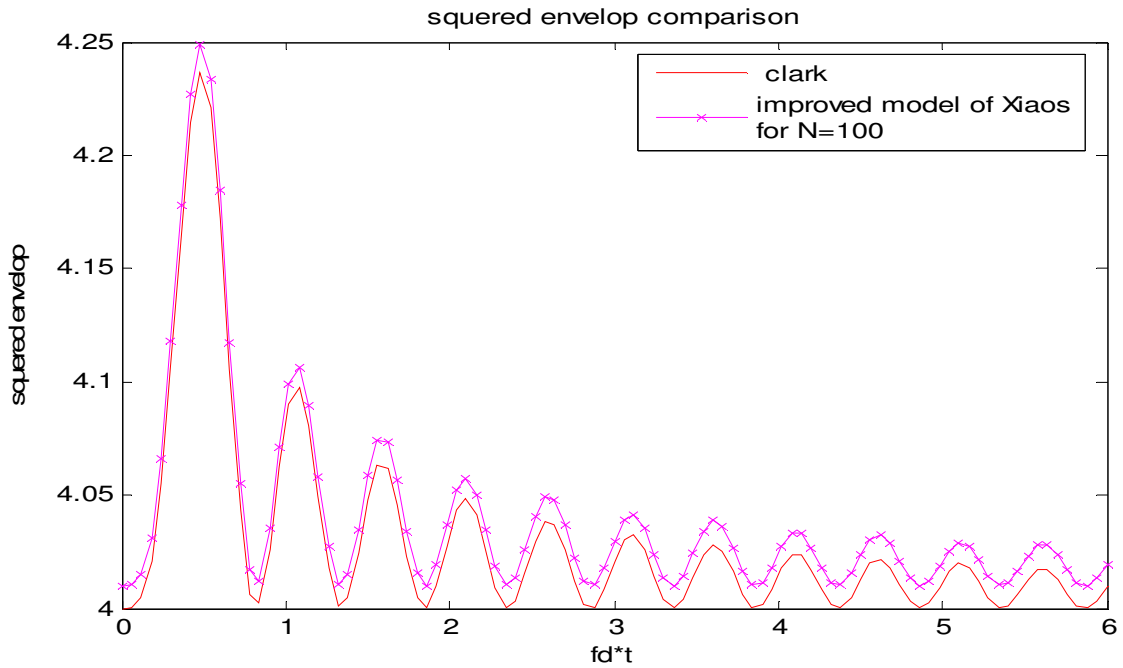


Fig 3.4b correlation of the Squared envelop comparison for different N

Variance of in phase/quadrature component comparison of Clark and Xiao's

As seen in the plots of Fig 3.4a and 3.4b, the variance of the two models perfectly converges, but the effect of N is observed in both models that as N increases the variance decreases and implies that the variance decreases as N increases and the models approach to the reference mathematical model

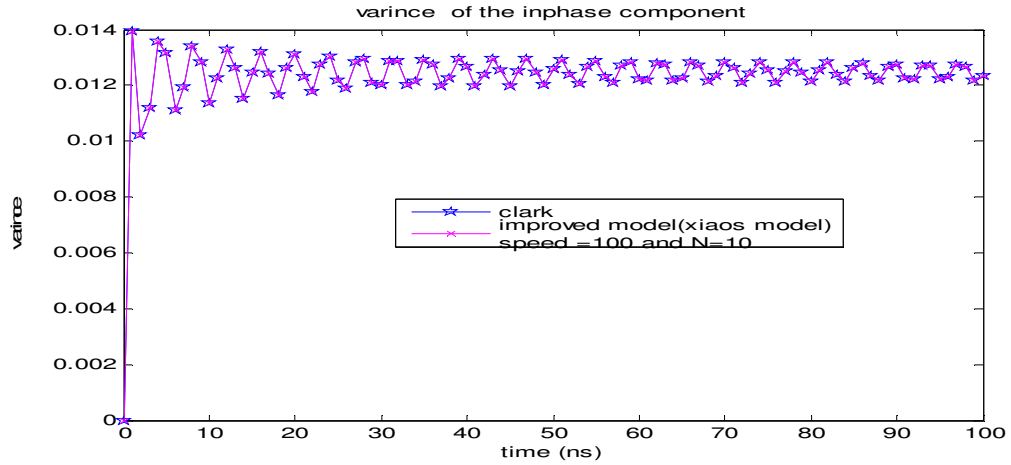


Fig 3.5a Variance comparison for different N

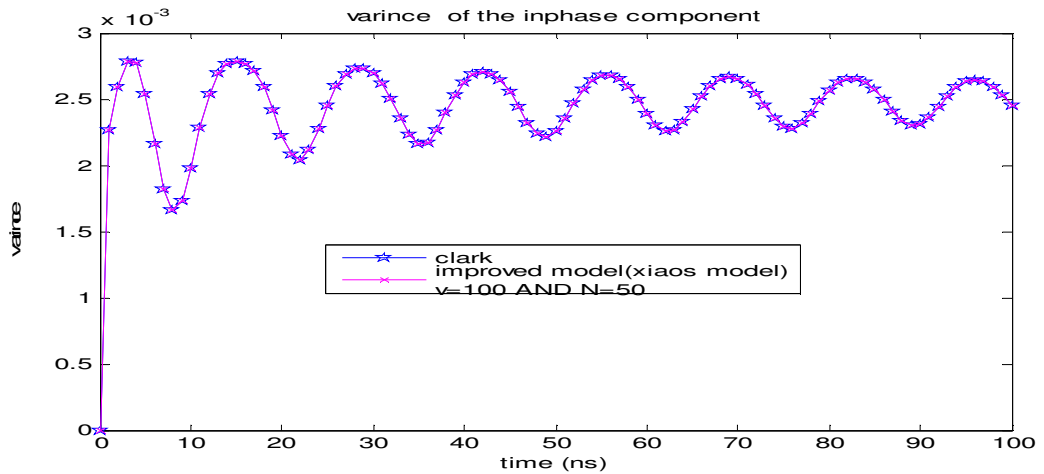


Fig 3.5b Variance comparison for different N

First order statistics

If we assume that the number of sinusoids is large, i.e. $N > 10$ and depending on the presence or absence of the LOS component, all the above simulation channel models can have an envelope modeled as Rayleigh or Rician (if there is LOS) and the phase is uniformly distributed. The expressions of the envelope and phase for both Rayleigh and Rician models are given in Equ (2.3) and (2.4) and the simulations of the two PDFs is given below.

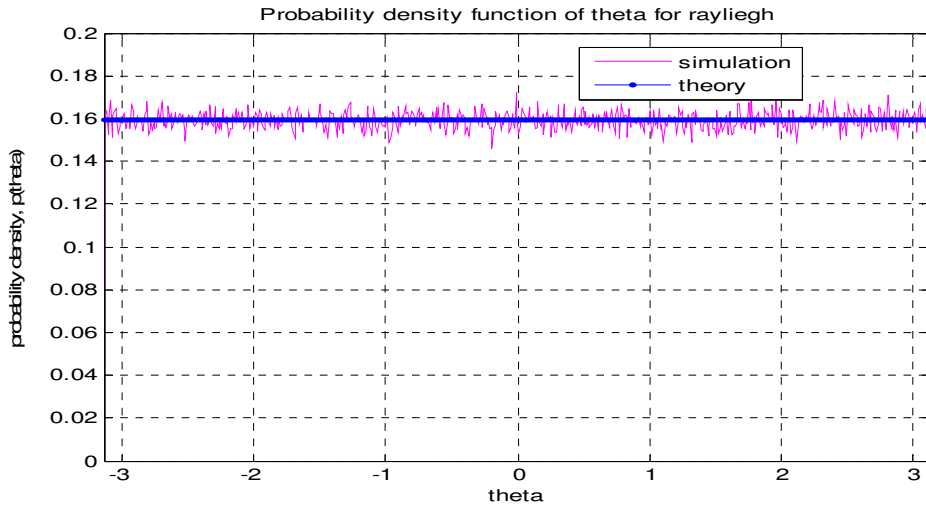


Fig 3.6 PDF of the phase angle

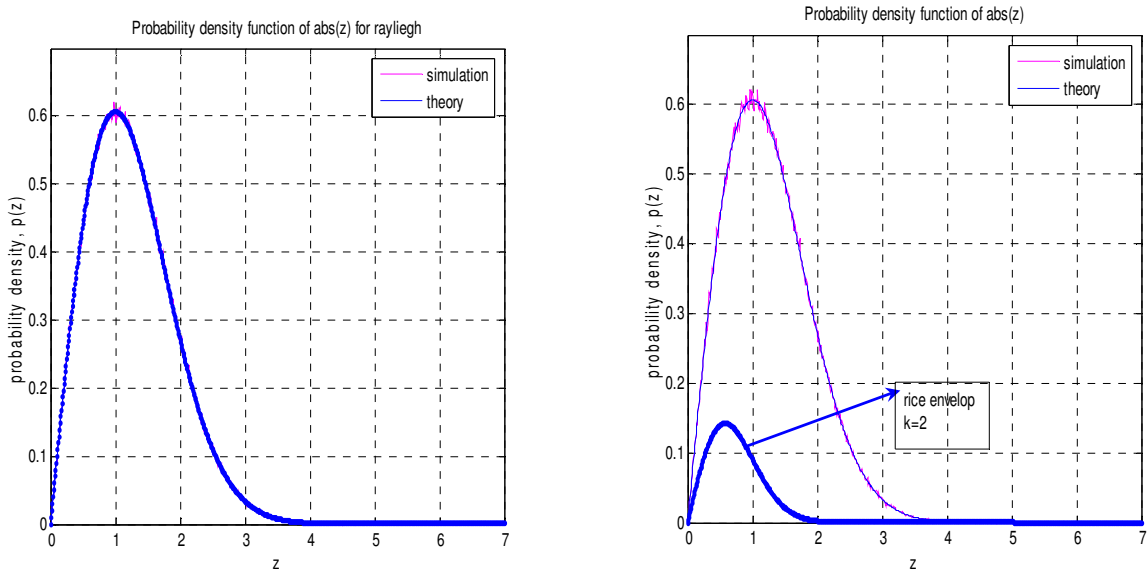


Fig 3.7 PDF of the envelop

The simulation of the PDF is shown above. Since the PDF of the phase angle θ is uniformly distributed for both models, the K factor has no effect on it. But in the PDF of the envelope the effect of the K factor is clearly shown. As K increases, the multipath components are superimposed on dominant signal which is the direct line of sight.

Generally the SOS model has limited application in which the Doppler Effect is assumed to be constant due the assumption that the speed of the terminal is constant.

3.2.2 Transfer function based model

The wireless channel can be considered as a filter with some impulse response of the form $C(\tau, t)$. The diagrammatical representation of the wireless channel can be given as follows.

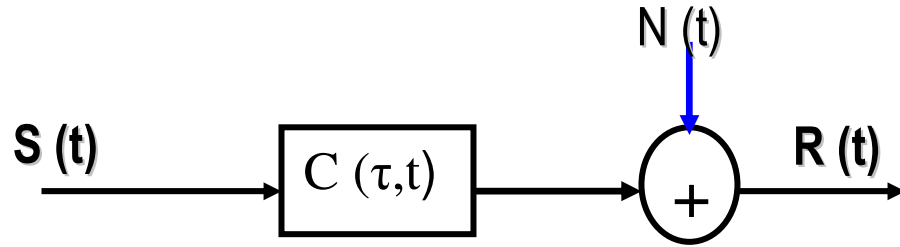


Fig 3.8 Channel model representation

Where $S(t)$ =transmitted signal

$R(t)$ =received signal

$C(\tau, t)$ =impulse response (The channel)

$N(t)$ =additive noise

The expression of the received signal is given by

$$R(t) = S(t) * C(\tau, t) + N(t) \quad (3.18)$$

Where $C(\tau, t)$, in turn, is given as

$$C(\tau, t) = \sum_{n=0}^{N(t)} \alpha_n(t) * e^{-j\phi_n(t)} * \delta(t - \tau_n(t)) \quad (3.19)$$

The main factors that determine the impulse response function $C(\tau, t)$ are

$\alpha_n(t)$ =multi-path attenuation factor,

$\tau_n(t)$ =multi-path delay due to the multi-path Scatterers

$\Phi_n(t)$ =phase shift and

$N(t)$ =number of multi paths

3.2.2.1 Transfer function variables

1. Attenuation factor($\alpha_n(t)$)

The attenuation factor is the main variable which defines the strength of the received signal. Considering N different paths, the received signal can be represented as

$$R(t) = \alpha_0 s(t) e^{-j\phi_0} + \alpha_1 s(t - \tau_1) e^{-j\phi_1} + \alpha_2 s(t - \tau_2) e^{-j\phi_2} + \dots + \alpha_n s(t - \tau_n) e^{-j\phi_n} \quad (3.20)$$

Where R(t) is the received signal and S(t) is the transmitted signal. Here α_n is the path loss factor or attenuation factor.

2. Phase ($\Phi_n(t)$)

The phase $\Phi_n(t)$ is the total effect of the carrier frequency f_c , Doppler frequency f_d , the time delay (multi-path delay spread) and the original phase of the transmitted signal and is given as

$$\phi_n(t) = 2\pi((f_c \pm f_d(t))(t - \tau_n(t))) + \phi_0 \quad (3.21)$$

Where f_c is the carrier frequency

$$f_d(t) = f_m \cos(\theta_n) \quad (3.22)$$

In turn f_m = maximum Doppler frequency when the angle of arrival of the signal is zero is given by

$$f_m = v/\lambda \quad (3.23)$$

Here also v is the speed of the receiver relative to the transmitter, θ_n is the angle of arrival of multi-path signal, $\tau_n(t)$ is the multi-path delay relative to the shortest path which is the direct line of sight. Multi-path Time delay is the main determinant factor for the phase change.

3. Multi-path delay ($\tau_n(t)$)

The multi-path time delay which is the relative difference between the shortest and the longest time is expressed highly by the path distance

$$\tau_n(t) = d_n(t)/c \quad (3.24)$$

Where $d_n(t)$ is the path length and c is the speed of light

4. Number of paths

The number of the path followed by the signal depends on the signal band width, the coherent channel bandwidth and the type of scattering environment. On the other hand for the frequency selective fast fading channel of fig (3.11)

$$N = [T_m \times W_c] + 1 \quad (3.25)$$

Where T_m =the multi-path delay spread, W_c =the signal bandwidth and by definition, $T_m=1/W_{Bc}$, where the W_{Bc} is the channel coherent bandwidth so, finally equ (3.28) becomes

$$N = \left[\frac{W_c}{W_{Bc}} \right] + 1 \quad (3.26)$$

Where B_w is the signal bandwidth and W_{Bc} is the channel coherent bandwidth. For the fast frequency non selective fading channel, it is preferably assumed to have only one path. This is due to the fact that multipath delay is much smaller than the symbol period and as a result the ratio of signal bandwidth and coherent bandwidth is less than one. N is greater than one for frequency selective fast fading channel since $B_w > W_{Bc}$. So the general expression of the signal at the receiver after inserting all the above variables is given below

$$R(t) = \sum_{n=1}^N \alpha_n(t) u(t - \tau_n(t)) e^{j[2\pi(f - f_d(t))(t - \tau_n(t)) + \phi_0]} \quad (3.27)$$

3.2.2.2 Diagrammatical representation

1. Frequency flat:-

Since only one path is to be considered in frequency non selective channel, the received signal model of equ (3.27) is reduced to

$$R(t) = \alpha_0(t) \times e^{j2\pi(f_c \pm f_d) + \phi_0} \times u(t) + n(t) \quad (3.28)$$

In this case the transfer function $h(t)$ which is independent of the delay spread

$$h(t) = \alpha_0(t) \times e^{j2\pi(f_c \pm f_d) + \phi_0} \times \delta(t) \quad (3.29)$$

Here α_0 is the path gain, f_c and f_d are carrier and Doppler frequencies respectively, $\delta(t)$ is the delta function, Then the elaborated diagrammatical representation is given by

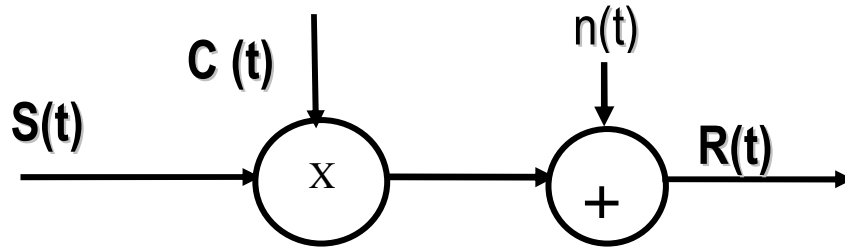


Fig 3.10 Flat fading channel representation

2. Frequency selective fading channel

In the fig 3.11 the path impulse response h is given as

$$h_n(t, \tau) = \alpha_n(t) \times e^{j\phi_n(t)} \delta(t - \tau_n(t)) \quad (3.30)$$

Finally the received signal is given by general expression of

$$R(t) = \alpha_0(t) \times s(t) + \sum_{n=1}^N \alpha_n(t) \times s(t - \tau_n(t)) \quad (3.31)$$

The diagrammatical representation of the frequency selective channel is given as below in Fig 3.11

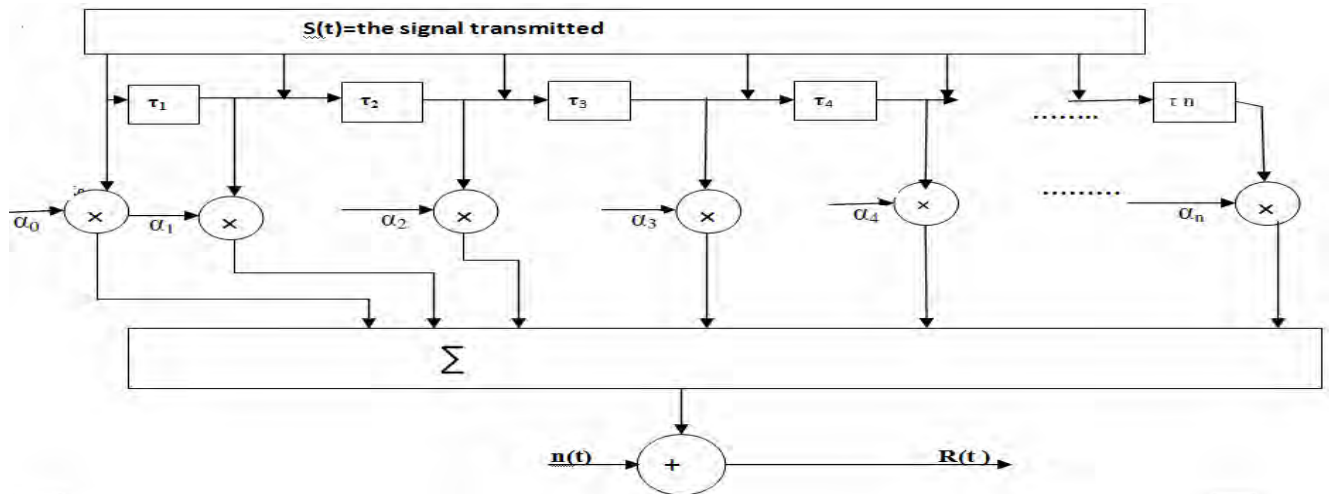


Fig 3.11 frequency selective channel representation

In frequency selective channel given the measured reference power delay profile, it is possible to determine the path gain and the path delay. The reference power delay profile is given in [13] as follows

$$P_{\tau}(\tau) = \begin{cases} ce^{-b\tau}, & 0 \leq \tau \leq \tau_{\max} \\ 0, & \text{else} \end{cases} \quad (3.32)$$

Where $\tau_{\max} = 7\mu\text{sec}$ and $b=1\text{MHz}$, $c = \frac{1}{10^{-6}(1-e^{-7})}$ used to normalize the profile to unity. But without loss of generality the multipath power-delay profile of the tapped-delay line channel simulator can be expressed by,

$$\tilde{P}_{\tau}(\tau) = \sum_{n=0}^{N-1} \tilde{\alpha}_n^2 \delta(\tau - \tilde{\tau}_n) \quad (3.33)$$

This is a finite sum of N weighted delta functions which are located at τ_n with a corresponding weight of the square of the path gain α_n^2 . Applying the method of equal distance method (MED) [6], let $P_{\tau}(\tau)$ be given specified or measured power delay profile characterized by the fact that it is equal to zero outside the interval of $I=(0, \tau_{\max})$. The discrete propagation delays τ_n are defined by multiples of a constant quantity $\Delta\tau$ according to the following expression for $N>1$,

$$\tilde{\tau}_n = n \times \Delta\tau, n = 0, 1, \dots, N - 1 \quad (3.34)$$

$\Delta\tau$ is related to τ_{\max} by the expression $\Delta\tau = \frac{\tau_{\max}}{N-1}$

By partitioning $I=(0, \tau_{\max})$ in to N sub interval which is given as

$$I_n = \left[\tilde{\tau}_n - \frac{\Delta\tau}{2}, \tilde{\tau}_n + \frac{\Delta\tau}{2} \right), \quad n = 0, 1, 2, \dots, N-1$$

Imposing this on our channel model that the integral over the reference power delay profile given in Equ (3.32) and the simulated profile of Equ (3.33), finally equating them gives as

$$\int_{\tau \in I_n} p_{\tau}(\tau) d\tau = \int_{\tau \in I_n} \tilde{p}_{\tau}(\tau) d\tau, \quad n = 0, 1, 2, \dots, N - 1 \quad (3.35)$$

Then finally after substitution

$$\tilde{\alpha}_n = \sqrt{\int_{\tau \in I_n} p_\tau(\tau) d\tau} \quad (3.36)$$

Where $S_\tau(\tau)$ is deterministically defined by the parameters of b, c and τ_{\max}

3.2.3 General simulation model

Existing models for simulation of fast fading channels use only maximum Doppler frequency to represent the effect caused by the maximum moving speed of the terminal without considering the effect of the changes in the magnitude and the direction of motion. Such simplified assumption is in strong contrast with real-world communication systems in which the velocity of a moving terminal may change in both magnitude and direction in the duration of transmission. Due to this shortcoming of the existing models, a new model should be developed. This new model is based on the Sum-of-sinusoids method and accounts for the new channel characteristics due to the changes in the magnitude and direction of the terminal's velocity at an instant-by-instant basis.

3.2.3.1 System representation

An instance we mean that, the time at which only one specific speed in specific direction is available for terminal. For k different instants, we mean that k different speeds with their respective direction are available. Generally the instant can be one, or more than one and the speed can be zero in case of slow fading, constant with direction assumed to the x -axis in case of the previously existing SOS models or else it can be varying in both magnitude and direction .the representation of each instance is given as in Fig 3.12 as in [41]

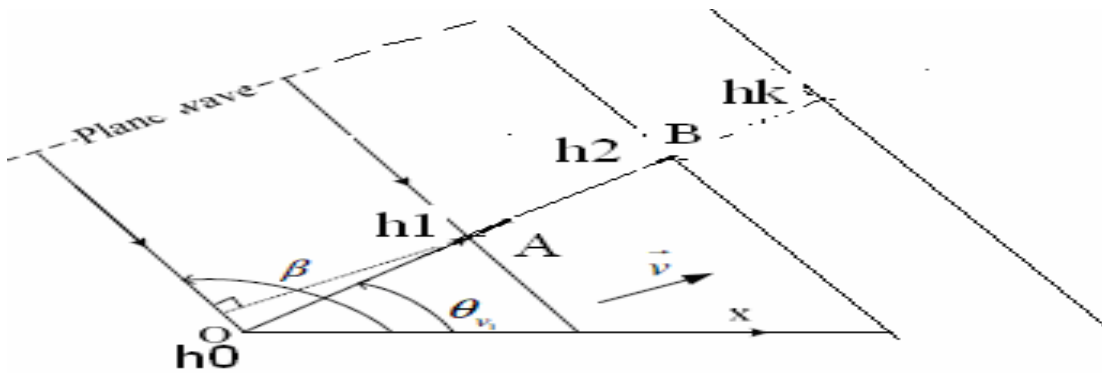


Fig 3.12 representation of instances

In case of the previous SOS models, it is assumed that only one instance in specific direction that is parallel to the x-axis is assumed.

This model can simulate fast fading channels for all states of motion for a terminal in the wireless communication environment such as at rest, motion with constant speed, acceleration, changes in direction of motion. We are assuming that k instances, the channel can be considered as having k cascade of filter model. The transfer function is to be considered finally as product of all the impulse response function of each filter.

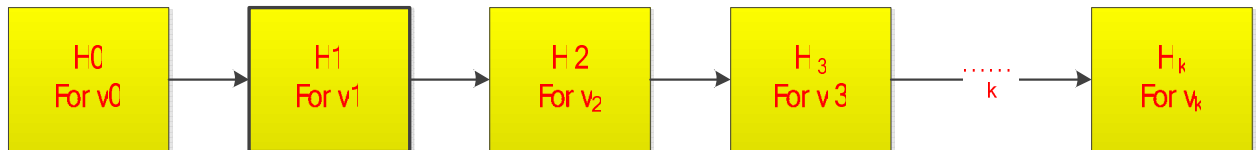


Fig 3.13 cascade representation of channel

Comparing this diagram with that of fig 3.12, H_0 is the impulse response without incorporating the effect of the speed at 0 and H_1 is the impulse response due to the motion variation and the initial H_0 at the next instance which is at A in Fig 3.12. Proceeding in such away up to the k^{th} instance and we can obtain H_k .

3.2.3.2 Modeling the speed

In this model the speed of the mobile terminal is varying in magnitude and direction at each instant. But since it should have some value at each instance in the range of the pedestrian up to vehicular land terminal motion, there should be a means to include the speed in the simulation. In this case it is assumed that the speed is uniformly distributed in the interval of pedestrian to vehicular. So the magnitude of the speed is represented as uniformly distributed between the typical pedestrian speeds up to the vehicular speed of 100kmphr. This distribution is the simplest to apply and to take the k speeds. In addition to this the angle θ_{v_k} , which is the direction of each speed with the x-axis is also assumed to be uniformly distributed between $-\pi$ up to π .

In order to derive each of the transfer functions of Fig 3.13, the velocity of each instance should also have some vector representation once they are randomly selected from the uniform

distribution. Assume that we have k different instances with their k^{th} magnitude and direction as given in Equ (3.37) as in [41]

$$\vec{v}_k = |v_k| e^{i\theta_{vk}} \quad (3.37)$$

Where $|v_k|$ is the magnitude of the velocity at the k^{th} instant, θ_{vk} is the direction of the velocity and assume that there are N possible multipath angles of arrival due to multipath propagation.

3.2.3.3 Path Gain representation

Let $\vec{g}(\beta_n)$ be the gain vector of the n^{th} scattering wave which is given by

$$\vec{g}(\beta_n) = |g(\beta_n)| e^{i\phi_n} \quad (3.38)$$

where $|g(\beta_n)|$ is the magnitude of $\vec{g}(\beta_n)$ and assumed to have magnitude of $\sqrt{\frac{1}{N}}$ for purpose of power normalization, β_n is the angle that the n^{th} multipath propagated wave makes with the x-axis, and ϕ_n denotes the phase of the n -th wave.

3.2.3.4 Doppler frequency

This frequency is due to the speed of each instant and the angle of arrival of the signal at that instant. So here like the speed of each instant, we have k different Doppler frequencies. As seen in the above we have V_k different speeds. From fig 3.12, we can get the angle of arrival for signal received at 1st instance which is given as $\beta_n - \Theta_{v1}$, where β_n is the angle of the n^{th} signal with the x-axis and Θ_{v1} the angle between the speed and the x-axis. The Doppler frequency of the first

instance is then given by $f_{d1} = \frac{V_1}{\lambda} * \cos(\beta_n - \Theta_{v1})$, proceeding in to the k^{th} instance, at the k^{th} instance the Doppler frequency is given by

$$f_{dk} = \frac{V_k}{\lambda} * \cos(\beta_n - \theta_{vk}) \quad (3.39)$$

3.2.3.5 Channel impulse response functions (h_k)

At this time, once we have the above parameters, it is time to derive each of the transfer functions represented in Fig 3.13.

The channel impulse response h_0 at the origin of the user's motion is given as in [24, 25, 41] by

$$h_0 = \sum_{n=0}^N |g(\beta_n)| e^{j\phi_n} \quad (3.40)$$

Assume that, as seen from the Fig 3.12, h_0 is the channel impulse response at point 0 and let at the next instance the channel impulse response be h_1 , and assuming the speed at this instant is v_1 , and due to this speed some fading in bandwidth is produced which is given by Equ. (3.39) as

$$f_{d1} = \frac{v_1}{\lambda} * \cos(\beta_n - \theta_{v1}),$$

then in Fig 3.12 at A, the impulse response can be expressed as follows due to the cascaded, filter impulse response is the product. The only effect of that instance is in the frequency modulation due to the Doppler Effect.

$$h_1 = \sum_{n=0}^N h_0 \left(e^{j \left[2\pi f_{d1} t \right]} \right) \quad (3.41a)$$

Then by substituting h_0 and f_d to the above equation, finally we get

$$h_1 = \sqrt{\frac{1}{N}} \sum_{n=0}^N e^{j 2\pi \left[\frac{v_1}{\lambda} t * \cos(\beta_n - \theta_{v1}) \right]} \quad (3.41b)$$

And proceeding to the next instant having different velocity let v_2 , then the impulse response

$$\text{becomes } h_2 = \sqrt{\frac{1}{N}} \sum_{n=0}^N h_1 e^{j \left[2\pi f_{d2} t \right]} \quad (3.42a)$$

Where $f_{d2} = \frac{v_2}{\lambda} * \cos(\beta_n - \theta_{v2})$, Substituting the value of the h_1 to the above expression

then

$$h_2 = \sqrt{\frac{1}{N}} \sum_{n=0}^N \left(e^{j \left[\frac{2\pi}{\lambda} t \left(v_2 \cos(\beta_n - \theta_{v2}) + (v_1 \cos(\beta_n - \theta_{v1}) + \phi_n) \right) \right]} \right) \quad (3.42b)$$

Proceeding in such away and assuming k instants as defined above, the transfer function at the k^{th} instant starting from the initial instant is

$$h_k = \sqrt{\frac{1}{N}} \sum_{n=0}^N h_{k-1} e^{j \left[2\pi f_{dk} t \right]} \quad (3.43a)$$

$$h_k = \sqrt{\frac{1}{N}} \sum_{n=0}^N e^{j \left[\frac{2\pi}{\lambda} t \left\{ \sum_{m=1}^j v_m \cos(\beta n - \theta_{vm}) + \phi_n \right\} \right]} \quad (3.43b)$$

The channel impulse response in the form of in phase and quadrature component just by splitting in to real and imaginary parts as a function of the instant k is given as

$$h(k) = hc(k) + jhs(k) \quad \text{Where}$$

$$h_c(k) = \sqrt{\frac{1}{N}} \sum_{n=0}^N \cos \left[\frac{2\pi}{\lambda} t \sum_{m=1}^k \{v_m | \cos \alpha_{mb}\} + \phi_n \right] \quad (3.44a)$$

$$h_s(k) = \sqrt{\frac{1}{N}} \sum_{n=0}^N \sin \left[\frac{2\pi}{\lambda} t \sum_{m=1}^k \{v_m | \cos \alpha_{mb}\} + \phi_n \right] \quad (3.44b)$$

Here $\alpha_{mn} = \beta n - \theta_{vm}$ is the angle of arrival of the n^{th} signal

$$\beta n = \frac{2\pi n + \theta_n}{N}, n=1,2,3,\dots,N \quad \text{This is taken from the Xiao's model and is the angle between}$$

the n^{th} signal and the x-axis. These model is totally in the form of sum of sinusoid with speed magnitude of v_m of the m^{th} instant and angle of α_{mn} , Then having the in phase and quadrature components, it is possible to derive the auto/cross correlations of the in phase and quadrature components from the above impulse response.

$$\begin{aligned} R_{hchc}(\tau) &= R_{hshs}(\tau) = E[h_c(k)h_c(k+\tau)] \\ &= \frac{1}{N} \sum_{n=1}^N \left\{ \cos \left[\frac{2\pi}{\lambda} t \sum_{m=1}^k \{v_m | \cos \alpha_{mn}\} + \phi_n \right] \cdot \cos \left[\frac{2\pi}{\lambda} t \sum_{m=1}^{k+\tau} \{v_m | \cos \alpha_{mn}\} + \phi_n \right] \right\} \end{aligned} \quad (3.45a)$$

$$\begin{aligned} R_{hchs}(\tau) &= R_{hshc}(\tau) = E[h_s(k)h_c(k+\tau)] = \\ &= \frac{1}{N} \sum_{n=1}^N \left\{ \sin \left[\frac{2\pi}{\lambda} t \sum_{m=1}^k \{v_m | \cos \alpha_{mn}\} + \phi_n \right] \cdot \cos \left[\frac{2\pi}{\lambda} t \sum_{m=1}^{k+\tau} \{v_m | \cos \alpha_{mn}\} + \phi_n \right] \right\} \end{aligned} \quad (3.45b)$$

These expressions are general for all communication environments. But let's consider at least two stable states: moving towards a certain direction with a constant speed, or staying still at rest.

CASE I: For a terminal moving with a constant speed and the direction of motion of the terminal is parallel to the x axis. If the magnitude of the terminal's velocity is constant, say $|v|$ and According to the derived model above, i.e. by substituting the values for v_m and θ_{mn} by $|v|$ and 0 respectively in to Equ (3.44a) and Equ (3.44b), we can have

$$h_c(k) = \sqrt{\frac{1}{N}} \sum_{n=0}^N \cos \left[\frac{2\pi}{\lambda} t(k+1) |v| \cos \beta n + \phi n \right] \quad (3.46a)$$

$$h_s(k) = \sqrt{\frac{1}{N}} \sum_{n=0}^N \sin \left[\frac{2\pi}{\lambda} t(k+1) |v| \cos \beta n + \phi n \right] \quad (3.46b)$$

Here if we assume the maximum velocity to be $|v_m|$ and the wavelength of the signal is λ , the maximum Doppler frequency is given by $f_d = \frac{|v_m|}{\lambda}$. By substituting these values to the above equations, perfectly matches to the improved Xiao's model which is

$$h_c(k) = \sqrt{\frac{1}{N}} \sum_{n=0}^N \cos [2\pi f_d t(k+1) \cos \beta n + \phi n] \quad (3.47a)$$

$$h_s(k) = \sqrt{\frac{1}{N}} \sum_{n=0}^N \sin [2\pi f_d t(k+1) \cos \beta n + \phi n] \quad (3.47b)$$

Hence, the proposed channel simulator is convergent to Xiao's model when the terminal is moving in certain direction at a constant speed.

CASE II: when the terminal is at rest, then the velocity $v_m=0$, the simulator will be

$$h_c(k) = \sqrt{\frac{1}{N}} \sum_{n=1}^N \cos \phi n \quad (3.48a)$$

$$h_s(k) = \sqrt{\frac{1}{N}} \sum_{n=1}^N \sin \phi n \quad (3.48b)$$

The above two are the common expressions of slow Rayleigh fading channels; the proposed model will be convergent to the slow fading channel if the terminal stays still.

According to the above analysis, we can say that the proposed simulator is convergent to Xiao's model when the terminal is moving with a constant speed in a certain direction, thereby, has the statistical features of Clarke's model.

Therefore, the proposed simulator can be used for simulation of all kinds of motion for a terminal considering of both magnitude and direction of the terminal's velocity. Hence, it can be considered as a general model, not only for the fast moving terminals, but also for all kinds of Rayleigh fading scenarios.

This model can be compared with the improved Xiao's model by using the autocorrelation spectrum. This can be done by varying the number of instance of the general model from k up to no instant and by generating k different random speed from the uniform distribution. The speed is assume to be uniformly distributed in the interval of pedestrian speed and vehicular speed

3.3 Effect of movement of mobile terminal

The relative motion between base station and receiving antenna results in a random frequency modulation due to the introduction of the Doppler spread or shift in each of the multi-paths.

It is tried to elaborate in Section 3.2.2 of Equ (3.24) that the phase shift $\Phi_n(t)$ is dependent on the Doppler frequency [1, 14]. The main problems which are observed in the channel due to motion of the terminal are fading in bandwidth, Widening of the spectrum, Change of bit error rate performance due to Doppler spread, the change of the LCR(frequency of fading) and AFD(the time the signal power stays below the reference).

3.3.1 Effect of movement of terminal on the envelop

If we see the combined effect of Doppler and multi-path propagation as shown in the figure below, the received signal for two paths only can be given by

$$y(t) = A \exp \left[j 2 \pi f_c \left(1 - \frac{v}{c} \right) t \right] + A \exp \left[j 2 \pi f_c \left(\left(1 - \frac{v}{c} \cos \theta \right) t \right) \right] \quad (3.49)$$

As seen in the above equation the transmitted signal is received as a pair of tones for the two paths.

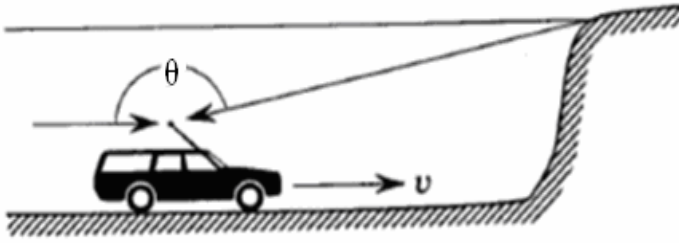


Fig 3.13 effect of both multi-path and movement

This effect can be viewed as a spreading of the transmitted signal frequency and hence as a special case of frequency dispersion caused by the channel and the combined effect of speed and multi-path propagation. Equ (3.52) can be rewritten as

$$y(t) = A \left[\exp \left(-j2\pi f_c \frac{v}{c} t \right) + \exp \left(-j2\pi f_c \frac{v}{c} \cos \theta t \right) \right] e^{j2\pi f_c t} \quad (3.50)$$

The envelop of the received signal $y(t)$ can be observed from the squared bracket and after some mathematical calculation is given as

$$R = 2A \left| \cos \left[2\pi \frac{v}{c} f_c \frac{1 - \cos \theta}{2} t \right] \right| \quad (3.51)$$

This equation clearly shows important effects of speed and the angle of arrival. The envelop of the received signal exhibits a sinusoidal variation with time, occurring with frequency of $f = \frac{v}{c} f_c \frac{1 - \cos \theta}{2}$. The effect of speed is so visible that if $v=0$, the Doppler frequency becomes zero and $R=2A$. As N approaches infinity, the envelope is modeled by either Rayleigh or rice depending whether there is direct LOS or not and by considering the in phase and quadrature components as Gaussian distributed.

3.3.2 Doppler power spectrum

The power spectrum answers the question “how much of the signal is at a frequency f ?” Power spectrum is the measure of the power level of the signal at a particular frequency, or it is the measure of the power per unit frequency. Doppler power spectrum is the range of the signal’s power within the Doppler spread. Let assume the following

- $p(\alpha)d\alpha$ = fractional part of total incoming power in $d\alpha$ of angle α
- A = average receive power for isotropic antenna
- $G(\alpha)$ = azimuthal gain pattern of mobile antenna as a function of α

As $N \rightarrow \infty$ then $p(\alpha)d\alpha$ goes from discrete distribution to continuous Distribution

Total received power can be expressed as [1]:

$$P_r = \int_0^{2\pi} AG(\alpha)p(\alpha)d\alpha \quad (3.52)$$

$A \cdot G(\alpha) \cdot p(\alpha) d\alpha$ = differential variation of received power with Doppler Shift for the n^{th} wave arriving at angle α_n to the x-axis is given by equ (3.25).

Instantaneous frequency of received signal component arriving at angle α is an even function of α . (e.g. $f(\alpha) = f(-\alpha)$). $S(f)$ = PSD of received signal \rightarrow differential variation of received Power with frequency is $S(f)df$, $AG(\alpha)p(\alpha)d\alpha$ = differential variation of received power wrt angle of arrival, $S(f)df = A[p(\alpha)G(\alpha) + p(-\alpha)G(-\alpha)]|d\alpha|$, because of the even function definition $S(f)$ is given in [1,12]. Here it is assumed that the environment is with isotropic scattering characteristics. $S(f) = 0$ for $|f - f_c| > f_m$ and $S(f)$ is centered on f_c but it is normalized to 0 as seen in fig (3.15) outside the limits of $f_c \pm f_m$. Each arriving wave has carrier slightly offset from f_c due to angle of arrival.

For different antenna, we can have different antenna gain and for this simulation, it is taken that the gain of the vertical $\lambda/4$ antenna ($G(\alpha) = 1.5$) and incoming power $p(\alpha) = 1/2\pi$, uniformly distributed over $[0, 2\pi]$. So finally the Doppler spectrum is given as [1, 10, 12] is given as

$$S_{E_z}(f) = \frac{1.5}{\pi f_m \sqrt{1 - \left(\frac{f - f_c}{f_m}\right)^2}} \quad (3.53)$$

For the land mobile terminal, by varying the speed from pedestrian (6kmphr) to vehicular (100kmphr) we can observe the broadening effect. The U-shaped PSD is given in Fig 3.15 for three selected speeds. For different value of the speed of the mobile, it is possible to estimate the

range where the signal is presented and the fading in frequency. The carrier frequency here is $f_c=900\text{MHz}$. From Fig 3.15 ,We can see that as the speed increase the Doppler bandwidth increases and it becomes so sever as speed approaches to the vehicular level. So for higher speed ,the width of the spectrum on which the signal falls increases.

Output at $fc \pm f_m = \infty$ i.e., Doppler components arriving at exactly 0° & 180° have very large PSD since it is direct line of sight and is very strong.

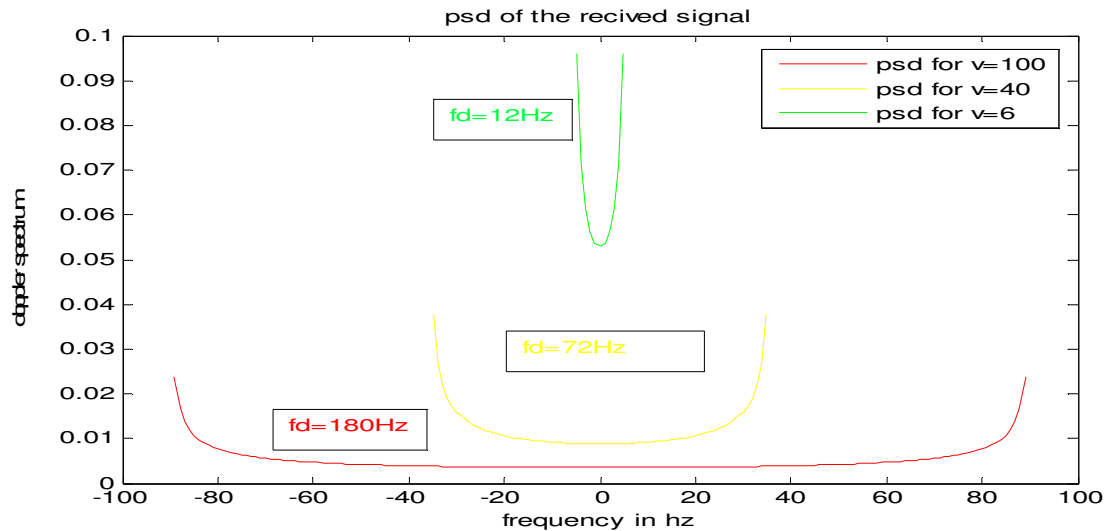


Fig. 3.14 Doppler power spectrum for different speed

In addition to the above effects of speed of moving terminal, the speed has also an effect on the performance measurement parameters which is the main concern of the next sections.

3.4 Performance measurement of fading channel

In AWGN the probability of symbol error depends on the received SNR or, equivalently, on γ_s . But in a fading environment the received signal power varies randomly over distance or time due to shadowing and/or multipath fading. The most important parameters that measures the performance of the fading channel are

- ✓ Outage/fading probability
- ✓ Fading duration
- ✓ Fading rate
- ✓ Bit error rate

3.4.1 Fading probability

The fading probability is defined as the probability that the instantaneous error probability exceeds a specified value or equivalently, the probability that the output SNR, γ , falls below a certain specified threshold, γ_0 as in [25, 33, 47].

As seen from the diagram below the fading probability is the probability that the signal power is below the threshold value.

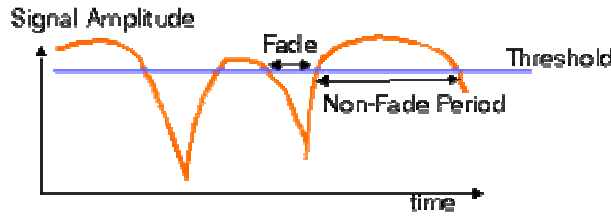


Fig 3.15 fading signal

The mathematical definition of the fading probability is

$$P_{out} = p(\gamma_s < \gamma_0) = \int_0^{\gamma_0} p_{\gamma_s}(\gamma) d\gamma \quad (3.54)$$

Since the probability density function of the SNR is exponential for Rayleigh fading channel and by using this distribution, the expression of the fading probability can be written as is [33]

$$P_{out} = \int_0^{\gamma_0} \frac{1}{\bar{\gamma}_s} e^{-\gamma_s / \bar{\gamma}_s} d\gamma_s = 1 - e^{-\gamma_0 / \bar{\gamma}_s} \quad (3.55)$$

Where $\bar{\gamma}_s$ is required average SNR

Inverting the formula of the fading probability, the required average SNR is as in [25, 32, 33]

$$\bar{\gamma}_s = \frac{\gamma_0}{-\ln(1 - P_{out})} \quad (3.56)$$

The quantity called fade margin is defined from the fading probability. Fading margin is used to define the accepted performance of the channel.

$$F_d = -10 \log[-\ln(1 - P_{out})]$$

$$P_{acc} = 100 \times (1 - P_{out}) \quad (3.57)$$

In communication, the term **fade margin (fading margin)** has the following meanings [25]:

- A design allowance that provides for sufficient system gain or sensitivity to accommodate expected fading, for the purpose of ensuring that the required quality of service is maintained.
- The amount by which a received signal level may be reduced without causing system performance to fall below a specified threshold value. It is mainly used to describe a communication system such as satellite, for example a system like global star operates at 25-35 dB Fade margin.

Fading probability is independent of the speed of variation of the channel, i.e. independent of the speed of the mobile terminal. It is only dependent on the power level taken as a reference and the strength of signal envelop which is dependent on the number of paths followed by the signal.

3.4.2 Fading rate

Level crossing rate (LCR) or sometimes also called rate of fading is the expected number of times, the envelop can crosses the specified level towards positive direction [1, 2, 33].

The level crossing rate is an indication of the fading rate and an important parameter for diversity systems. The level crossing rate (LCR) is a second order statistics of fading and is affected by the speed of the mobile receiver. Level crossing rate (LCR) is related with BER of the channel, if

- ✓ The bit rate is R_b
- ✓ The mean power or threshold level is P_m and
- ✓ The envelop/power level crosses it N_r times \rightarrow then the BER is give below as

$$BER = \frac{N_r}{R_b} \quad (3.58)$$

LCR provides important information for the statistics of burst errors [47, 49], which facilitates the design and selection of error correction techniques. Theoretical fading rate or the level crossing rate at envelope R is defined as the rate at which a fading signal envelope crosses level R in any direction, In general, is given by

$$N_r = \int_0^{\infty} \dot{r} p(R, \dot{r}) d\dot{r} \quad (3.59)$$

Where the dot indicates the time derivative and $p(R, \dot{r})$ is the joint probability density function of r and \dot{r} , respectively. The general theoretical and common expression of LCR as in [2, 5, 7, 8] is given by

$$N_r = \sqrt{(2\pi(1+K))} \rho f_d \exp[-K - (1+K)\rho^2] I_0[2\rho\sqrt{K(1+K)}] \quad (3.60)$$

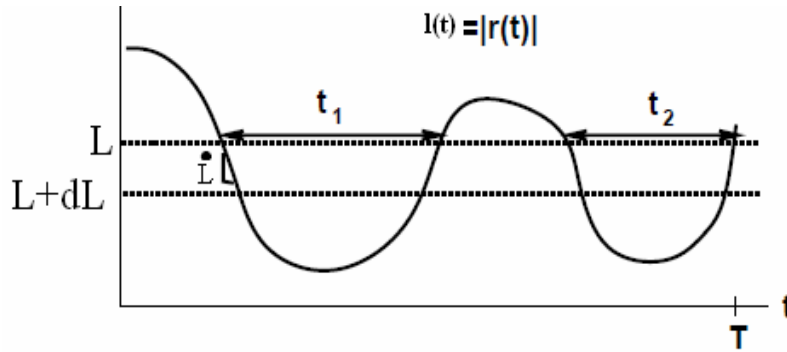
Setting $K=0$, i.e. for Rayleigh fading channel, the expression for the level crossing rate is given as

$$N_r = \sqrt{(2\pi)} \rho f_d \exp[-\rho^2] \quad (3.61)$$

LCR is dependent on the reference level R and the speed of the terminal. From Equ (3.62) level crossing rate or the fading rate is related to the BER. Indirectly, we can relate BER of the channel with speed of terminal and the reference power level.

3.4.3 Average duration of fade

The average signal fade duration is the average time that the signal power level stays below a given target **level L**. This target level is often obtained from the signal amplitude or power level required for a given performance metric like BER. Let t_i denote the duration of the i^{th} fade below level L over a time interval $[0, T]$, Thus t_i equals the length of time that the signal envelope stays below L on its i^{th} crossing. $l(t)$ be the envelope of the signal $r(t)$. Since $l(t)$ is stationary and ergodic, for T sufficiently large we have as in [1, 5, 25, 33]



Figs 3.16 fade duration of the received signal

$$P(l(t) < L) = \frac{1}{T} \sum_i t_i \text{ Then, for Rayleigh distribution, it is obtained that}$$

$$\overline{t}_L = \frac{e^{\rho^2} - 1}{\rho f_D \sqrt{2\pi}} \quad (3.62)$$

Where $\rho = \frac{L}{\sqrt{P_r}}$

Note that the above equation is the average fade duration for the signal envelope (amplitude) level of L , the target amplitude, and P_r , the average envelope level. By a change of variables it is easily shown that equ (3.65) also yields the average fade duration for the signal power level with $\rho = \sqrt{P_0/P_r}$ where P_0 is the target power level and P_r is the average power level. Note that average fade duration decreases with Doppler, since as a channel changes more quickly it remains below a given fade level for a shorter period of time. The average fade duration also generally increases with ρ for $\rho \gg 1$. This is because as the target level increases relative to the average, the signal is more likely to be below the target. The implicit expression of average fade duration for Rician fading is more complicated to compute [2, 5]. The AFD, average time that the envelope stays below the specified level, has direct relation with BER. Comparing the bit period (T_b) and the AFD (T_z), we can conclude the following

- ✓ If $T_z = T_b$, single error event has occurred, only one bit is affected by the deep fade
- ✓ If $T_z \ll T_b$, the fading is averaged out over a bit period, so the fading can be neglected. because no bit stays below that level and almost no error occurred.
- ✓ If $T_z \gg T_b$, many subsequent error events occurred. This is due to the fact that so many bits enter to the deep fade region.

This conclusion is for static channel keeping the coherent time of the channel constant and only the reference level is varying. But if we take the speed of terminal as varying parameter and keeping the level constant, the conclusion above is reversed. As speed increases frequency of crossing the level increases where as it stays very small time in the deep fade. But it quickly returns to a deep fade. In this case, the frequency of entering in to the deep fade increases so that the frequency of the signal being affected by error increases. The ratio of T_z and T_b provides a good conclusion about the number of bits affected by error (BER) and average fading duration.

Generally, both LCR and AFD have direct relation with the Doppler frequency. This frequency in turn has direct relation to the speed of the mobile. LCR and AFD, have also a relation with the number of paths followed by the signal in frequency selective channel. In turn the number of paths are also related to the mean power level or the threshold level so that the relation b/n the LCR and AFD with that of the number of path is to be considered.

3.4.4 Bit error rate

3.4.4.1 BER of frequency selective fading channel

Frequency-selective fading channels are hostile to wireless communication since they possess both fading and inter-symbol interference (ISI) effects [4]. Effects of deep fade can reduce the signal power to less than -30 dB below its average whereas ISI effects cannot be reduced by simply increasing transmit power.

AWGN is an ideal channel on which the BER is better as compared to the fading channels, and is an ideal channel with no fading that only additive noise is the problem.

Frequency selective channel is a channel which do have N resolvable multi-path which are affected by an independent fading. In addition to the N multi-paths, a delay spread also has an effect on this channel. Due to this multi-path delay spread, power delay profile is produced which is the strength of the power of each delayed paths. Assuming the transmitted signal be as given [27] by

$$s(t) = \sqrt{\frac{2E_s}{T_s}} V(t - T_s) \quad (3.63a)$$

$$R(t) = \sum_{n=0}^N s(t - T_s - \tau_n) r_n \cos(2\pi f_c t + \theta + \phi_n) + n(t) \quad (3.63b)$$

Where $v(t)$ = the rectangular pulse

Using the minimum mean square error detection mechanism and linear equalization, the bit error rate is evaluated. But in this thesis, to evaluate the BER performance no adaptive equalizer is used. The main factors which influence the BER in Frequency selective channel are

- Expected number of paths followed by the signal ,N

- rms Delay spread , τ_n
- Power delay profile strength r_n

- **Rms delay spread**

In most cases the rms delay spread is considered constant for specific channel but as one changes the environment where the channel is to be considered, the rms delay spread also changes.

The table below shows some of the standard values of the rms delay spread [10].

Table 3.1 rms delays spreads

Environment	T rms
urban	1-25 μ sec
suburban	0.2-2 μ sec
indoor	25-250nsec

By varying this parameter, we can get different performance for different environments. The smaller the rms delay spread the performance is better. This is due to reduction of interference.

- **Number of paths**

The relative numbers of paths or echoes have reasonable effect on the BER of the FSFC [26]. As N increases the signal quality decreases due to the high interference in such a way that the vulnerability to noise increases. As N increases so that rms delay spread increases and this leads to high interference which in turn decreases the quality of the signal. Decreasing N decreases the BER, but also decrease the envelop level of the signal. The number of path is related to the signal bandwidth and coherent channel bandwidth. So decreasing N means decreasing of the signal bandwidth so that it approaches to narrow band signal. The pros and cons related to the narrow band and wideband signal should be considered and an average N Should be considered which can satisfy both the average BER and the signal level.

- **Power delay profile**

The effect of the delay gain or delay profile is also visible in the performance of the BER of the frequency selective channel. Each delayed signal has its own power level compared to the strong signal, i.e. the LOS which is given [1, 4, 33] by

$$p(\tau) = \alpha \exp\left(-\frac{\tau}{D}\right), \quad \tau \geq 0 \quad (3.64)$$

Parameter α describes the power level implied in the delay spread model relative to the power level of the main signal component. D is the root-mean-squared (rms) delay spread. We define the power delay profile as the average of the echoes arriving with time delay τ .

$$p(\tau) = E\{r^2(\tau)\} \quad (3.65)$$

In this thesis work, only α which is parameter used to relate the power in the Direct LOS and the delayed signals is taken to relate BER and the power level of the delayed signal. This parameter has direct relation to each of the delayed power strength. As α increases, the power level of each of the delayed path increase and so that the interference.

3.4.4.2 BER of fast fading channel

The BER of the fast fading wireless channel is due to the Doppler spread caused by the speed of the mobile [33]. Assuming that the transmitted signal is $s(t)$ and the received signal is $r(t)$ given as

$$s(t) = \cos(2\pi f_c t) \quad (3.66a)$$

$$r(t) = \alpha(t) \times \cos(2\pi(f_c t - f_d t)) \quad (3.66b)$$

The main variables here to measure the BER performance are the Doppler spread due to the speed of the mobile terminal and the bit rate, R_b or the bit period.

The error floor decreases with data rate $R_b = 1/T_b$. This is true in general for irreducible error floors of differential modulation due to Doppler, since the channel has less time to de-correlate between transmitted symbols and as bit rate increases the bit period decreases so that the channel approaches to slow fading and the performance is improved.

This phenomenon is one of the few instances in digital communications where performance improves as data rate increases. Surprisingly, in these simulations the error floor increases with vehicle speed, despite the fact that at higher vehicle speeds, the channel de-correlates less over a symbol time.

CHAPTER FOUR

SIMULATION RESULT AND DISCUSSION

In this chapter the main simulation results which demonstrate the theoretical analyses of the previous chapter are to be presented. Comparison of the general model with that of Xiao's model with its algorithm is presented using the correlation function. Next to this, the main fading channel performance evaluation parameters are given. Simulation results of the fading probability, fading rate, fading duration and the BER of both fast fading and frequency selective channel are separately demonstrated. The fading probability, fading rate, fading duration are simulated as a function of number of paths and speed of terminal and BER of fast fading channel is simulated as a function of speed of mobile terminal and the bit period . For the case of the frequency selective fading channel, the BER is simulated as a function of number of path, power delay level and the rms delay spread.

4.1 Simulation parameters

Table 4.1 simulation parameters

parameter	Value	remark
Carrier frequency(f_c)	0.9GHz	Cellular
Sampling time	$1/(4*f_c)$	
Channel bandwidth	10 KHz	
Number of bits	10^6	Generated for simulation
Speed of terminal	6,40,100 kmphrs	Used for comparison
Modulation type	BPSK	
Noise	AWGN	
Bit rates	(100,1000,10000) bps	Used for fast fading
	1Mbps	For the frequency selective
Detection mechanism	MMSE	
Software	MATLAB	

4.2 Basic Assumptions

- ✓ Perfect synchronization in time and frequency is available (no timing errors or oscillator drift)
- ✓ Perfect channel state information at the receiver
- ✓ Single cell environment i.e., movement of terminal within one cell environment

4.3 Comparison of the general model with Xiao's model

4.3.1 Basic algorithm for comparison

At this time the only thing that we got for comparison of the new model and the Xiao's model is the autocorrelation function. The algorithm followed to generate the autocorrelation functions is: Set N which is the number of multipath, and k is the number of instants where the single paths receiver can have k speeds. Then using the uniform distribution, generate k different speeds finally take the average of these speeds and assign this speed to the Xiao's model. Repeat this until the speed needed is obtained. Generate the correlation of the N signals finally change k from the initial value step by step to 1 which is the Xiao's model then compare the two models.

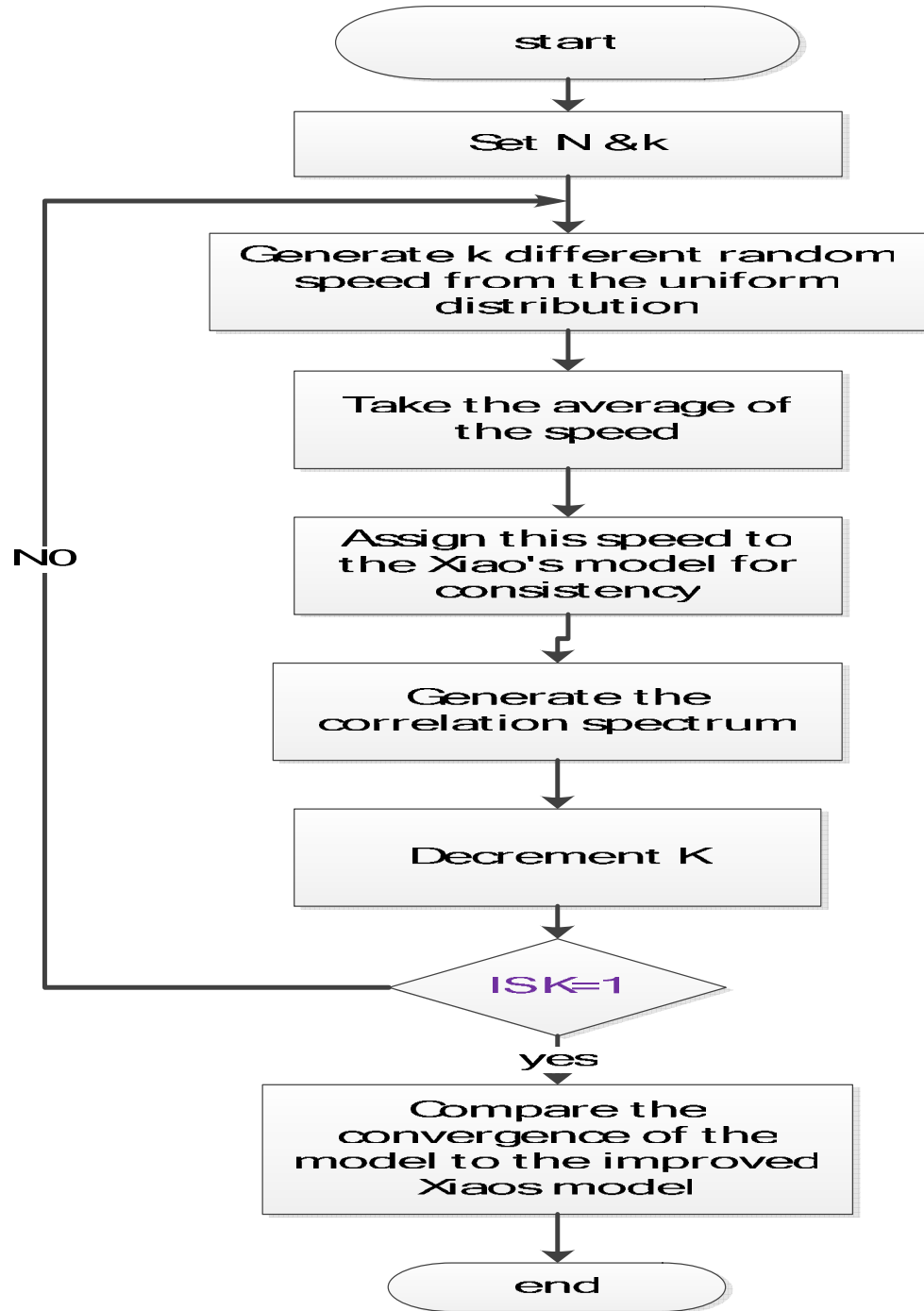


Fig 4.1 Flow chart for comparison of the general model and Xiao's

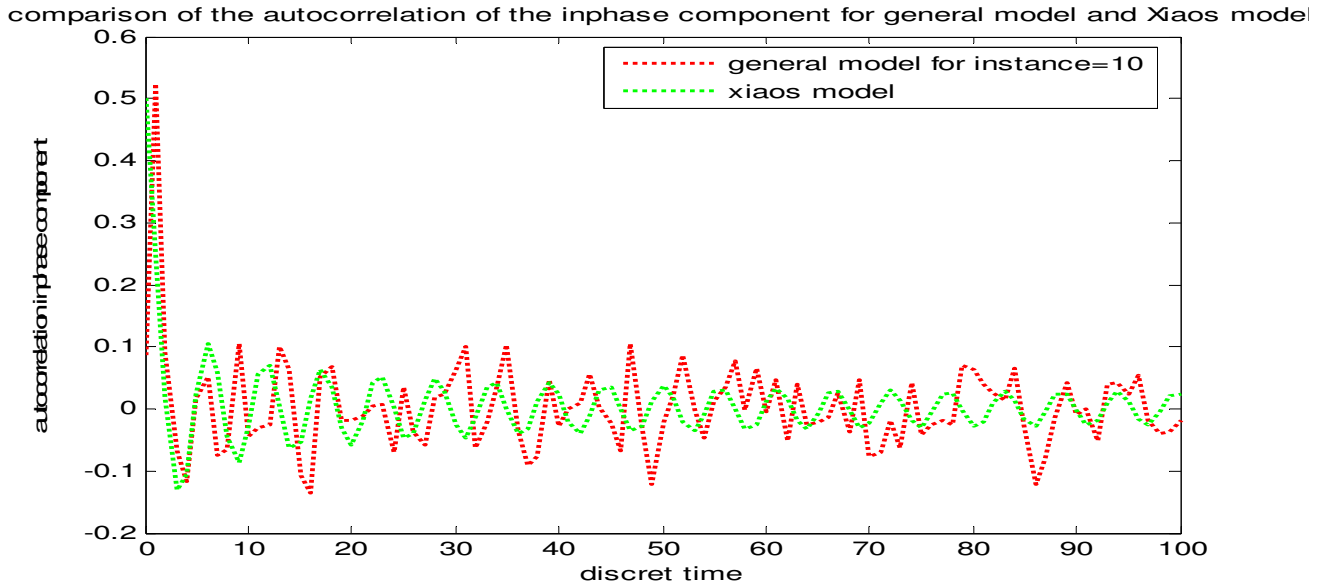


Fig 4.2a Correlation spectrum of general model for instance=10 and Xiao’s model

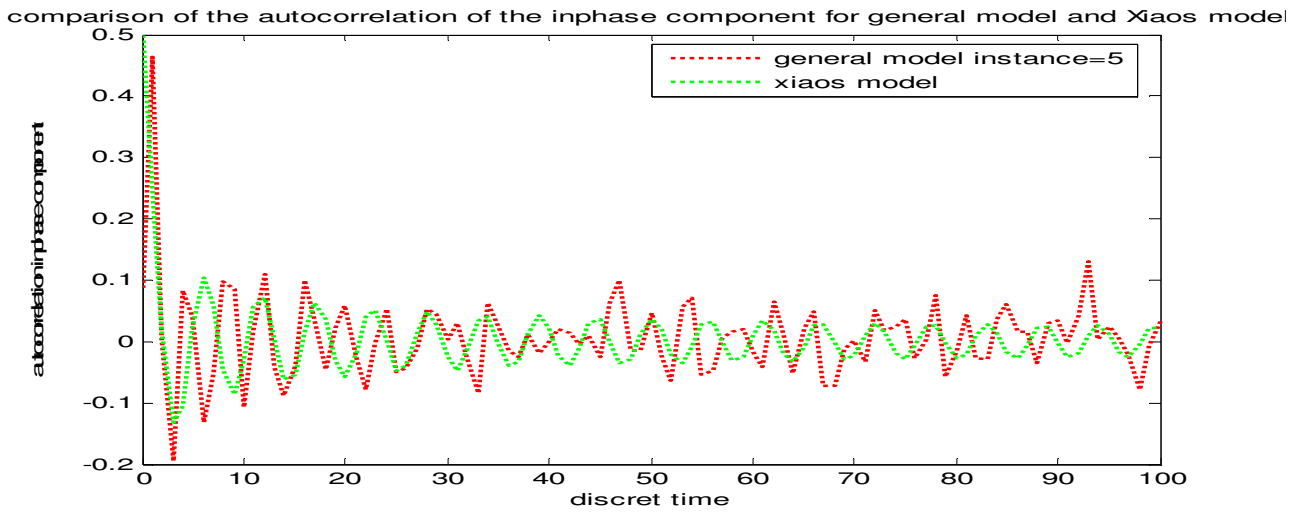


Fig 4.2b Correlation spectrum of general model for instance=5 and Xiao’s model

Note: as seen from the figures above (Fig 4.2a, Fig 4.2b), for constant number of multipath, if the numbers of instants are large the performance of the channel is comparatively low. Comparing the above two figures, Fig 4.2b is relatively better than Fig 4.3a. For single instant as seen from Fig 4.2c which means only one constant speed is considered, the correlation is relatively better than both of the above. Since the comparison is with the improved model which is the Bessel function, this general model also approaches to that improved model especially for large N.

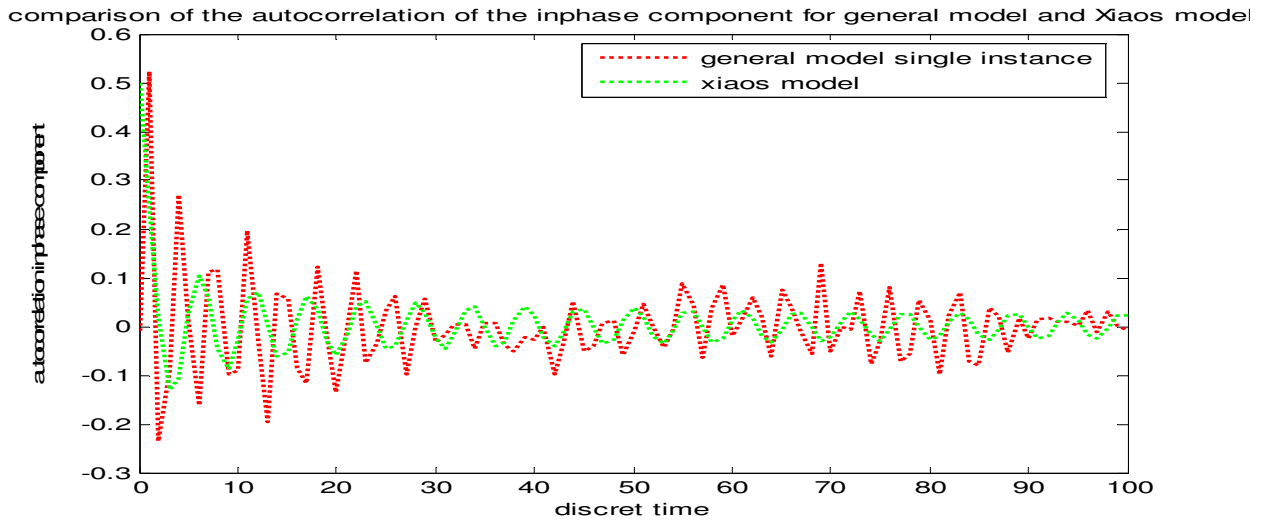


Fig 4.2c Correlation spectrum of general model for no instance and Xiao’s model

4.4 Simulation of fading probability

The fading probability is the probability that the signal power is below some specified level, i.e. the threshold level which is assumed to be an accepted for good performance.

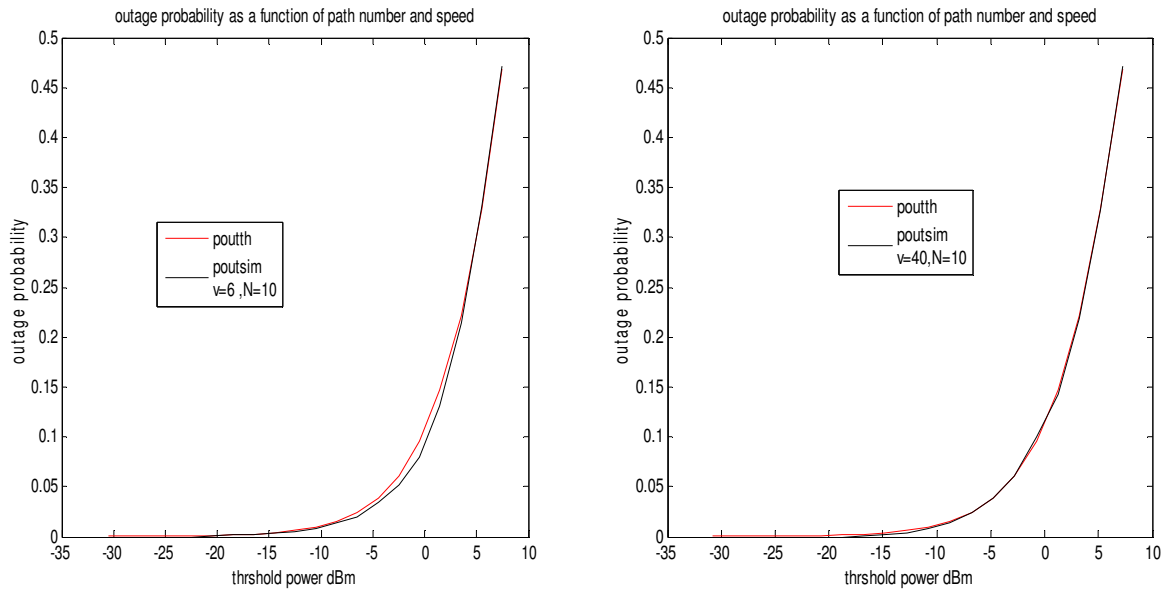


Fig 4.3 comparison of P_{out} for different speed

As it is seen in Fig 4.3, fading probability is independent of the speed of the mobile terminal. For both plots the probability at any threshold is the same.

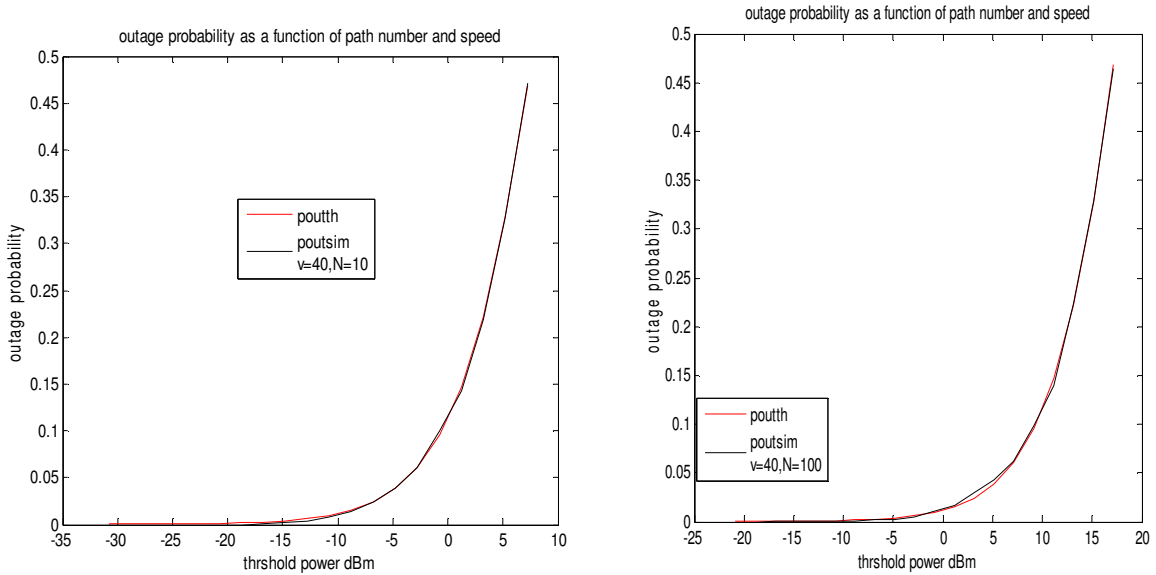


Fig 4.4 P_{out} for different number of paths

In both cases, i.e. for Fig 4.3 and Fig 4.4, the probability of fading increases as the threshold power level increases. This is due to the fact that as the threshold reference level increases and if we keep the transmitted signal remains the same, then the probability of remaining below that level increases. The effect of the number of paths is demonstrated in fig 4.4, as N increases, the fading probability decreases. This is due to the fact that as N increases the signal power increases and keeping the reference level constant, the probability of being above that level increase.

4.5 Rate of fading or LCR

The level crossing rate, N_r , is the expected rate at which the signal power or envelop crosses a specified signal level, R , in the positive direction. Both speed of mobile terminal and number of multi-path has great effect on this parameter. LCR is dependent on how fast the channel varies and this in turn is dependent on the coherent time and Doppler spread. The higher the speed the smaller the coherent time and the higher the level crossing rate.

Generally all this effects are summarized in the Figs 4.5 and 4.6 and Table 4.2 below. Here the relation of LCR and BER is also given.

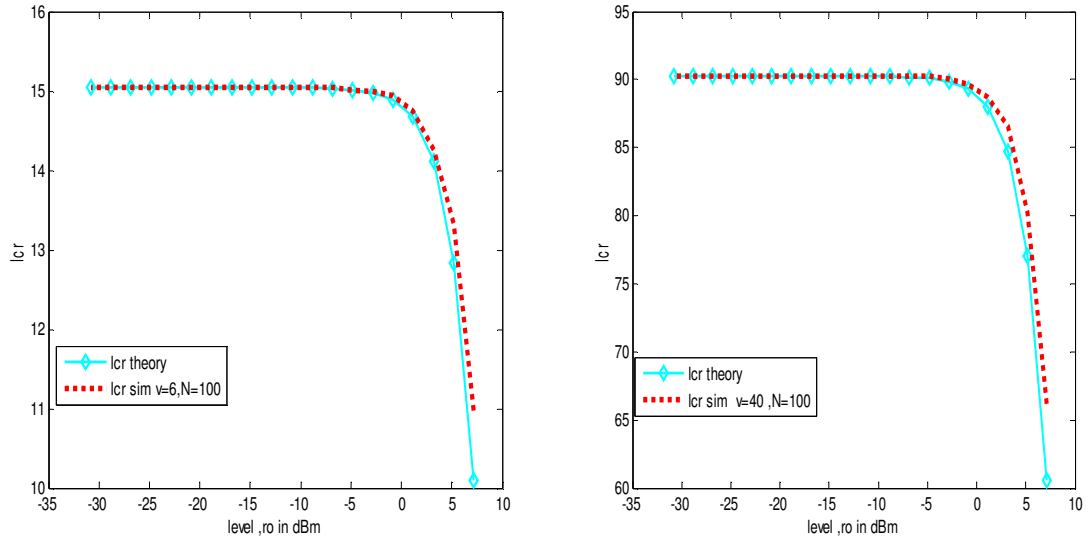


Fig 4.5 LCR for different speed

Taking data from Fig 4.5 and Fig 4.6, the following table is constructed for the given speed and reference level.

Table 4.2 LCR vs. BER

Speed (kmphr)	Bit rate(bps)	Level (dB)	Fade rate(lcr)	BER =Lz/(Rb)
6	10000	-8.885	15.04	0.0015
40	10000	-8.885	90.24	0.009024
100	10000	-8.885	225.6	0.02256

As seen from the Table as the speed increases, for constant level, fading rate (LCR) increases so that BER also increases. Since the definition of BER is number of bits in errors per total number of bits transmitted, the above table implies that, the smaller the speed the slower the bits enter to the deep fade so that the BER is smaller and performance is better. But as speed increases LCR increases and BER increases.

For example for 100kmphr speed if we transmit 100000 bits per second then 2256 bits are considered to be in error

The effect of N, the number of multi-path, is also given. But its effect is on the range of the reference level taken and no change on the fading rate.

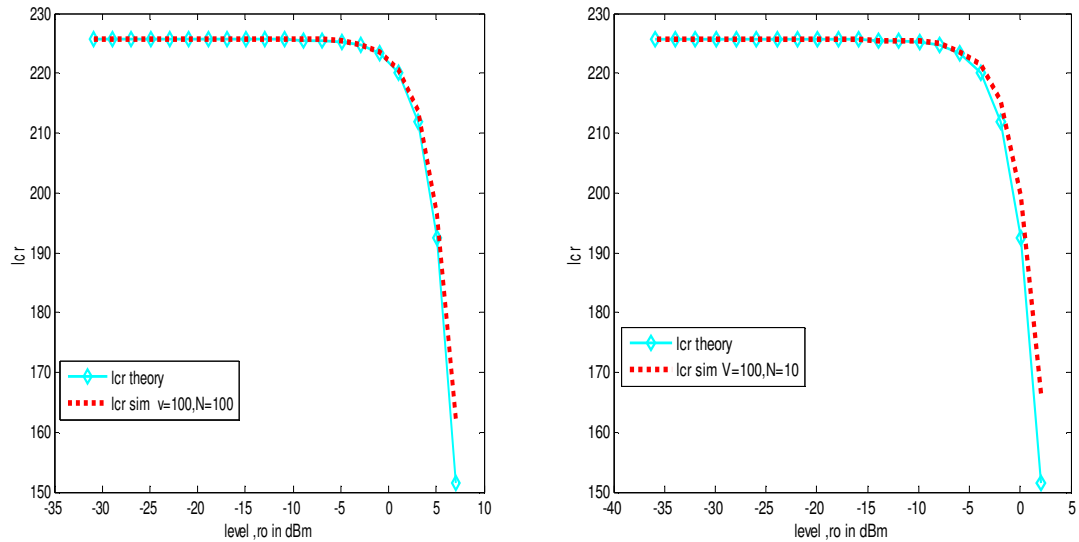


Fig 4.6 LCR for different N

4.6 Average fade duration

Average fade duration is the average time that the signal level stays in deep fade or below the acceptance reference level. The following diagrams and table summarize the effect of the speed and multi-path on the average fade duration.

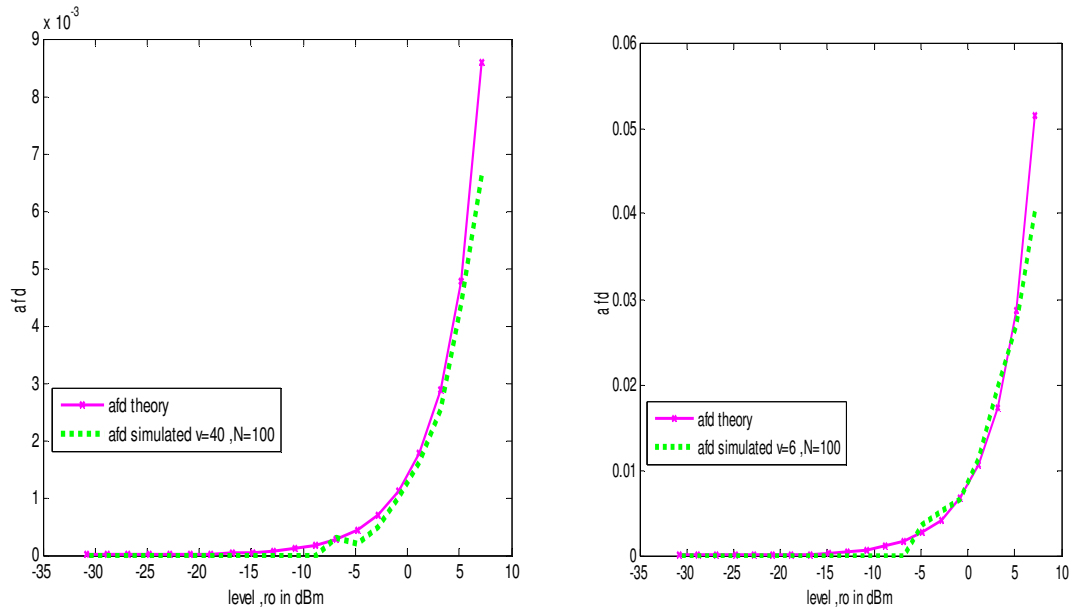


Fig 4.7 AFD comparison for different value of speed

AFD is an important parameter for the design of error controlling codes. The average fade duration is dependent on the speed of terminal. In the above Fig 4.7, the effect seems negligible. But since it is to be compared with the bit period which is very small, so even very small change of AFD have great effect on the system performance. As speed increases fading duration decreases. The coherent time of the channel decreases as speed increases and the channel change frequently in very short period of time. So the signal power stays in deep fade for very short period of time but it returns very frequently. This is summarized on the Table 4.1

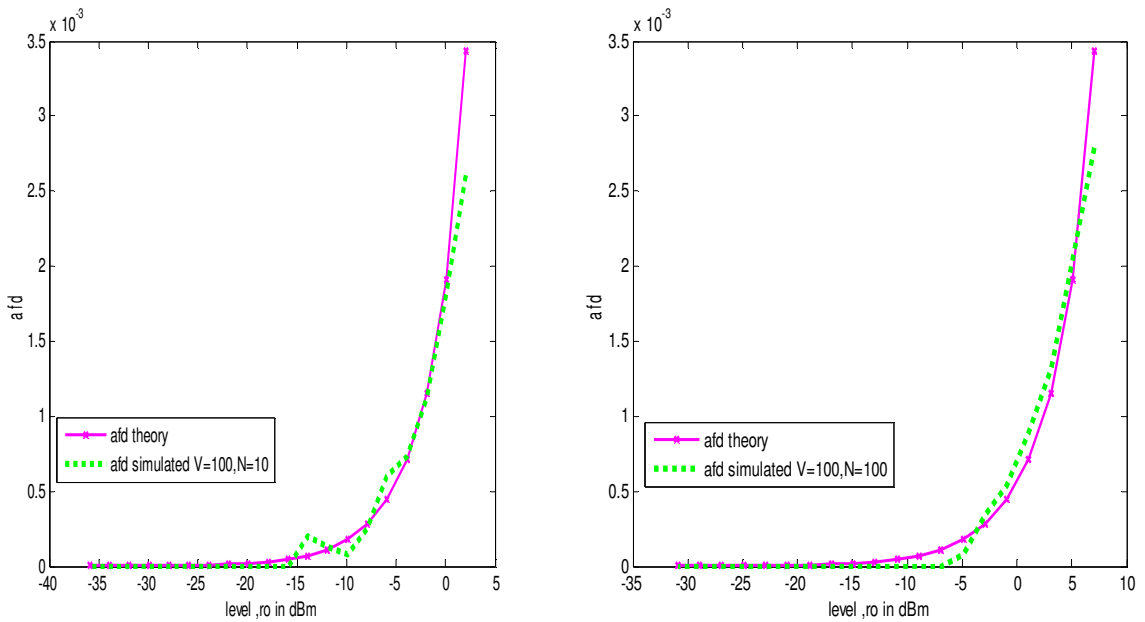


Fig 4.8 AFD for different N

It is obvious that as the number of multi-path increases, AFD decreases since the probability of being above the reference accepted level decreases.

Table 4.3 bit period vs. AFD

Speed (kmphr)	Level(dB)	Bit time(sec)	AFD (sec)	Remark
6	-8.90	10^{-4}	$1.054 \cdot 10^{-3}$	Moderately Slow fading
40	-8.90	10^{-4}	$1.757 \cdot 10^{-4}$	Single error event
100	-8.90	10^{-4}	$7.0264 \cdot 10^{-5}$	Fast fading and many error burst occurs

For the constant level taken in the table, increasing the speed increases the rate of fading the. Due to this the fading duration decreases. But even though the time it stays in that fade region decreases, its frequency increases. So the smaller the AFD the faster it enters in to a deep fade and the BER is relatively high. But if we consider only the reference level, for static channel as the level increases the AFD increases and the BER Increase. If The speed constant, as the reference level increases, the AFD increases exponentially as seen Fig 4.6 and Fig 4.7 so that the number of bits affected by a deep fades increases.

4.7 Simulation of the BER of FSFC

Algorithm used for BER simulation of FSFC

As discussed in Section 3.4.4.1, the BER of frequency selective channel is dependent on the parameters like Average number of multi-path, rms delay spread and Power delay profile. The effect of each parameter on the BER performance is to be discussed in this section.

Note that here no equalizer is used and as clearly described in Table 4.1, the transmission mechanism is BPSK. Here also the channel is modeled as static Rayleigh and the noise is AWGN. It is only the multipath effects (the number of path, delay profile and rms delay) of the channel are to be seen. In order to see the effect, we have to simulate the BER. In order to simulate we have to follow this algorithm.

STEP1: Initialization

N (number of paths), α , N delays

STEP2: Discrete Power delay profile generation

Using the α , τ_{rms} , and the N delays,

Generate N possible power delay profiles

Take these N PDP strengths

Use these for the generation BER in FSFC

STEP3: take only N as variable and keep the other constant to see the performance.

Change N

Repeat step2

See the performance and see the effect and conclude

STEP4: take only τ_{rms} as a variable keep other parameters constant

Set the environment (indoor, suburban, and urban)

STEP4.1: set the rms delay of indoor

Repeat step 2

See the performance and see the effect and conclude

STEP4.2: Set the rms delay of sub urban

Repeat step 2

See the performance and see the effect and conclude

STEP4.3: Set the rms delay of urban

Repeat step 2

See the performance and see the effect and conclude

STEP5: take only α as a variable to see its effect

Repeat step 2, See the performance and see the effect and conclude

4.7.1 BER for different value of N

The system performance degrades as the average number of multi-path components N increase. One should note here that, no equalization is used. This is due to the fact that as N decreases the signal level concentrates to the symbol of the first signal, i.e. to the line of sight signal which implies that the quality of the signal increases so that performance improved. Since N is related to the signal and channel band width, increasing N means increasing of the signal bandwidth so that it becomes wideband. So the wide band channel is highly vulnerable to interference as well as other signal degradation. In Fig 4.9b the performance is improved as N decreases to 4 especially up to SNR of 15dB, beyond that the BER becomes independent of SNR so equalizer improves this problem.

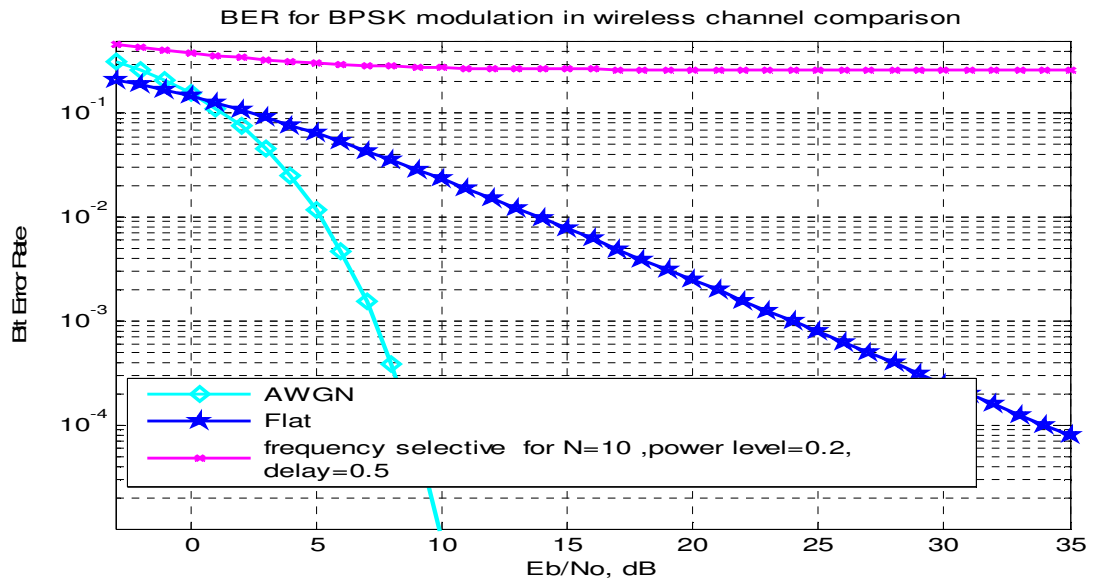


Fig 4.9a BER of FSC for different N

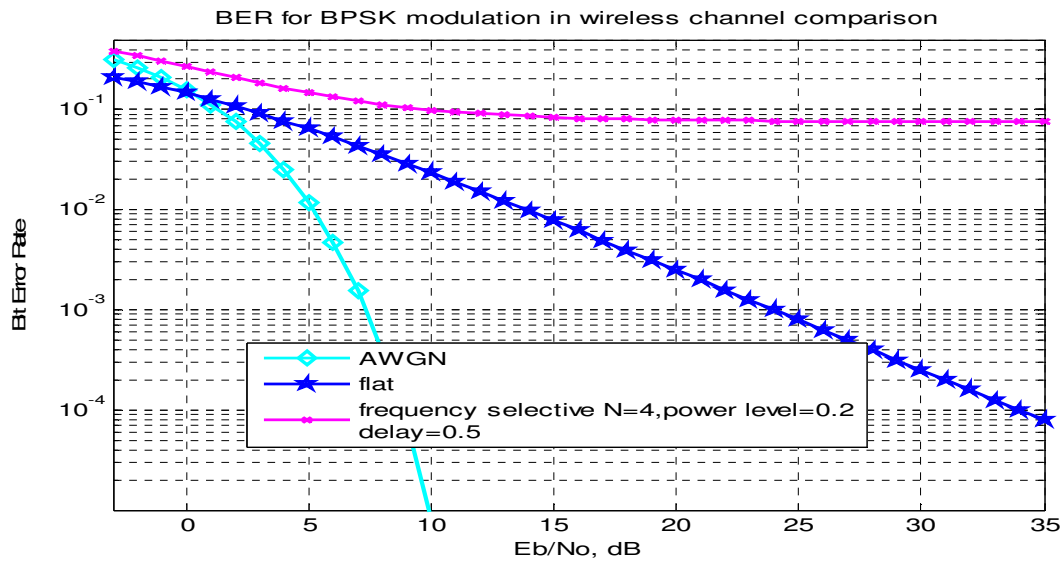


Fig 4.9b BER of FSC for different N

4.7.2 BER for different rms delay

Case I: indoor environment delay ranging from 25-250 ns and the BER plot is demonstrated below.

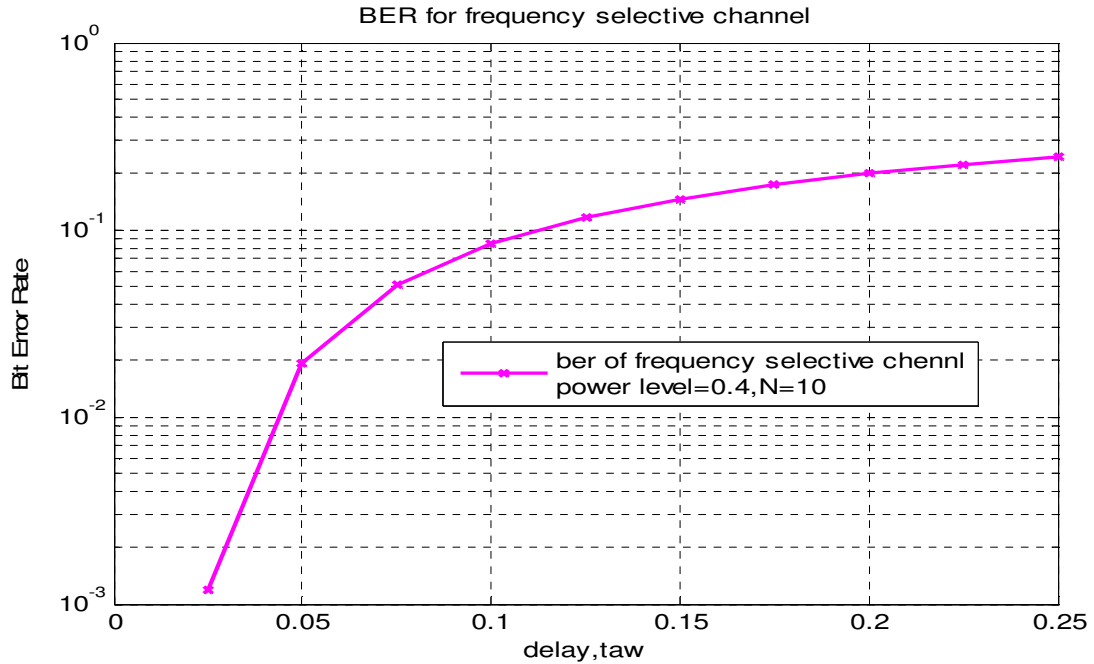


Fig 4.10 BER as a function of RMS delay spread of indoor environment

The BER changes slowly even though the delay increases. Performance of the indoor is better relative to the suburban and urban environments because of the smaller effect of the ISI due to smaller value of delay spread.

Case II: suburban environment delay ranging from 0.2-2 microsecond

For this type of environment the range of the BER is from 0.199 to 0.79 for that range of delay spreads, the increment is Sharpe up to $1\mu\text{sec}$. As shown in the Fig 4.11. This is directly related with increment of the rms delay spread. Because, rms delay spread is the mean standard deviation of the delay time of each path, then the increment of rms delay is directly related with the delay time of each path. As the delay time increases, interference increase and the signal is in error. So BER is high for this type of environment relative to the indoor. For such environments, it is preferred to choose the maximum rms delay spread of up to $1\mu\text{sec}$.

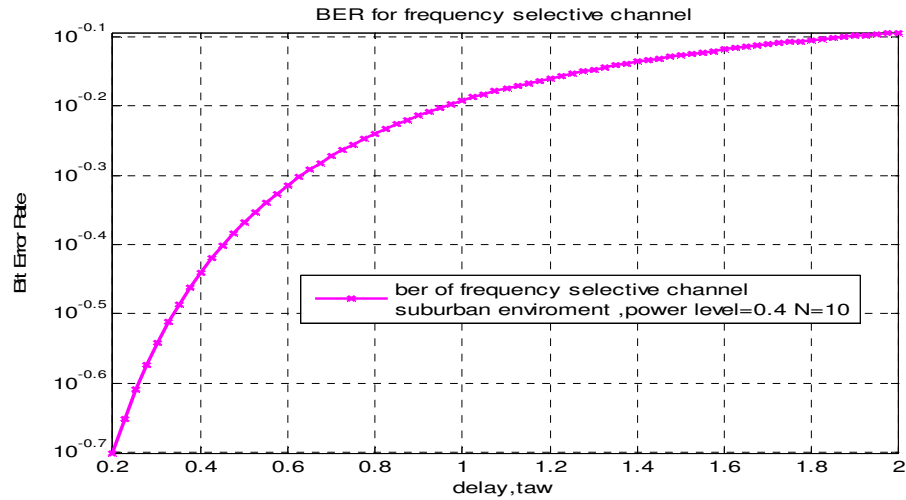


Fig 4.11 BER of sub urban environment
CASE III: urban environment delay ranging from (2-25 μ sec)

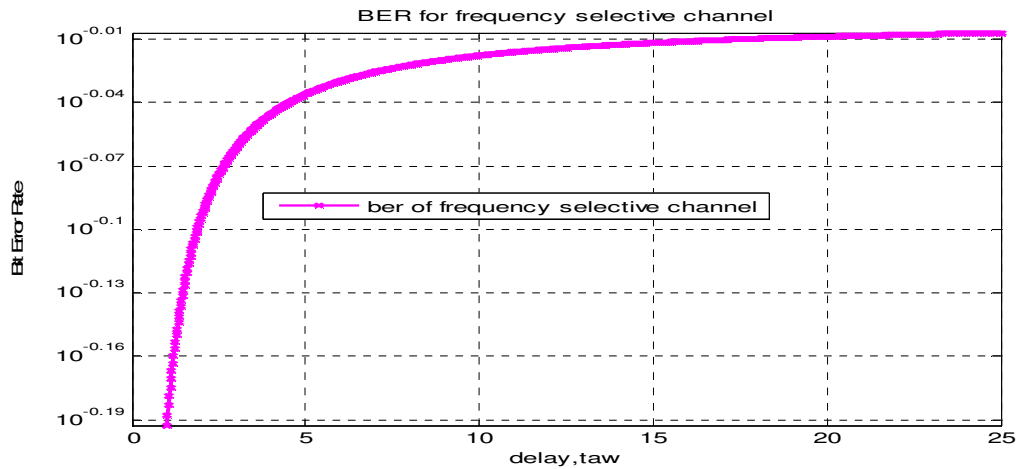


Fig 4.12 BER of urban environment

In the plot of Fig 4.12 the effect of delay spread is so visible that the BER at delay =1 μ sec=0.656 and increasing the delay increases the BER logarithmical for SNR=8dB and power and number of path. The range of the BER is from 0.6418 to 0.98 for that range of the delay spread. So even though the SNR is very large the BER is very destructive so that it is an ideal to take the rms delay spread to be up to 25 μ sec. The preferable maximum delay spread for such environment is 7 μ sec.

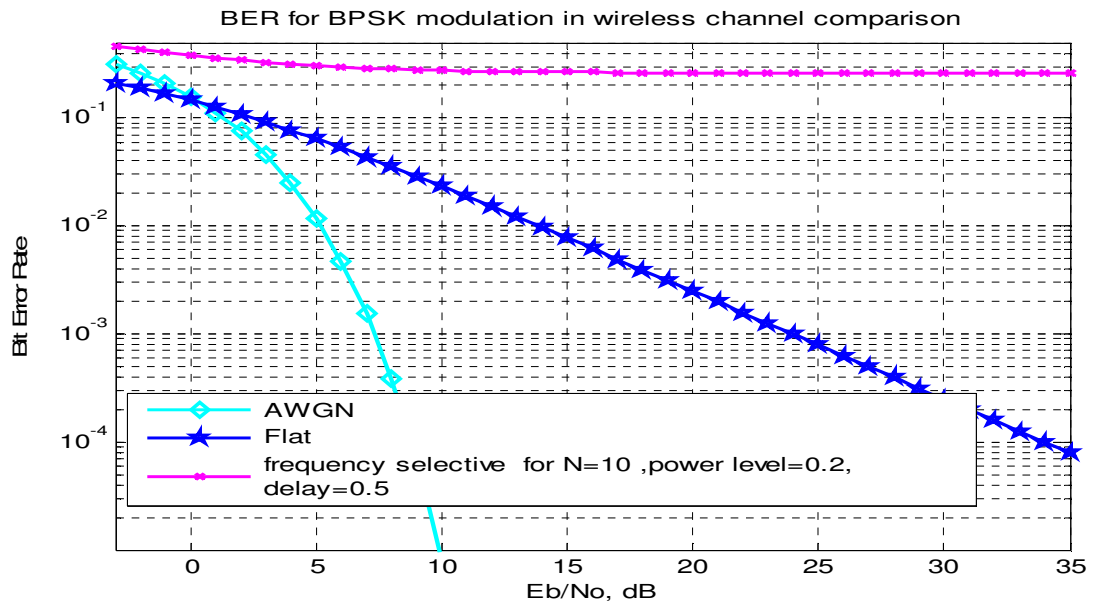


Fig 4.14a BER for different rms delay

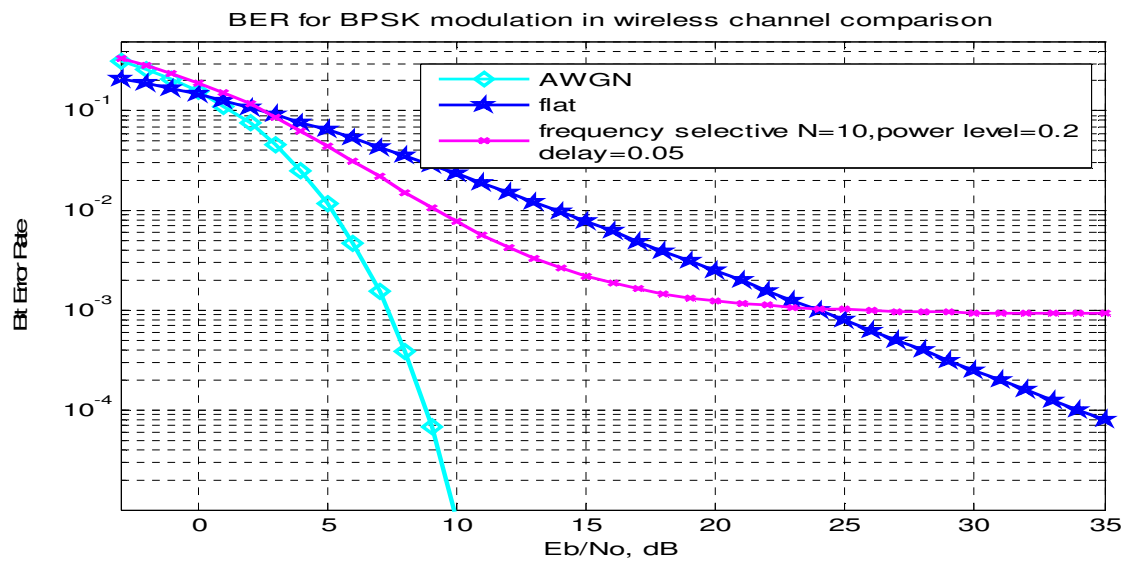


Fig 4.14b BER for different rms delay

In general, the curves on plots above shows the BER vs SNR, that the effect of the inter symbol interference becomes dominant as the delay spread increases, the BER tends towards an irreducible error rate. Fig 4.14b show that, as the normalized rms delay becomes smaller, the effect of the ISI decreases and the BER almost approaches to the flat fading channel so that the

system performance improves. Here also in order to further improve the performance beyond 20dB SNR and to approach to the flat fading channel an equalizer is required.

4.7.3 BER for different value of power delay level (α)

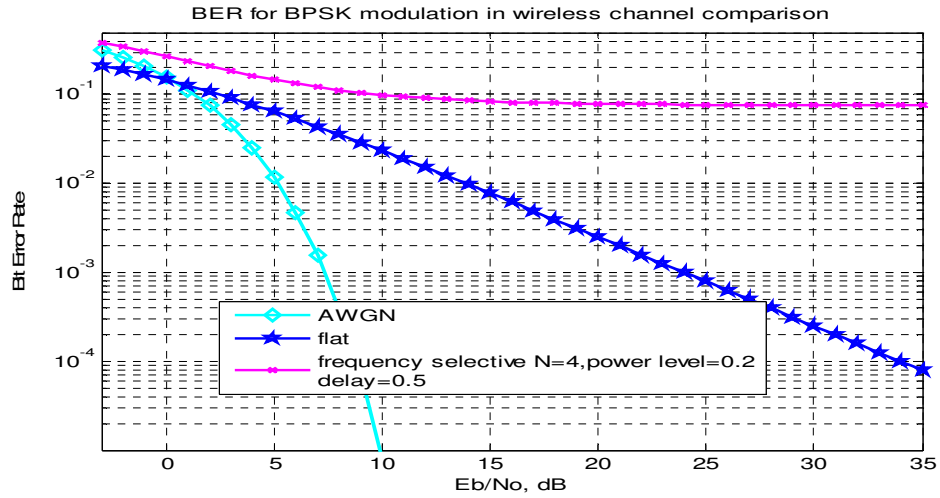


Fig 4.15a BER for power level, $\alpha = 0.2$

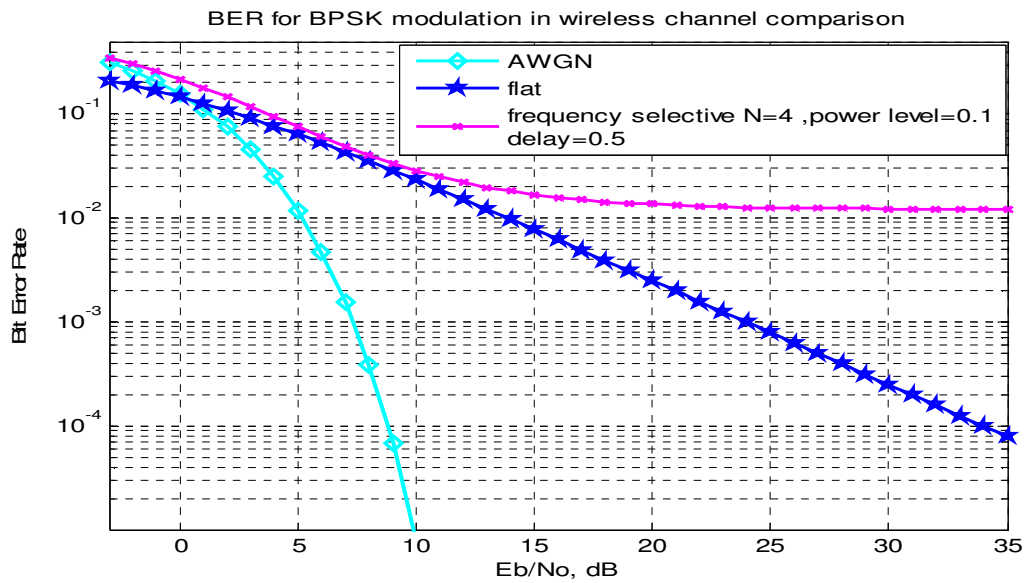


Fig 4.15b BER for power level $\alpha=0.1$

Note: The power level implied in the delay spread relative to the power level of the main signal component, which is described by α , has a strong influence on system performance. The power level of each multi-path is dependent on this relative power α and as this power coefficient

increases the power of each path also increases and the ISI also increases. As it is seen in Fig 4.15a and Fig 4.15b, the BER in the plot can be compared at different value of the power delay level implied relative to the main signal at the same rms delay, N and SNR. So for smaller value of α , the performance is better and up to 15 dB SNR the performance approaches to the flat fading as seen in Fig 4.15b.

4.8 Bit error rate of fast fading channel

In the previous sections, we have seen the effect of speed of the terminal. One of the effects is the effect on the performance of the channel. Variation of the channel is measured by the coherent time of the channel. This in turn is dependent on the speed of the mobile terminal. For higher speed of the terminal, the channel varies very fast. In this section we are going to see the effect on the performance of the channel by looking the effect on the BER. In addition to the speed of the terminal, bit rate also have a dominant effect on the BER of the channel. For high bit rate the effect of the speed can be reduced. The performance of Rayleigh is also compared with that of Rician channel and as usual Rician channel performs better than Rayleigh channel. The plots below demonstrate these facts.

As it is seen from **Fig 4.16a**, for high speed the channel is relatively affected by error. This is much sever also if the bit rate is relatively small. The gap in performance between each speed of mobile terminal is high if the transmission rate is small. This result is completely agreed with the conclusions stated in fading rate and fading duration. Performance improves for higher bit rate as function of power signal to noise ratio.

Comparing Fig 4.16a, Fig 4.16b and Fig 4.16c, as bit rate increases, the effect of the channel variation due to speed of mobile terminal decreases. But considering the effect of the speed only, for higher speed the performance decreases. This is due to the variation of the channel and the channel can go frequently to a deep fade during the variation and affected by this deep fade so that the performance is degraded

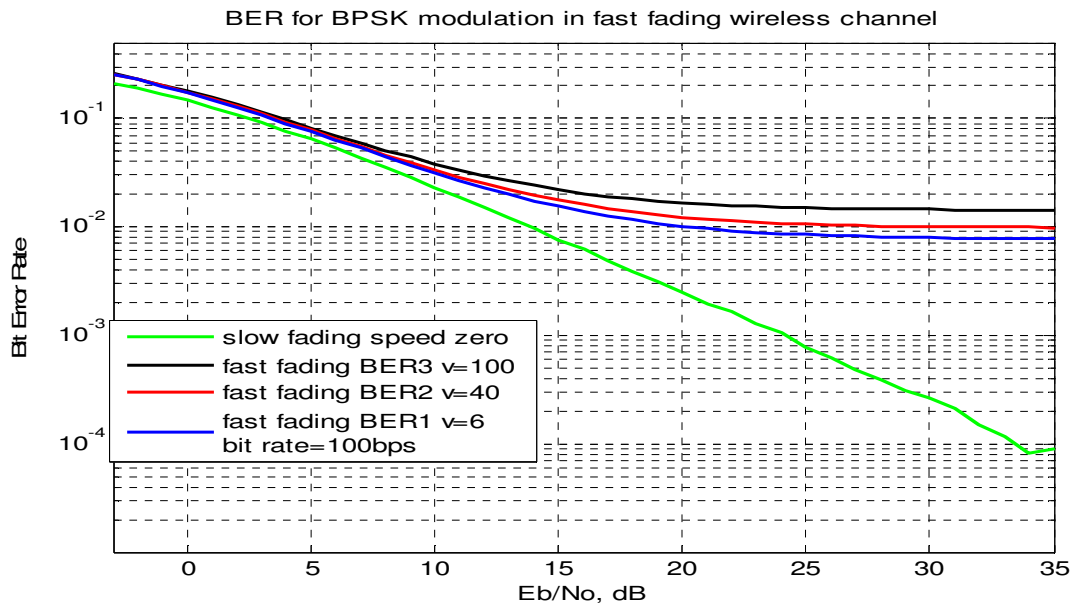


Fig 4.16a BER vs. SNR for 100bps

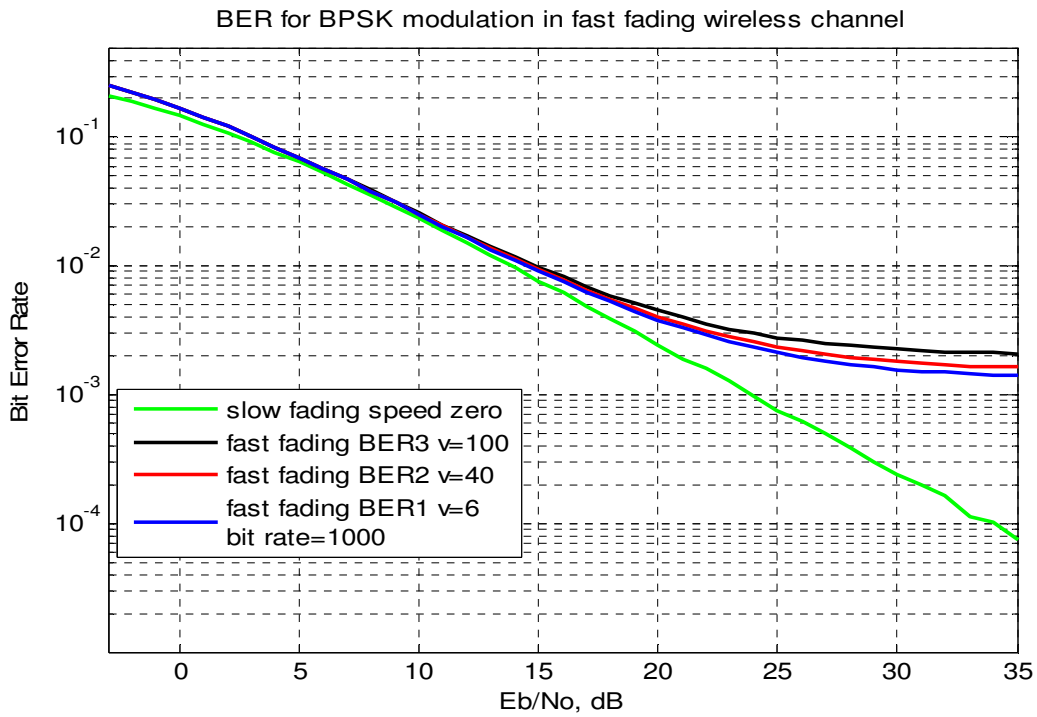


Fig 4.16b BER vs. SNR for 1000bps

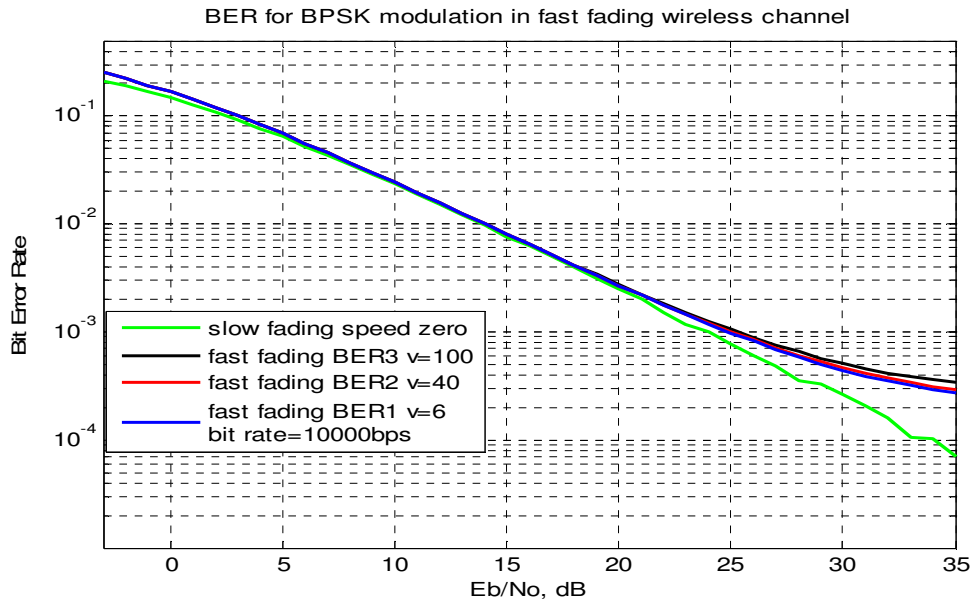


Fig 4.16c BER vs. SNR for 10000bps

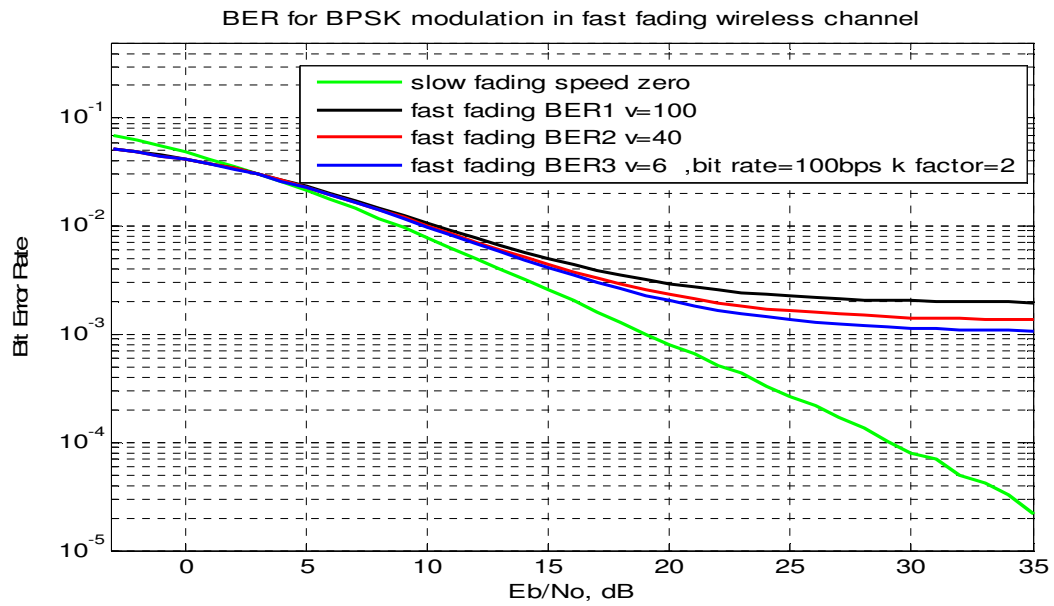


Fig 4.17 Effect of k-factor on BER

Comparing Fig 4.16a and Fig 4.17, for the same speed of terminal and bite rate, the Rician fading channel performs better than Rayleigh fading channel.

CHAPTER FIVE

CONCLUSION AND RECOMENDATION

5.1 Conclusion

Wireless communication's performance is limited on the performance of the wireless channel. The wireless channel is expected to provide multimedia services with transmission capabilities that are able to handle higher data rates and higher mobility. In turn, the reliability of the channel depends on the understanding of its Modeling mechanism and how it behaves in a given specific environment. Multipath fading which is caused due to the propagation mechanism of the signal in the given environment is the main series problem of the wireless fading channel. In this thesis, statistical modeling of the small scale fast fading wireless channel followed by simulation of the performance of the fading channel is thoroughly studied for land mobile terminal.

In chapter three, the different types of wireless channel modeling mechanism are presented. First, the different types of SOS models are presented. Next to this the transfer function based model is presented. Here the parameters of the transfer function are discussed. Generally this model is based on modeling of the attenuation or path gain, path delay, phase delay and number of paths. The path gain is dependent on the reflection coefficient, antenna gain, distance between receiver and transmitter and the signal wavelength. The path delay, whereas, is dependent only the path distance difference. The phase is dependent on the carrier frequency, speed of terminal and the path delay. The numbers of paths define weather the channel is wideband or narrow band and is related to the signal band width and coherent bandwidth of the channel. But in both SOS and the transfer function based model the speed of the terminal is assumed to be constant. The general model represents the channel in all states of motion, i.e. accelerated, constant speed, and a terminal at rest. This models the channel by an instant by instant method where each instant has its own speed. Finally this model converges to the SOS reference model in the case of the constant speed. In addition to this, the main effects of the speed of mobile terminal are also present. Mobile speed has an effect the envelop power level of the signal and in the fading bandwidth. And finally, at this chapter the main parameters which can be used in the

performance measurements of the fading channel are presented. These are fading probability, fading rate, fading duration and the BER.

In chapter four, the main results are discussed. In the 1st section of this chapter comparison of the general model with the selected Xiao's model is presented. Xiao's model is selected because it is the best out of the other SOS models. The parameter used for comparison is the autocorrelation function. For constant N , by decreasing k (the number of instant) from 10 to 1, it is seen in fig (4.2) and as k approaches to one the two models almost performs the same. Next to this section the performance measurements are simulated. Fading probability is simulated as a function of number of path, speed of mobile terminal and the reference power level. Fig 4.3 and 4.4 show that fading probability is independent of speed and increases as the number of path increases. The fading rate and fading duration are also simulated as a function of speed of the mobile terminal, number of paths and the reference power level. For constant N , as speed increase the fading rate also increases and since it is related to the BER by equ (3.62), the BER also increase. The effect of N is related on the reference power level. In case of the fading duration as speed increases, the fading duration decrease but the rates of entering into this deep fade level increase.

BER is another parameter which is mainly concerned on this chapter. BER is simulated to show the effect of multipath propagation and speed of mobile, i.e. for both frequency selective channel and fast fading channel is presented here. In case of the frequency selective channel, BER is simulated as a function of the number of path, rms delay, and the power level in the power delay profile. With no equalization the smaller the number of path keeping the other parameters constant, the performance is better. Similar to this the smaller the rms delay spread, the better the performance. In case of the power delay profile, similarly performance is better for smaller delay strength. This discussion implies that if the channel is more wideband, the performance is much more sever. BER performance in fast fading channel is evaluated as function of speed of mobile terminal and bit rate. For Smaller speed, the performance is better. And increasing the bit rate also improves the performance for high speed of terminal.

5.2 Recommendation for future work

- ❖ *Performance measurement of the BER considering the effects of both multipath and variable speed simultaneously:* In this Thesis, performance is measured regarding the multipath and the speed of terminal separately. But, measurement of the performance considering both multipath and speed of terminal is another challenging not considered here. In addition to this,
- ❖ *Measurement of the channel BER performance for variable speed:* In this thesis performance of fast fading channel is measured for constant speed. But for time varying speed of terminal, measurement of the performance is another challenge.
- ❖ *Modeling a wireless channel in maritime(water environment) communication environment:* in this thesis all the models and Simulations are assumed in land mobile terminal .modeling and simulation of wireless channel in maritime environment is another communication engineer challenge

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