Implementing SC-FDMA & OFDM in MATLAB

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Abstract:-**The UMTS Long Term Evolution (LTE) is an emerging technology in the evolution of 3G cellular services. Single Carrier Frequency Division Multiple Access (SC-FDMA) & Orthogonal Division Multiple Access (OFDMA) are major part of LTE. OFDMA was well utilized for achieving high spectral efficiency in communication system. SC-FDMA is introduced recently and is used for uplink multiple access scheme in LTE system. The Multiple Access Scheme in Advanced Mobile radio system has to meet the challenging requirements for example high throughput, good robustness, efficient Bit Error Rate (BER), high spectral efficiency, low delays, low computational complexity, low Peak to Average Power Ratio (PAPR), low error probability etc. In this report, the performance of SC-FDMA and OFDMA of LTE physical layer is investigated by considering different modulation schemes (BPSK, QPSK, 16QAM and 64QAM) on the basis of PAPR, BER and error probability by simulating the model of SC-FDMA & OFDMA. The Additive White Gaussian Noise (AWGN) channel is used and frequency selective (multipath) fading in the channel is introduced by using Rayleigh Fading model to evaluate the performance in presence of noise and fading. The simulated result shows that the OFDMA has high power spectral density. The considered modulation schemes also have a significant impact on the PAPR of both OFDMA and SC-FDMA such that the higher order modulations increase PAPR in SC-FDMA and decrease PAPR in OFDMA. However, the overall value of PAPR is less in SC-FDMA for all modulation schemes.**

Keywords: OFDMA, SC-FDMA, LTE, BER, PAPR.

I. INTRODUCTION

Radio technologies have undergone increasingly rapid evolutionary changes in the recent past. As technology progresses to take advantages of more complex channel characteristics, the channel modeling required to emulate the radio environment for testing becomes both more critical and more complex. For instance, when bandwidths are increased (to Support higher data rates) receivers become more susceptible to Inter-Symbol Interference (ISI). To ensure that measurements in the lab accurately correlate to the Quality of the user's experience, channel models must account for all the aspects of the practical radio environment.

Multipath fading occurs in any environment where there is multipath propagation and there is some movement of elements, within the radio communications system. This may include the radio transmitter or receiver position, or in the elements that give rise to the reflections. The multipath fading can often be relatively deep, i.e. the signals fade completely away, whereas at other times the fading may not cause the signal to fall below a useable strength. The fading channel is modeled with simulink and Monte Carlo method is applied if the fading is severe compared to the Rayleigh distribution model. Of course, the Rayleigh distribution is a special case of Nakagami-m when m=1. In multi path channels, small scale fading is the main issue to concentrate for communication engineer. Due to this small scale fading, the signal strength gets rapid changes over a small travel distance.

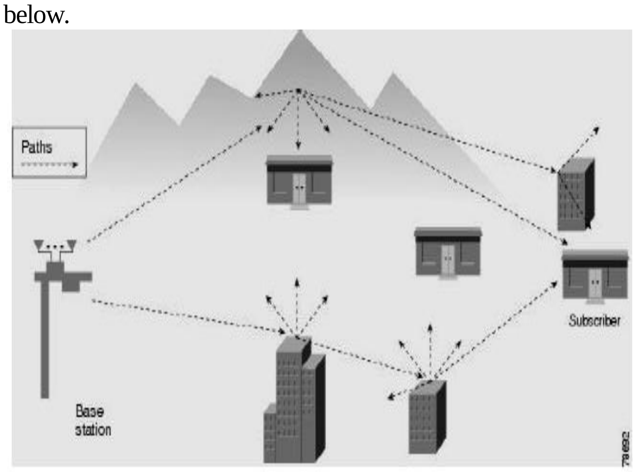
The type of fading experienced by a signal propagating through a mobile radio channel depends on the nature of transmitted signal with respect to characteristics of the channel. For HF ionosphere channel, Rayleigh distribution approximates the short-term fading statistics. But, if the variations in HF channel are high, then the simple Rayleigh model is unfit to characterize the channel, where we should to use the simulink model.

II. FADING

The most troublesome and frustrating problem in receiving radio signals is variations in signal strength, most commonly known as 'Fading'.

A. Multi path fading

Multipath fading is a feature that needs to be taken into account when designing or developing a radio communications system [1-2]. In any terrestrial radio communications system, the signal will reach the receiver not only via the direct path, but also as a result of reflections from objects such as buildings, hills, ground, water, etc that are adjacent to the main path as shown below.



Types of multi path 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. Depends upon it, the multi path fading is mainly classified into 2 types.

1. Large scale fading
2. Small scale fading

The following figure shows the complete classification of small scale and large scale fading types.

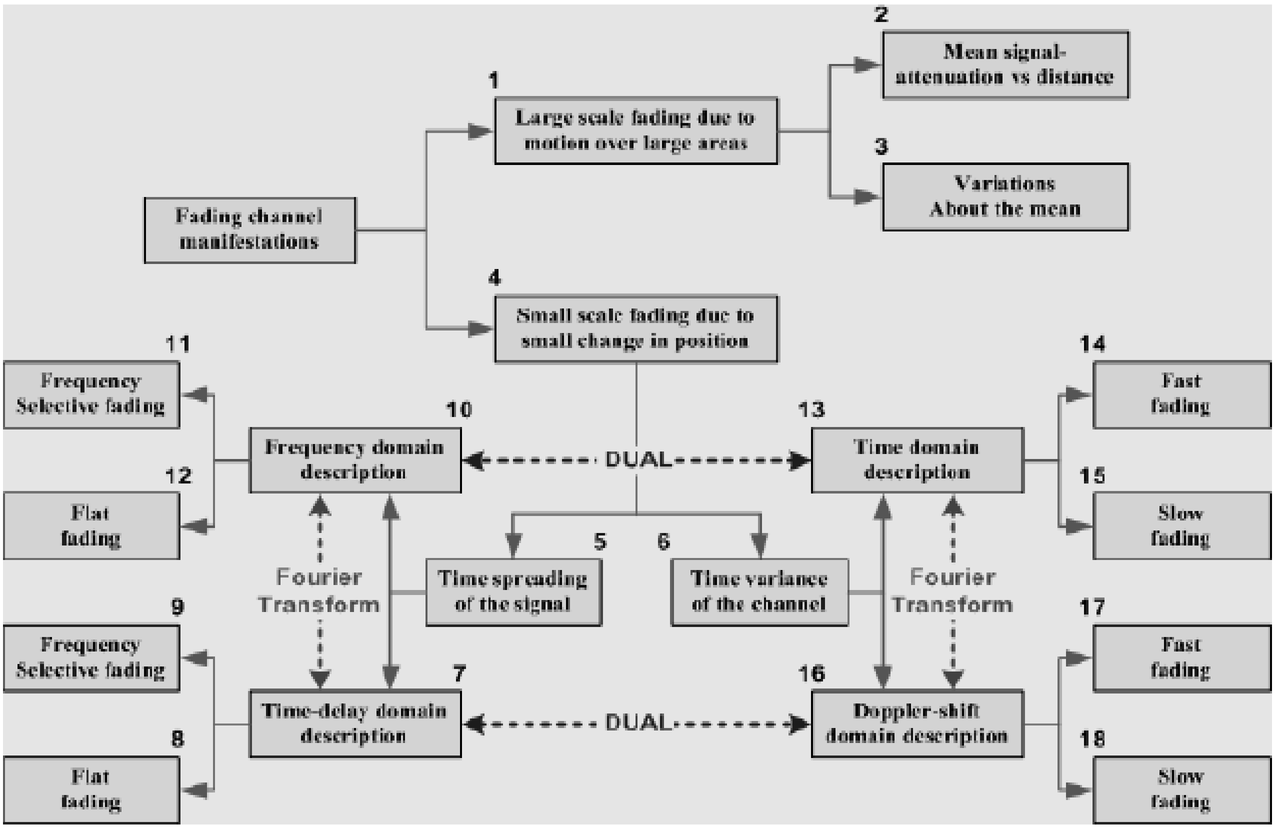


Figure 1.2: Types of multi path fading

1. Large-Scale Fading

Fading, that concentrates on the ,mean signal strength for an arbitrary transmitter- receiver (T-R) separation distance 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 ionosphere and is calculate 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. 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 fig 1.3 illustrates the relation between small scale and large scale fading.

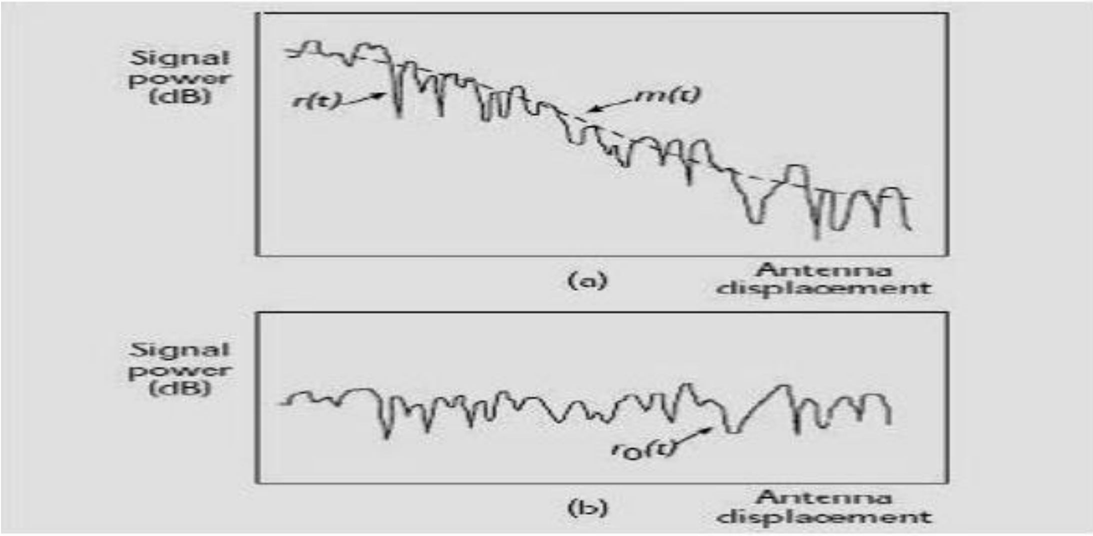


Figure 1.3: Large scale& small scale fading

In fig 1.3(a), Small scale fading is superimposed on large scale fading can be easily identified. In fig 1.3(b) large scale fading m (t) has been removed in order to view the small scale fading r_0 (t).

III. STOCHASTIC PROCESSES

A random process is a function of the elements of a sample space, S, as well as another independent variable, t. Given an experiment, E, with sample space, S, the random process, X (t), maps each possible outcome, $\zeta \epsilon$ S, to a function of t, x (t, ζ), as specified by some rule. These random signals play a fundamental role in the fields of communications, signal processing, control systems, and many other engineering disciplines. In the study of deterministic signals, we often encounter 4 types or classes of signals:

(1) Continuous time and continuous amplitude signals are a function of a continuous independent variable, time. The range of the amplitude of the function is also continuous.

(2) Continuous time and discrete amplitude signals are a function of a continuous independent variable, time—but the amplitude is discrete.

(3) Discrete time and continuous amplitude signals are functions of a quantized or discrete independent time variable, while the range of amplitudes is continuous.

(4) Discrete time and discrete amplitude signals are functions where both the independent time variable and the amplitude are discrete.

The following figure explains these different types of random processes:

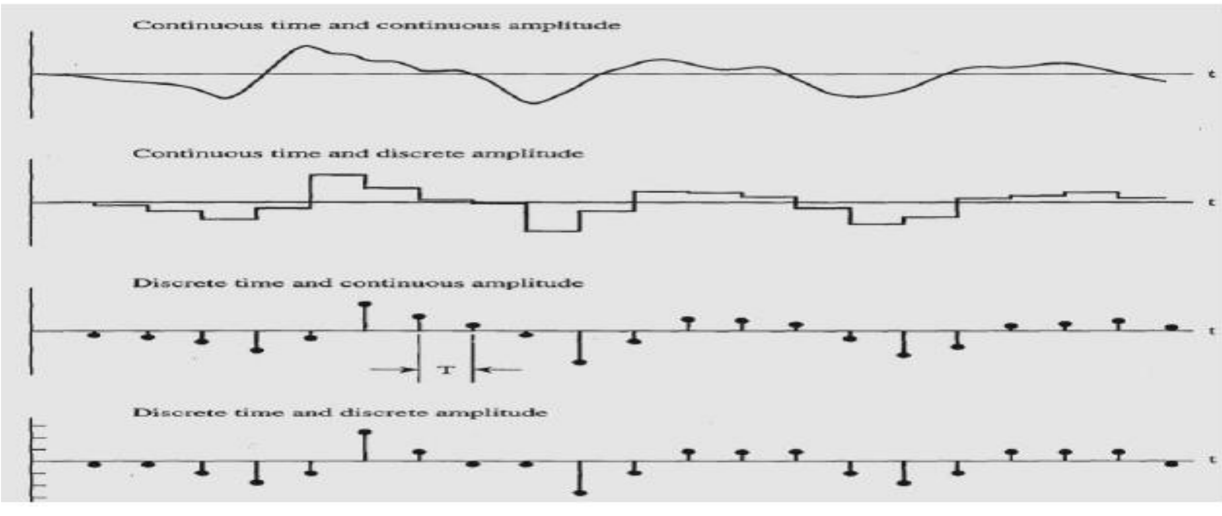


Figure 2.8: Types of Random processes

A random variable, X, is a function of the possible outcomes,ζ of an experiment. Now, we would like to extend this concept so that a function of time x (t) (or x[n] in the discrete time case) is assigned to every outcome,ζ of an experiment. The function, x (t), may be real or complex and it can be discrete or continuous in amplitude. Strictly speaking, the function is really a function of two variables, x(t, ζ), but to keep the notation simple, we typically do not explicitly show the dependence on the outcome, just as we have not in the case of random variables. The function x(t) may have the same general dependence on time for every outcome of the experiment or each outcome could produce a completely different waveform. In general, the function x (t) is a member of an ensemble (family, set, collection) of functions. X (t) represents the random process, while x (t) is one particular member or realization of the random process [3].

Different types of random processes

Even though there are number of random processes which can be useful to model different systems, a few of them have much importance in wireless applications. These are used to design a reliable communication link between transmitter and receiver depends on the time varying statistical behavior of existing channel. The most useful random processes which are useful to characterize small-scale fading are

- Gaussian random process
- Rayleigh random process
- Ricean random process

Gaussian distribution

A Gaussian random variable is one whose probability density function can be written in the general form [3]

$$\boldsymbol{f_x}(x)=\frac{1}{\sqrt{2\pi\sigma^2}}\boldsymbol{e}^{\frac{-(x-m)^2}{2\sigma^2}} \quad , \quad -\infty < \boldsymbol{x} < +\infty$$

(2.30)

The PDF of the Gaussian random variable has two parameters, m and σ, which have the interpretation of the mean and standard deviation respectively. The parameter σ^2 is referred to as the variance. In general, the Gaussian PDF is centered about the point x = m and has a width that is proportional toσ.

The CDF is required whenever we want to find the probability that a Gaussian random variable lies above or below some threshold or in some interval. The CDF of a Gaussian random variable is written as

$$\boldsymbol{F_x}(x)=\int_{-\infty}^{x}\frac{1}{\sqrt{2\pi\sigma^2}}\boldsymbol{e}^{\frac{-(y-m)^2}{2\sigma^2}}dy \qquad (2.31)$$

It can be shown that it is impossible to express this integral in closed form. Because Gaussian random variables are so commonly used in such a wide variety of applications, it is standard practice to introduce a shorthand notation to describe a Gaussian random variable, X ~ N (m, σ2). This is read —X is distributed normally (or Gaussian) with mean, m, and variance, σ=2.

The following figure shows the PDF and CDF of a Gaussian random variable

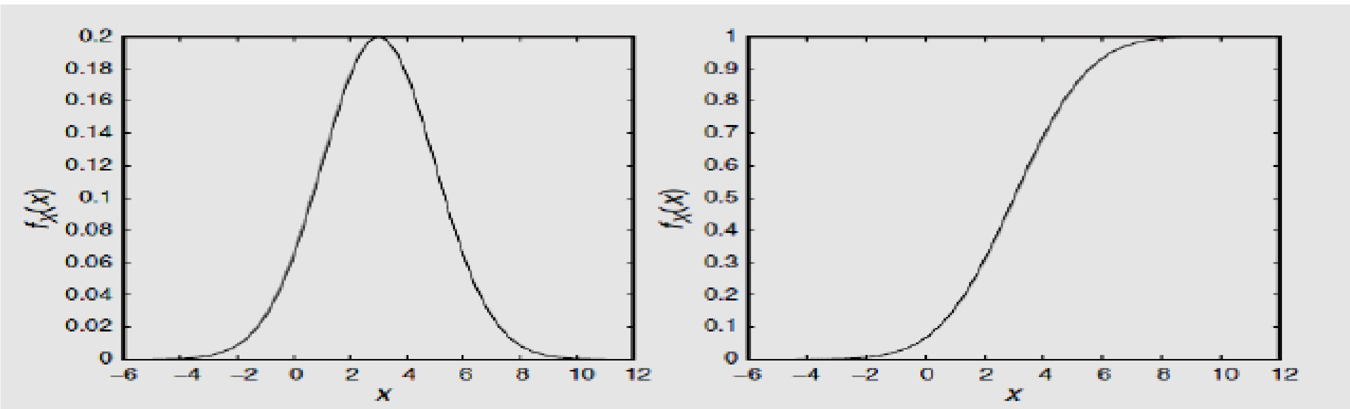


Figure 2.9: PDF and CDF of a Gaussian random variable with m=3 and σ = 2.

Rayleigh distribution

A Rayleigh random variable has a one-sided PDF. The functional form of the PDF and CDF are given (for any □ > 0) by

f_(x(x))= (x/σ^2) exp(-x^2/(2σ^2)) u(x) (2.32)

F_x(x) = (1- exp (-x^2/(2σ^2)))u(x) (2.33)

The following figure shows the PDF and CDF of a Rayleigh random variable X.

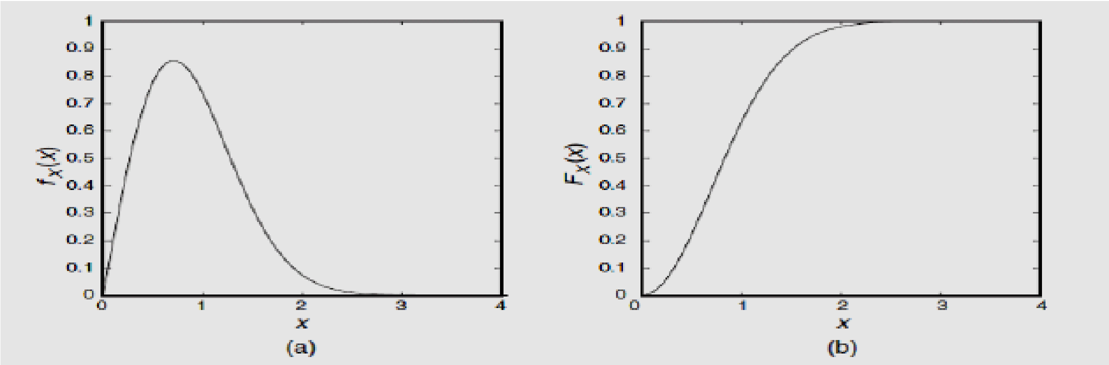


Figure 2.10: PDF and CDF of a Rayleigh random variable, σ2 = 1/2.

The Rayleigh distribution is described by a single parameter, σ2, which is related to the width of the Rayleigh PDF. In this case, the parameter σ2 is not to be interpreted as the variance of the Rayleigh random variable. The Rayleigh distribution arises when studying the magnitude of a complex number for which real and imaginary parts both follow a zero-mean Gaussian distribution. The Rayleigh distribution arises often in the study of non coherent communication systems and also in the study of land mobile communication channels, where the phenomenon known as fading is often modeled using Rayleigh random variables.

Ricean distribution

A Ricean random variable is closely related to the Rayleigh random variable (in fact, the Rayleigh distribution is a special case of the Ricean distribution). The functional form of the PDF for a Ricean random variable is given (for any v > 0 and any σ > 0) by

$$f_x(x) = \left(\frac{x}{\sigma^2}\right) \exp\left(-\frac{x^2+v^2}{2\sigma^2}\right) I_0 \left(\frac{vx}{\sigma^2}\right) u(x) \quad (2.34)$$

In this expression, the function Io(x) is the modified Bessel function of the first kind of order zero, which is defined by

$$I_0 = \frac{1}{2\pi} \int_0^{2\pi} e^{x\cos\theta} d\theta \quad (2.35)$$

Like the Gaussian random variable, the CDF of a Ricean random variable cannot be written in closed form.

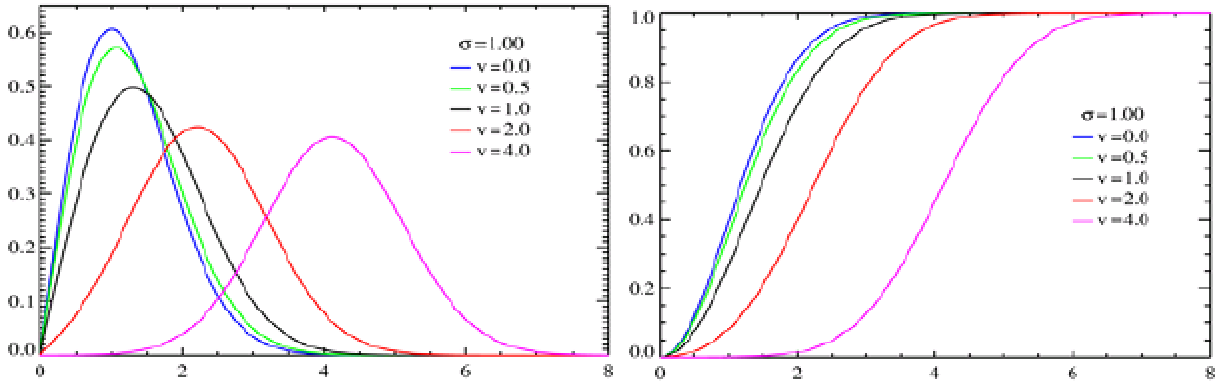


Figure 2.11: PDF and CDF of a Ricean random variable

IV. LITERATURE REVIEW

1) Zheng, Y. R. and Xiao, C., "Simulation models with correct statistical properties for Rayleigh fading channels", 2003. A statistical discrete-time model is proposed for simulating wideband multiple-input multiple-output (MIMO) fading channels which are triply selective due to angle spread, Doppler spread, and delay spread. The new discrete-time MIMO channel model includes the combined effects of the transmit filter, physical MIMO multipath channel fading, and receive filter, and it has the same sampling period as that of the MIMO receiver. This leads to very efficient simulation of physical continuous-time MIMO channels. A new method is also presented to efficiently generate the MIMO channel stochastic coefficients. The statistical accuracy of the discrete-time MIMO channel model is rigorously verified through theoretical analysis and extensive simulations in different conditions. The high computational efficiency of the discrete-time MIMO channel model is illustrated by comparing it to that of the continuous time MIMO channel model. The new model is further employed to evaluate the channel capacity of MIMO systems in a triply selective Rayleigh fading environment. The simulation results reveal some interesting effects of spatial correlations, multipaths, and number of antennas on the MIMO channel capacity.

2) Nikolay Kostov, “Mobile Radio Channels Modeling in Matlab”, December 2004, Several transmission modes are defined in IEEE 802. 11 a/b/g WLAN standards. A very few transmission modes are considering for IEEE 802. 11 a/b/g in physical layer parameters and wireless channel characteristics. In this paper, a MATLAB based approach for is used for BER estimation of AWGN channel using Monte-Carlo method. Further BER estimation of AWGN channel is compared with that of Rayleigh fading channel. MATLAB based Monte Carlo simulation example is presented, which comprises performance estimation of Binary phase shift keying (BPSK) signaling over a Rayleigh fading channel [13]. Also various mitigation effects are studied and their effects are shown[11].

3) Turkka, M. Renfors, “Evaluation of radio links and networks”, 1996.They showed the results of narrowband path loss measurements in a typical urban and suburban mobile-tomobileradio environment at 900 MHz band. The measurements were made with two omni-directional antennas with a transmitter and a receiver antenna height of 1.5 meters. The results of measurements provide practical values for path loss exponent and standard deviation of shadowing in a non line-of-sight radio environment. These parameters can be used with a simple power law path loss model to predict reliable communication ranges for future communication systems operating in a mobile-to-mobile environment, such as a relay extended cellular networks, non-line-of-sight vehicle-to-vehicle communications or relay assisted positioning applications.

4) Sang Wu Kim, Ye Hoon Lee “Minimum duration outage for cellular systems: a level crossing analysis”, May 1996. They consider combined rate and power adaptations in direct-sequence code-division multiple-access communications, where the transmission power and the data rate are adapted relative to channel variations. We discuss the power gain that the combined adaptations provide over power adaptation. Then, we consider an integrated voice and data transmission system that offers a constant bit rate voice service, using power adaptation and a variable bit rate data service with rate adaptation. We present an expression for the required average transmission power of each traffic type having different quality-of-service specifications and discuss the capacity gain over power adaptation for voice and data.

5) Patzold, M., “Mobile fading channels”, West Sussex, UK: John Wiley & Sons, 2002 explained an outage analysis of wireless systems operating in gamma-shadowed Nakagami-faded environments where the desired signal also suffers from cochannel interference. The interfering signals are also subject to fading and shadowing. Based on the obtained signal to interference ratio (SIR) probability density function (pdf), closedform expressions for the outage probability are obtained in both cases of statistically identical interferers and multiple interferers with different parameters. The effects on the aforementioned performance metric of the reuse distance and of the combined fading, shadowing and co-channel interference are analyzed subsequently. The newly derived closed-form expressions for the outage probability allow as to acess the effects of the different channel and interference parameters easily.

6) M. Surendra Raju, A. Ramesh and A. Chockalingam, “BER Analysis of QAM with Transmit Diversity in Rayleigh Fading Channels”, in IEEE 2003 present a log-likelihood ratio (LLR)based approach to analyze the bit error rate (BER) performance of quadrature amplitude modulation (QAM) on Rayleigh fading channels without and with transmit diversity. We derive LLRs for the individual bits forming a QAM symbol both on flat fading channels without diversity as well as on channels with transmit diversity using two transmit antennas (Alamouti’s scheme) and multiple receive antennas. Using the LLRs of the individual bits forming the QAM symbol, we derive expressions for the probability of error for various bits in the QAM symbol, and hence the average BER. In addition to being used in the BER analysis, the LLRs derived can be used as soft inputs to decoders for various coded QAM schemes including turbo coded QAM with transmit diversity, as in high speed downlink packet access (HSDPA) in 3G.

7) Md. Sipon Miah, M. Mahbubur Rahman, T. K Godder, Bikash Chandra Singh and M. Tania Parvin, “ performance comparison of AWGN ,Flat fading and frequency Selective fading channel for wireless communication system using 4QPSK ” 2011 described the first build up a wireless communication simulator including Gray coding, modulation, different channel models (AWGN, flat fading and frequency selective fading channels), channel estimation, adaptive equalization, and demodulation. Next, test the effect of different channel models to the data and image in receiver with constellation and BER (bit error rate) plots under 4QPSK modulation which is a high data rate then QPSK. For Image data source, we also compare the received image quality to original image in different channels. At last, give detail results and analyses of the performance improvement with channel estimation and adaptive equalization in slow Rayleigh fading channel. For frequency selective fading channel, use linear equalization with both LMS (least mean squares) and RLS (Recursive Least Squares) algorithms to compare the different improvements. We will see that in AWGN channel, the image is slight degraded by random noise; in flat fading channel, the image is serious degraded by random noise and block noise; in frequency selective fading channel, the image is very serious degraded by random noise, block noise, and ISI.

8) Martin Crew1, Osama Gamal Hassan2 and Mohammed Juned Ahmed3 “A simple transmit diversity technique for wireless communications”, Oct. 1998’ investigated how to design precoders to achieve full diversity and low decoding complexity for MIMO systems. First, we assume that we have 2 transmitters each with multiple antennas and 2 receivers each with multiple antennas.

Each transmitter sends codewords to respective receiver at the same time. It is difficult to handle this problem because of interference. Therefore, we propose an orthogonal transmission scheme that combines space-time codes and array processing to achieve low complexity decoding and full diversity for transmitted signals. Simulation results validate our theoretical analysis.

9) Gayatri S. Prabhu and P. Mohana Shankar,"Simulation of Flat Fading Using MATLAB for Classroom Instruction". An approach to demonstrate flat fading in communication systems is presented here, wherein the basic concepts are reinforced by means of a series of MATLAB simulations. Following a brief introduction to fading in general, models for flat fading are developed and simulated using MATLAB. The concept of outage is also demonstrated using MATLAB. We suggest that the use of MATLAB exercises will assist the students in gaining a better understanding of the various nuances of flat fading.

10) Martin Haardt, Josef A. Nossek,"Modeling mobile radio channels by echo estimation", Sept. 1994 explained a new Jacobi-type method to calculate a simultaneous Schur decomposition (SSD) of several real-valued, non-symmetric matrices by minimizing an appropriate cost function. Thereby, the SSD reveals the "average eigen structure" of these non-symmetric matrices. This enables an R-dimensional extension of Unitary ESPRIT to estimate several undamped R-dimensional modes or frequencies along with their correct pairing in multidimensional harmonic retrieval problems. Unitary ESPRIT is an ESPRIT-type high-resolution frequency estimation technique that is formulated in terms of real-valued computations throughout. For each of the R dimensions, the corresponding frequency estimates are obtained from the real eigen values of a real-valued matrix. The SSD jointly estimates the eigen values of all R matrices and, thereby, achieves automatic pairing of the estimated R-dimensional modes via a closed-form procedure that neither requires any search nor any other heuristic pairing strategy. Moreover, we describe how R-dimensional harmonic retrieval problems (with R _ 3) occur in array signal processing and model-based object recognition applications.

Different fading models

The following table shows the different channel characterization corresponding to the different wireless environments.

ENVIRONMENT	CHANNEL TYPE
Mobile systems with no LOS path between transmitter and receiver antenna, propagation of reflected and refracted paths through troposphere and ionosphere, ship- to- ship radio links.	Rayleigh
Satellite links subject to strong ionospheric scintillation	Nakagami-q (Hoyt) (spans range from one-sided Gaussian (q=0) to Rayleigh (q=1)).
Propagation paths consisting of one strong direct LOC component and many random weaker components- microcellular urban and suburban land mobile, picocellular indoor and factory environments.	Nakagami-n (Rice) (spans range from Rayleigh ($n = 0$) to no fading ($n = •$))
Land mobile indoor mobile multipath propagation as well as ionospheric Nakagami-m (spans range from one-sided Gaussian radio links.	Nakagami-m (spans range from one-sided Gaussian radio links. m = 1/2), Rayleigh(m = 1) to no fading ($m = •$))

Terrain, buildings, trees -urban land mobile systems, land mobile satellite Log-normal shadowing Systems.	Log-normal shadowing
Nakagami-*m* multipath fading superimposed on log-normal shadowing. Composite gamma/log-normal. Congested downtown areas with slow-moving pedestrians and vehicles. Also in land mobile systems subject to vegetative and/or urban shadowing.	Composite gamma/log-normal
Convex combination of unshadowed multipath and a composite multipath/Combined (time-shared) shadowed/unshadowed. Shadowed fading. Land mobile satellite systems.	Combined (time-shared) shadowed/ unshadowed.

Table 4.1 Different Fading Models

V. SIMULATION AND RESULTS

Performance of a Signal

The good, bad, awful performance of various fading channels is represented in terms of Bit error probability versus $\boldsymbol{E_b/N_0}$, as shown [22].

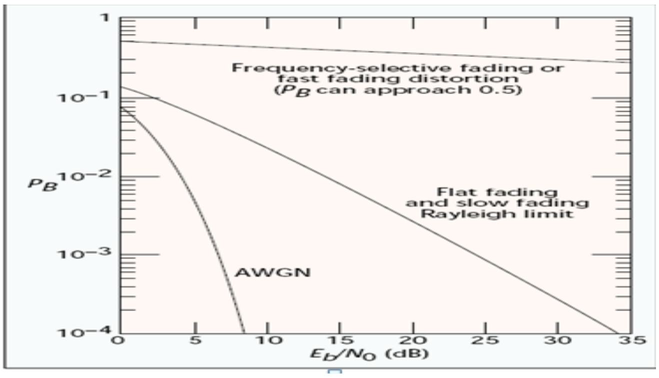


Figure 5.2: Performance of a signal

Mitigation methods to combat distortion

To combat distortion	To combat loss in SNR
Frequency-selective distortion • Adaptive equalization (e.g., decision feedback, Viterbi equalizer) • Spread spectrum — DS or FH • Orthogonal FDM (OFDM) • Pilot signal	**Flat-fading and slow-fading** • Some type of diversity to get additional uncorrelated estimates of signal • Error-correction coding
Fast-fading distortion • Robust modulation • Signal redundancy to increase signaling rate • Coding and interleaving	**Diversity types** • Time (e.g., interleaving) • Frequency (e.g., BW expansion, spread spectrum FH or DS with rake receiver) • Spatial (e.g., spaced receive antennas) • Polarization

Table 5.1 Methods to combat distortion

CONCLUSION & FUTURE SCOPE

In this thesis report, a technique Monte Carlo simulation has been implemented to model the Rayleigh Fading channel.

Firstly, it is done through one of the mathematical tools of Matlab (with the help of Bit error rate tool).Next it is done through Simulation technique with the help of simulation model. Then the various mitigation techniques are applied with Monte Carlo simulation model to combat the distortion of a signal.

The technique proposed here to model the Rayleigh Channel yields better results compared to the existing methods and it takes lesser time to do so. In fact, the problems encountered in the simulation, for generating the Rayleigh Channel are bypassed with a special technique as suggested in this work.

The simulation results show the comparison between various modulation techniques and the results of AWGN channel and Rayleigh channel. With the help various mitigation techniques better BER can be achieved. In terms of diversity it is easy to find a better diversity technique which is suitable for mobile receivers.

The channel simulated here can be useful for the performance comparison, like bit error rate (BER), signal to noise ratio (SNR), of different m-ary modulation schemes such as QPSK, PSK, OFDM… under different fading channels.

Future scope

The technique implemented here, uses the Monte Carlo simulation technique with various mitigation methods to combat the distortion. The procedure is already given in this report itself.

By using mathematical tool like MATLAB, as this thesis gives procedure about Rayleigh channel modeling ,Ricean channel modeling can be done with the help of Monte Carlo Simulation technique which gives practical applicability of this method for the most common situation occurred in mobile communications. With the help of all these mitigation methods better Bit error rates can be achieved.

Depending on the performance optimization and utility of existing and futuristic mobile radio channels it is easy to find a better technique which is suitable for mobile receivers.

As in this work mobile channel modeling is done with signals same technique can be applied on images as well.

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