Performance comparison between different channel models with channel estimation and adaptive equalization using Rayleigh fading channel.

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DECLARATION

I hereby declare that this thesis is based on the results found by our self. Materials of work found by other researcher are mentioned by reference. This thesis, neither in whole nor in part, has been previously submitted for any degree.

Signature of Supervisor

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Sadia Hamid Kazi

Signature of Author

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ABSTRACT

This thesis project is a comparison between the performances of different channel model with modulation, channel estimation, adaptive equalization for both linear and non-linear equalizer and demodulation techniques using slow Rayleigh fading channel with the target to reduce the fading effect for the multi-path wireless network and mobile communications. For channel models we have used flat fading and frequency selective fading (FSF) channel. For the comparison we have tested the effect of different channel models using different conditions under QPSK (Quadrature Phase Shift Keying) modulation with channel estimation, linear and non-linear equalization with Least Mean Squares (LMS) algorithm. We have tested the effect of the channel models using the input data and input image in receiver with BER (bit error rate) and SER (symbol error rate) plots under QPSK modulation. We want to simulate the flat fading channel and frequency selective fading channel in slow Rayleigh fading using a model simulated to GSM (Global System for Mobile Communication) system. We have used GSM carrier frequency and bandwidth and then compare mainly the theoretical BER with the simulated BER through a model with the target to reduce the fading effect of the wireless multi-path channel.

In the project we have used Matlab 7.0 for algorithms and simulations.

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1. INTRODUCTION

In wireless network and mobile communication systems, it is usually assumed that the fading process is a random effect with Rayleigh distribution and thus fading is a very common effect in wireless multi-path system. It is well known that the wireless multi-path channel causes arbitrary time dispersion, attenuation phase shift and rapid fluctuations of the amplitude in the received signal for a short period of time which is known as fading. For any wireless multi-path channel there is a probability of fading so our target was to reduce the fading effect in wireless multi-path channel. Fading is caused by interference between two or more versions of the transmitted signal which arrive at the receiver at slightly different times. Mobile communications and wireless network have experienced massive growth and commercial success in the recent years. However, the radio channels in mobile radio systems are usually not amiable as the wired one. Unlike wired channels that are stationary and predictable, wireless channels are extremely random and time-variant. There are many diversity techniques to address fading issue, such as OFDM, MIMO, RAKE receiver and etc but it may be still necessary to remove the amplitude and phase shift caused by the channel if someone wants to apply linear modulation schemes. In our thesis work we have actually done the channel estimation and linear and non-linear equalization for both the flat and frequency selective fading. The function of channel estimation is to form an estimate of the amplitude and phase shift caused by the wireless channel from the available pilot information and the equalizer removes the channel effect and minimizes the error. Channel estimation methods may be divided into two classes: pilot-based estimation and blind estimation. In our project, we will focus on pilot-based channel estimation with training data.

2. Background on multipath wireless communications and Fading:

2.1 Fading and multipath:

The wireless multi-path channel causes arbitrary time dispersion, attenuation phase shift and rapid fluctuations of the amplitude in the received signal for a short period of time which is known as fading. Fading refers to the distortion that a carrier-modulated telecommunication signal experiences over certain propagation media [13]. In wireless systems, fading is due to multipath propagation and is sometimes referred to as multipath induced fading. To understand fading, it is essential to understand multipath. In wireless telecommunications, multipath is the propagation phenomenon that results in radio signals' reaching the receiving antenna by two or more paths. Causes of multipath include atmospheric ducting, ionospheric reflection and refraction and reflection from terrestrial objects, such as mountains and buildings. The effects of multipath include constructive and destructive interference, and phase shifting of the signal. This distortion of signals caused by multipath is known as fading. In other words it can be said that in the real world, multipath occurs when there is more than one path available for radio signal propagation. The phenomenon of reflection, diffraction and scattering all give rise to additional radio propagation paths beyond the direct optical LOS (Line of Sight) path between the radio transmitter and receiver [21].

2.2 Fading Channels:

For most channels, where signal propagate in the atmosphere and near the ground, the free-space propagation model is inadequate to describe the channel behavior and predict system performance. In wireless system, s signal can travel from transmitter to receiver over multiple reflective paths. This phenomenon, called multipath fading, can cause fluctuations in the received signal’s amplitude, phase, and angle of arrival, giving rise to the terminology multipath fading. Another name, scintillation, is used to describe the fading caused by physical changes in the propagating medium, such as variations in the electron density of the ionosopheric layers that reflect high frequency radio signals. Both fading and scintillation refer to a signal's random fluctuations [22]. A Fading Channel is a communications channel which has to face different fading phenomenon while the signal is carried from the transmitter to the receiver. Fading Channels face a phenomenon called multipath (as described above) which occurs when all the radio propagation effects combine in a real world environment. In other words, when multiple signal propagation paths exist, caused by whatever phenomenon, the actual received signal level is the vector sum of the entire signals incident from any direction or angle of arrival. Some signals will aid the direct path, while other signals will subtract (or tend to vector cancel) from the direct signal path. The total composite phenomenon is thus called Multipath [21].

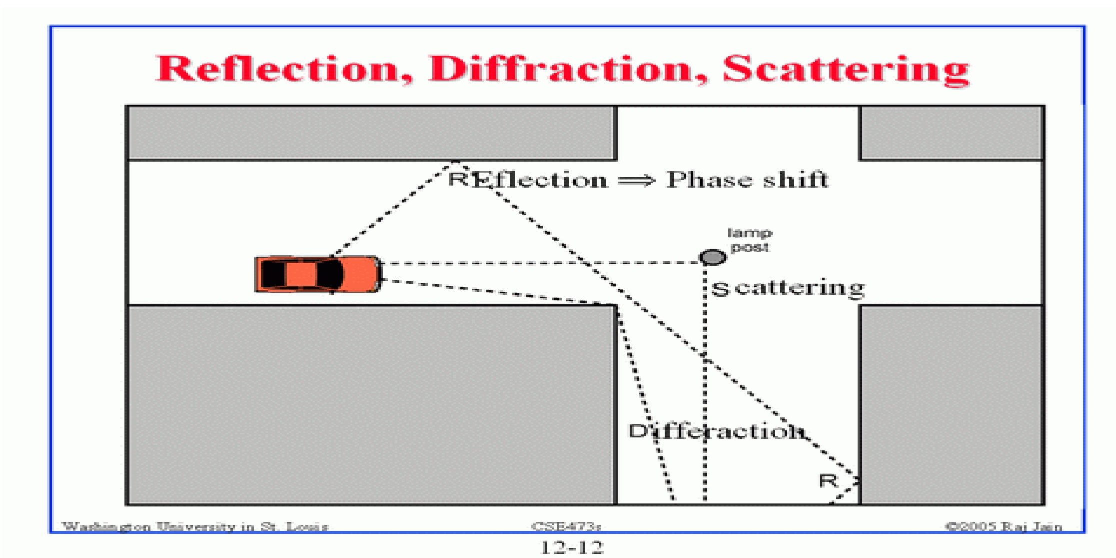
2.3 Causes of fading:

The causes of fading are mainly reflection, diffraction, scattering and Doppler shift.

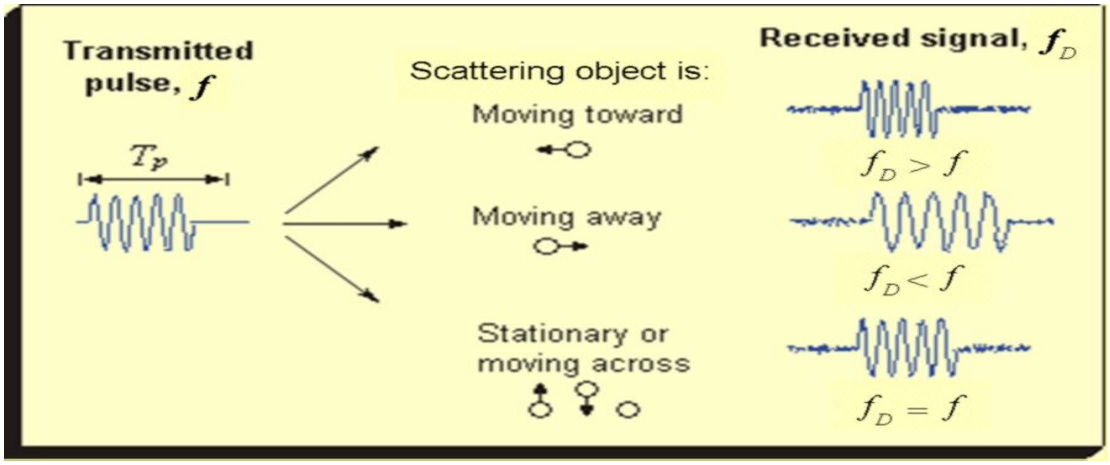
- Reflection
  - Occurs when waves impinges upon an obstruction that is much larger in size compared to the wavelength of the signal
  - Example: reflections from earth and buildings
  - These reflections may interfere with the original signal constructively or destructively

- Diffraction
  - Occurs when the radio path between sender and receiver is obstructed by an impenetrable body and by a surface with sharp irregularities (edges)
  - Explains how radio signals can travel urban and rural environments without a line-of-sight path

- Scattering
  - Occurs when the radio channel contains objects whose sizes are on the order of the wavelength or less of the propagating wave and also when the numbers of obstacles are quite large.
  - They are produced by small objects, rough surfaces and other irregularities on the channel
  - Follows same principles with diffraction
  - Causes the transmitter energy to be radiated in many directions
  - Lamp posts and street signs may cause scattering



2.3.1 Figure 1: Reflection, Diffraction, Scattering



2.3.2 Figure 2: Doppler shift

We simulate both flat fading and frequency selective fading channels by Clarke and Gans fading model [8] which is a property of Rayleigh fading channel. This model helped us to calculate the channel impulse response, Rayleigh distributed envelope and to produce different channels. Here we set velocity to get coherence time for both these two fading channels. In the receiver side, we need channel estimation for flat fading channel. Since we use PSK modulation in our model, the channel phase information in each coherence time need to be estimated .Then source data are adjusted by estimated phase for flat fading channel.

In our work we have used Rayleigh fading and Rayleigh fading is a small-scale effect. There will be bulk properties of the environment such as path loss and shadowing upon which the fading is superimposed [11].

- **2.4 <u>Types of Small-scale Fading(Based on multipath time Delay Spread):</u>**

2.4.1. Flat Fading

1. Bandwidth Signal < Bandwidth of Channel
2. Delay Spread < Symbol Period

2.4.2. Frequency Selective Fading

1. Bandwidth Signal > Bandwidth of Channel

2. Delay Spread > Symbol Period

- **2.5 <u>Types of Small-scale Fading(Based on Doppler Spread):</u>**

2.5.1 <u>Fast Fading</u>

High Doppler Spread, Coherence Time < Symbol Period, Channel variations faster than baseband signal variations

2.5.2 <u>Slow Fading</u>

Low Doppler Spread, Coherence Time > Symbol Period, Channel variations smaller than baseband signal variations [19].

2.6 <u>Small Scale Fading and multipath:</u>

- Small scale fading is caused by interference between two or more versions of transmitted signal which arrive the receiver at slightly different times

- <u>Multipath waves:</u> two or more versions of transmitted signal

- <u>Small scale fading:</u> Rapid change in signal strength over short distance or time, random frequency modulation due to varying Doppler shifts of different multipath signals, time dispersion caused by multipath delays, multipath varying in time due to the movements

- <u>Factors influencing small scale fading:</u> Multipath propagation, Speed of mobile, speed of surrounding objects, transmission bandwidth of the signal [17] [20].

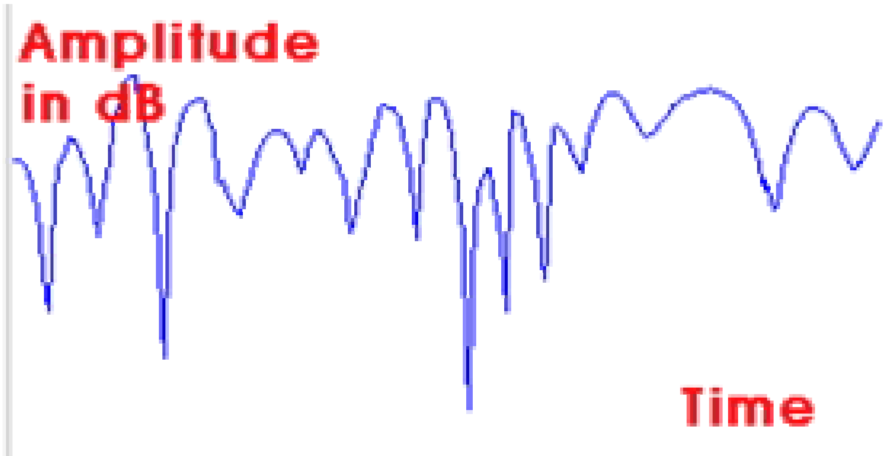
3. <u>Rayleigh fading:</u>

3.1 <u>Rayleigh fading and its characteristics:</u>

Rayleigh fading describes the received signal envelope distribution where all the components are non line of sight.

The basic model of Rayleigh fading assumes a received multipath signal to consist of a (theoretically infinitely) large number of reflected waves with independent and identically distributed inphase and quadrature amplitudes. This model has played a major role in our understanding of mobile propagation [23]. The mobile or indoor radio channel is characterized by 'multipath reception': The signal offered to the receiver contains not only a direct line-of-sight radio wave, but also a large number of reflected radio waves. Even worse in urban centers, the line-of-sight is often blocked by obstacles, and a collected of differently delayed waves is all what is received by a mobile antenna. These reflected waves interfere with the direct wave, which causes significant degradation of the performance of the link. If the antenna moves the channel varies with location and time, because the relative phases of the reflected waves change. This leads to fading: time variations of the received amplitude and phase. In a non-fading (thus fixed) radio channel the BER decreases rapidly when the signal-to-noise (or signal-to-interference) ratio is increased. In a fading channel, every now and then the received signal is very weak and many bit errors occur. This phenomenon remains present, even if the (average) signal-to-noise ratio is large. So the BER only improves very slowly, and with a fixed slope, if plotted on a log-log scale. (Diversity or error correction can help to make the slope steeper, hence improve performance.) A wireless system has to be designed in such way that the adverse effect of multipath fading is minimized. In the past, multipath has notoriously hindered the development of reliable and inexpensive mass-product systems [23].

Rayleigh fading can be a useful model in heavily built-up city centers where there is no line of sight between the transmitter and receiver and many buildings and other objects attenuate, reflect, refract and diffract the signal [11]. Rayleigh fading is a small-scale effect. There will be bulk properties of the environment such as path loss and shadowing upon which the fading is superimposed [11]. How rapidly the channel fades will be affected by how fast the receiver and/or transmitter are moving. Motion causes Doppler shift in the received signal components [11].



3.1.1 Figure 3: Rayleigh fading

This is a typical Rayleigh fading shape. For operating frequencies for GSM mobile phones when the velocity is increasing the Doppler shift is increasing and in One second of Rayleigh fading the Doppler shift will be higher.

3.2 <u>Channel Models:</u>

Mainly we have used flat fading and frequency selective fading. So we simulate two different channels:

1. Rayleigh flat slow fading channel
2. Rayleigh frequency selective slow fading channel.

In flat fading, the coherence bandwidth of the channel is larger than the bandwidth of the signal. Therefore, all frequency components of the signal will experience the same magnitude of fading.

In frequency-selective fading, the coherence bandwidth of the channel is smaller than the bandwidth of the signal. Different frequency components of the signal therefore experience decorrelated fading [13]. Frequency selective fading is a radio propagation anomaly caused by partial cancellation of a radio signal by itself — the signal arrives at the receiver by two different paths, and at least one of the paths is changing (lengthening or shortening). This typically happens in the early evening or early morning as the various layers in the ionosphere move, separate, and combine. The two paths can both be sky wave or one be ground wave [12].

When there is no fading it can be considered as AWGN channel and AWGN channel is very straightforward by just add a white Gaussian noise into signal to meet specified SNR. As our target was to reduce the fading effect, so we have worked on flat and frequency selective fading.

4. The methods of controlling delay spread in GSM system:

In our project, we have used GSM values to simulate and the GSM system handles the delay spread using Adaptive channel equalization and Channel estimation using training sequence [10]. We build up a slow fading channel for both flat fading and frequency selective fading and we have chosen two different environments to simulate them [15]. We have used RMS (root mean square) delay spread $\sigma\tau$, symbol period Ts and coherence time Tc.

5. Parameters of Mobile multipath Channels:

In order to compare different multipath channels we need parameters which quantify the multipath channel, they are:

5.1 Parameters:

Delay spread, Coherence bandwidth, Doppler spread, Coherence time [16].

Delay spread is the time difference between the arrival moment of the first (not necessarily always first) and the last multipath component. RMS delay spread is the time difference between mean and maximum excess delay. Excess delay is defined as the time delay value after which the multipath energy falls to X dB (a certain value) below the maximum multipath energy (not necesarily belonging to the first arriving component). Symbol period is the time duration of the symbol and coherence time is the time where all channel impulses are essentially invariant.

6. Scenarios or environments and the necessary values:

We wanted to simulate two different scenarios or environments: Urban and Sub-Urban, so that we can find out the effects, differences and characteristics of the two models very well [8].

We have got $\sigma\tau << Ts << Tc$ for a slow flat fading channel and $Ts < \sigma\tau < Tc$ for slow frequency selective fading channel. We choose a model simulated to GSM. We want to simulate two different channels flat fading and frequency selective fading channels using slow Rayleigh fading channel using a model simulated to GSM (Global System for Mobile Communications) system where the carrier frequency is 900 MHz and bandwidth of each channel is 200KHz and then compare mainly the theoretical BER (bit error rate) with the simulated BER. In Our simulation we have used the randomly produced data and the image to test the impact of mainly the BER performance for comparison between different channels. We have compared the results and analyses of the performance improvement with channel estimation and adaptive equalization in slow Rayleigh fading channel. In our model, we used quadrature phase shift keying QPSK modulation [7] which is a two bits per symbol representation to modulate the data.

6.1 Necessary parameter values to simulate GSM:

carrier frequency	900 MHz
Bandwidth per channel	200 KHz
Symbol period	5.00e-06 second

Using typical measured values we have simulate two scenarios: Urban and Sub-Urban [8].

6.2 Urban environment:

In the Urban environment, we simulate an environment, where RMS delay spread is 10 us and the user has the velocity of 5km/hr [18]. Now Tc =

9/(16*pi*fm) = 9*C/ (16*pi*fc*v) = 42.9ms. So it is a slow frequency selective fading channel.

6.3 Sub-Urban environment:

In the Sub-Urban environment, we simulate the environment, where RMS delay spread is 300ns and the user has a velocity of 20km/hr [18]. For 20km/hr, Tc = 9/(16*pi*fm) = 9*C/ (16*pi*fc*v)= 10.7ms, so it is a slow flat fading channel. In total we have calculated velocities for flat = 20 km/hr, frequency selective = 5 km/hr.

We have taken the BER- bit error rate, SER- symbol error rate and STD- standard deviation result for both flat and FSF. But we mainly emphasized on BER.

In both above two scenario, we suppose there are no dominant stationary (non-fading) signal component present at receiver side, such as a line-of-sight propagation path, and the fading follow a Rayleigh distribution, so both of them are slow Rayleigh fading channel.

For flat fading channel, N samples of complex Gaussian random variable are produced by directly generating N* fd/fs numbers of complex Gaussian random variable in frequency domain and h represents the channel impulse response with N samples. It is easy to prove that in N points IFFT, with sampling rate fs and Doppler shift fd, there are only N *fd/fs points of non-zero value in frequency domain.

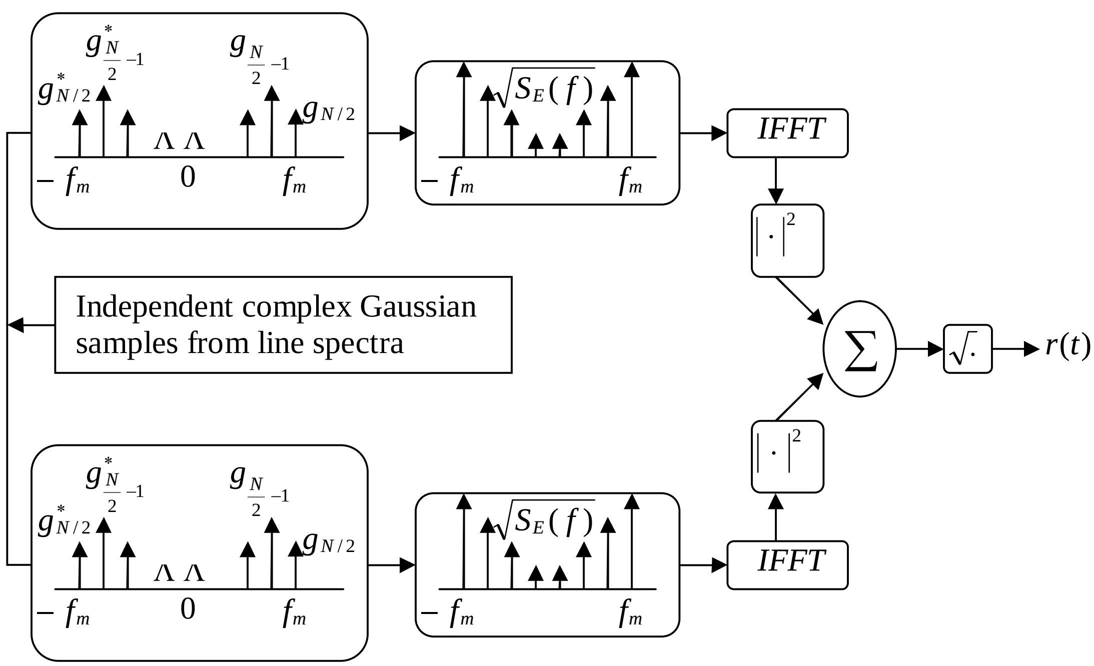
7. Simulation using Clarke and Gans fading model:

In the simulation we have used the Clarke and Gans fading model which is a property of Rayleigh fading channel, to get our result. A popular simulation method uses the concept of in-phase and quadrature modulation paths to produce a simulated signal with spectral and temporal characteristic very close to measured data. As shown in figure 4, two independent Gaussian low pass noise sources are used to produce in-phase and quadrature fading branches [9]. Each Gaussian source may be formed by summing two independent Gaussian random variables which are orthogonal .By using the spectral filter defined by equation

(1.1) For Doppler spectrum to shape the random signals in the frequency domain, accurate time domain waveforms of Doppler fading can be produced by using an inverse fast fourier transform (IFFT) at the last stage of the simulator.

$$S_E(f) = \frac{1.5}{\pi\, f_{\max}\sqrt{1-\left(\dfrac{f-f_f}{f_{\max}}\right)^2}}, \tag{1.1}$$

The method in Figure 4 uses a complex Gaussian random number generator (noise source) to produce a baseband line spectrum with complex weight in the positive frequency band. The maximum frequency component of the line spectrum is f_m . Using the property of real signals, the negative frequency component are constructed by simply conjugating the complex Gaussian values obtained for the positive frequencies .IFFT of the signal is purely real Gaussian random process in the time domain which is used in one of the quadrature arms shown in Figure 4. The random valued line spectrum is then multiplied with a discrete frequency representation of $\sqrt{S_E(f)}$ having the same number of points as the noise source.



7.1 Figure 4: Frequency domain implementation of a Rayleigh fading simulator at baseband.

To handle the case where equation (1.1) approaches infinity at the passband edge, the value of $S_E(f_m)$ is truncated by computing the slope of the function at the sample frequency just prior to the passband edge and extended the slope to the passband edge. Simulation using the architecture in Figure 4 is usually implemented in the frequency domain using complex Gaussian line spectra to take advantage of easy implementation of equation (1.1). This, in turn, implies that the low pass Gaussian noise components are actually a series of frequency components (line spectrum from $-f_m$ to f_m), which are equally spaced and each have a complex Gaussian weight.

7.2 <u>Steps of model:</u>

To implement the simulator shown in Figure 4 the following step are used [9]:

1- Specify the number of frequency domain points (N) used to represent $\sqrt{S_E(f)}$ and the maximum Doppler frequency shift (f_m).The value used for N is usually a power of 2.

2- Compute the frequency spacing between adjacent spectral lines as $\Delta f = 2f_m/(N-1)$ .This defines the time duration of a fading waveform, $T = 1/\Delta f$.

3- Generate complex Gaussian random variables for each of the $N/2$ positive frequency component of the noise source.

4- Construct the negative frequency components of the noise source by conjugating positive frequency values and assigning these at negative frequency values.

5- Multiply the in-phase and quadrature noise sources by the fading spectrum $\sqrt{S_E(f)}$.

6- Perform an IFFT on the resulting frequency domain signals from the in-phase and quadrature arms to get two N-length time series, and add the squares of each signal point in time to create an N-point time series like under the radical of equation :

$$|E_z(t)| = \sqrt{T_c^2(t) + T_s^2(t)} = r(t), \qquad (1.2)$$

7- Take the square root of the sum obtained in step 6 to obtain an N point time series of a simulated Rayleigh fading signal with the proper Doppler spread and time correlation.

We have compared between the flat fading channel and frequency selective fading channels for the BER of simulation vs. (versus) theoretical result. After the source data is produced, the pilot data is inserted into head of source data in each coherence time. It is used to estimate the random data shift of the fading channel and to adjust the received signal with recover result. We have used maximum 10 DB (0-10 DB) here while doing simulation. In our simulation, we set the pilot data as 8% of the total data length (pilot data plus source data) [3]. The training data is inserted into the head of the source data in each coherence time. In each coherence time we have taken the training sequence part as ones and sent it before the main data. We have produced the flat and frequency selective fading channels using following equation:

Fading received signal= (sent signal * channel impulse response) + noise.

For noise we have used AWGN (additive white Gaussian noise) here which is a white noise. The additive white Gaussian noise (AWGN) channel model is one in which the only impairment is the linear addition of wideband or white noise with a constant spectral density (expressed as watts per hertz of bandwidth) and a Gaussian distribution of amplitude [14]. Without fading which is the AWGN channel, is very straightforward by just add a white Gaussian noise into signal to meet specified SNR. We simulate both flat fading and frequency selective fading channels by Rayleigh fading model.

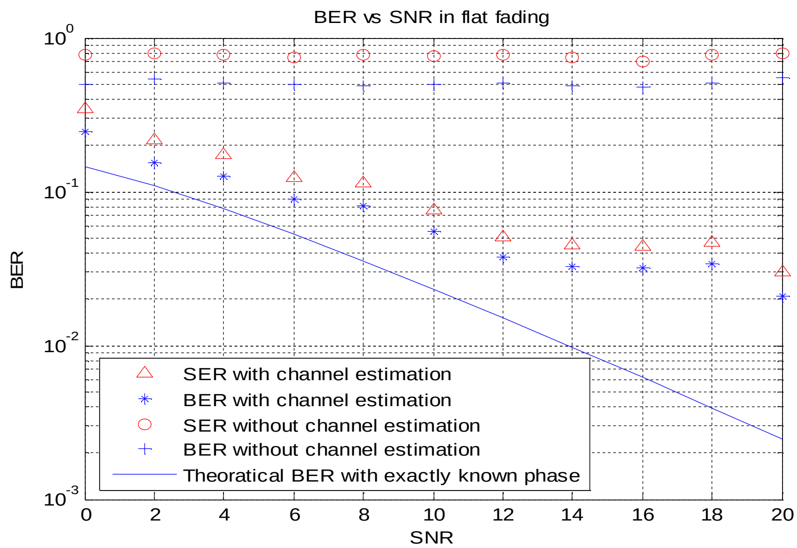
Channel estimation

8. Flat fading channel with Channel estimation:

Flat with velocity=20:

For flat fading, channel estimation has been used to get the better result [6].

8.1 Using data



8.1a Figure-5: BER of simulation vs. theoretical using data

Velocity	20
Ts	5.0000e-006
Tc	10.7e-003
Symbols per coherent time	2140
Training percentage	0.0800
Number of one time data	1969
Number of one time training	171

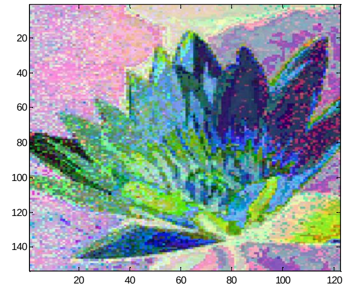
We have calculated the training data for each symbol and got 171 training data per symbol.

- Tc/Ts = 2140 @ 20km/hr *(.08)=171 training data

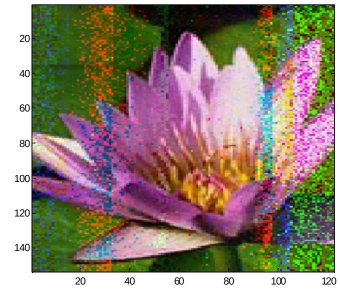
We have got error, mean error, error amplitude using the training data and adjusted the phase and amplitude by using absolute and mean error values.

8.2 Using image

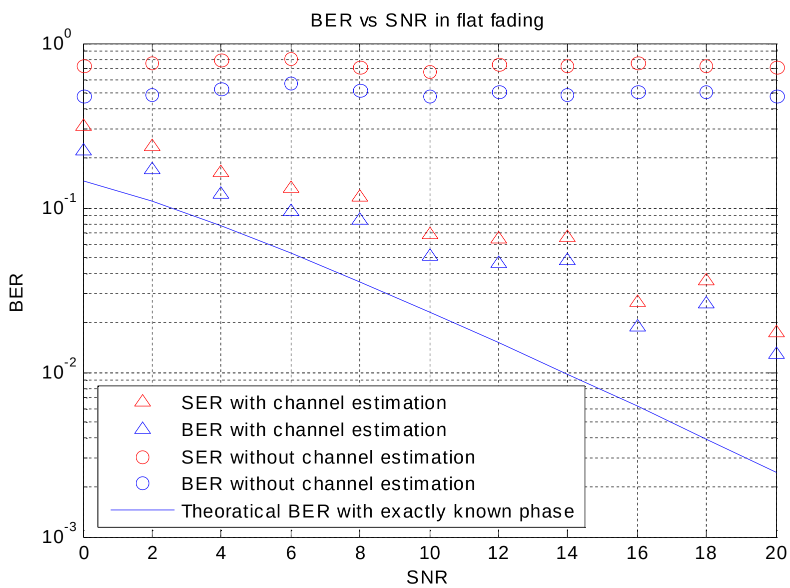
Input image



Received without estimation



Received with estimation



BER vs. SNR graph

8.2a Figure 6: Flat fading channel with and without Channel estimation using image

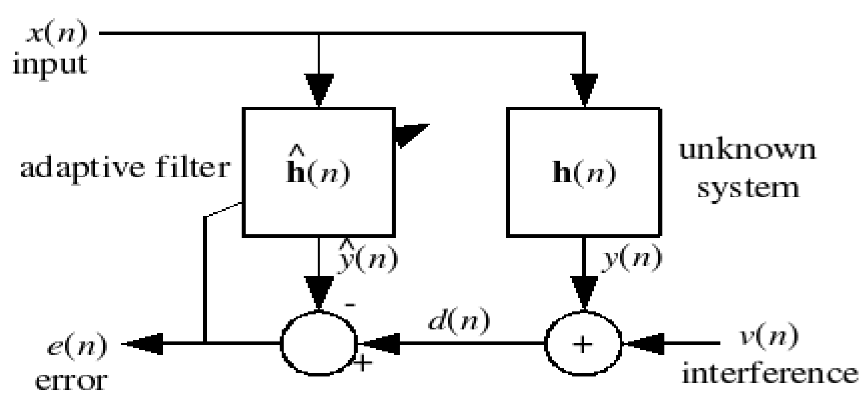
8.3 Performance of Flat fading channel with and without Channel estimation:

Here the BER and SER plots are shown for both with and without channel estimation. The BER performance of simulation result is worse than theoretical BER. However, due to the time-variant channel, we always have estimation error. For BER of simulation vs. theoretical the BER performance of simulation result is worse than theoretical BER since we do not know exactly the channel phase information and BER performance is improved dramatically in low SNR, while not in high SNR. Since in low SNR, white Gaussian noise dominate the BER error, which can be improved by enhancing SNR; while in high SNR, phase estimation error dominate the BER error, which can not be improved by simply enhancing SNR. For image quality of received vs. adjusted, the received image is plot at SNR = 25dB, we see that other than some random noise, there is some block noise in the image. This is due to the phase estimation error in a coherence time. For BER of Image vs. random data the correlation between image pixels does not affect the BER in flat fading channel.

Adaptive equalization

9. Frequency selective fading channel with adaptive equalization:

We have used LMS (least mean squares) algorithm in training mode for frequency selective fading channel [4]. An adaptive filter is a filter that self-adjusts its transfer function according to an optimizing algorithm. Because of the complexity of the optimizing algorithms, most adaptive filters are digital filters that perform digital signal processing and adapt their performance based on the input signal. By way of contrast, a non-adaptive filter has static filter coefficients (which collectively form the transfer function) [1]. Least mean squares (LMS) algorithms are used in adaptive filters to find the filter coefficients that relate to producing the least mean squares of the error signal (difference between the desired and the actual signal). It is a stochastic gradient descent method in that the filter is only adapted based on the error at the current time.



9a Figure: Simple Linear equalizer

Most linear adaptive filtering problems can be formulated using the block diagram above. That is, an unknown system is to be identified and the adaptive filter attempts to adapt the filter to make it as close as possible to , while using only observable signals x(n), d(n) and e(n); but y(n), v(n) and h(n) are not directly observable. The idea behind LMS filters is to use the method of steepest descent to find a coefficient vector which minimizes a cost function. We start the discussion by defining the cost function as

$$C(n) = E\left\{|e(n)|^2\right\}.$$

$C(n) = E\left\{|e(n)|^2\right\}$ is the mean squared error, where e(n) is defined in the block diagram section of the general adaptive filter and E{.} denotes the expected value.

For most systems the expectation function $E\left\{\mathbf{x}(n)\,e^*(n)\right\}$ must be approximated. This can be done with the following unbiased estimator

$$\hat{E}\left\{\mathbf{x}(n)\,e^*(n)\right\} = \frac{1}{N}\sum_{i=0}^{N-1}\mathbf{x}(n-i)\,e^*(n-i)$$

where *N* indicates the number of samples we use for that estimate. The simplest case is *N* = 1

$$\hat{E}\left\{\mathbf{x}(n)\,e^*(n)\right\} = \mathbf{x}(n)\,e^*(n)$$

For that simple case the update algorithm follows as

$$\hat{\mathbf{h}}(n+1) = \hat{\mathbf{h}}(n) + \mu\mathbf{x}(n)\,e^*(n)$$

Indeed this constitutes the update algorithm for the LMS filter.The LMS algorithm for a *p*th order algorithm can be summarized as

Parameters:	*p* = filter order
	μ = step size
Initialization:	$\hat{\mathbf{h}}(0) = 0$

Computation: For n = 0,1,2,...

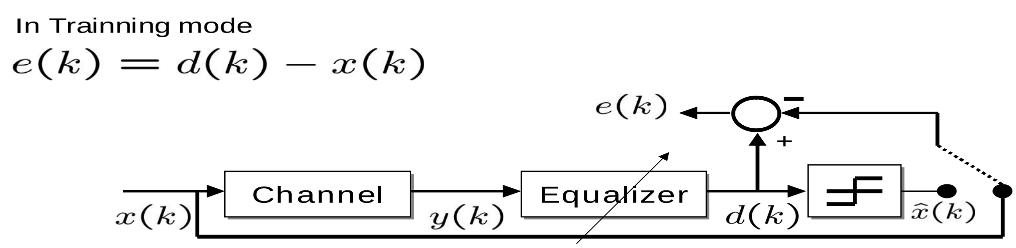
$$\mathbf{x}(n) = [x(n), x(n-1), \ldots, x(n-p+1)]^T$$

$$e(n) = d(n) - \hat{\mathbf{h}}^H(n)\mathbf{x}(n)$$

$$\hat{\mathbf{h}}(n+1) = \hat{\mathbf{h}}(n) + \mu\, e^*(n)\mathbf{x}(n)$$

where $\hat{\mathbf{h}}^H(n)$ denotes the Hermitian transpose of $\hat{\mathbf{h}}(n)$ [2]. In linear equalization the current and past values of the received signal are linearly weighted by equalizer coefficients and summed to produce the output and error is calculated from the known training sequence and from the product of weight and input

LINEAR EQUALIZER



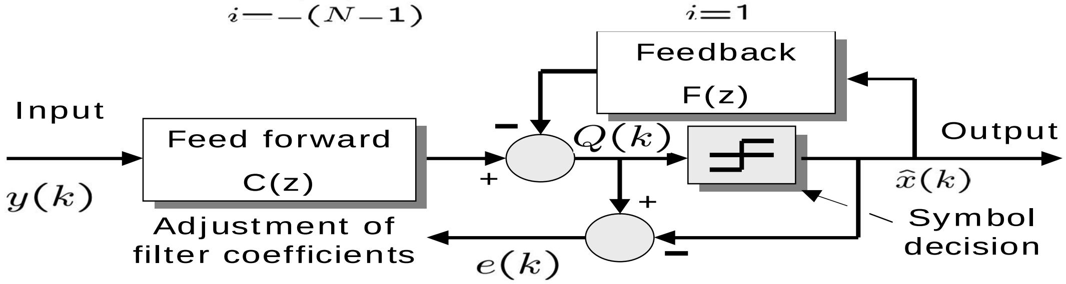
9b Figure: Simple linear equalizer

We have used decision feedback equalizer (DFE) here for non linear equalization.

Decision-Feedback Equalizer:

- The forward and feedback coefficients may be adjusted simultaneously to minimize the error.

$$Q(k) = \sum_{i=-(N-1)}^{0} c_i y(k-i) - \sum_{i=1}^{M} f_i \widehat{x}(k-i)$$



$$e(k) = Q(k) - \hat{x}(k)$$

9c Figure: Simple Decision feedback equalizer

In non linear equalization the error is calculated from the feedforward and feedback values with input and output respectively and from equalizer decision output.

9.1 <u>LMS algorithm steps:</u>

Equalizer output: $y[n] = \sum_{k=0}^{M-1} u[n-k] w_k^*[n]$

Estimation error: $e[n] = d[n] - y[n]$

Weight adaptation: $w_k[n+1] = w_k[n] + \mu u[n-k] e^*[n]$

New weights = Previous weights + (stepsize *Previous error * current input) (Stochastic Gradient Algorithm)

Previous error= Previous desired output - Previous actual output

y[n] is the output, w[k] is the weight of the equalizer, e[n] is the error, u[n-k] is the input.

We have used linear equalization in training only mode and non-linear equalization in decision directed mode [5]. For linear equalization we have used simple linear equalizer and for non-linear equalization we have used decision feedback equalizer (DFE).

In non-linear equalization both the feedforward and feedback weights are used but in linear equalization there are no feedback weights.

We have used 8 weights for linear equalizer and 8 feedforward and 7 feedback weights for non-linear equalizer.

Training Mode:

To make equalizer suitable in the initial acqusition duration, a training signal is needed. In this mode of operation, the transmitter generates a data symbol sequence known to the receiver.

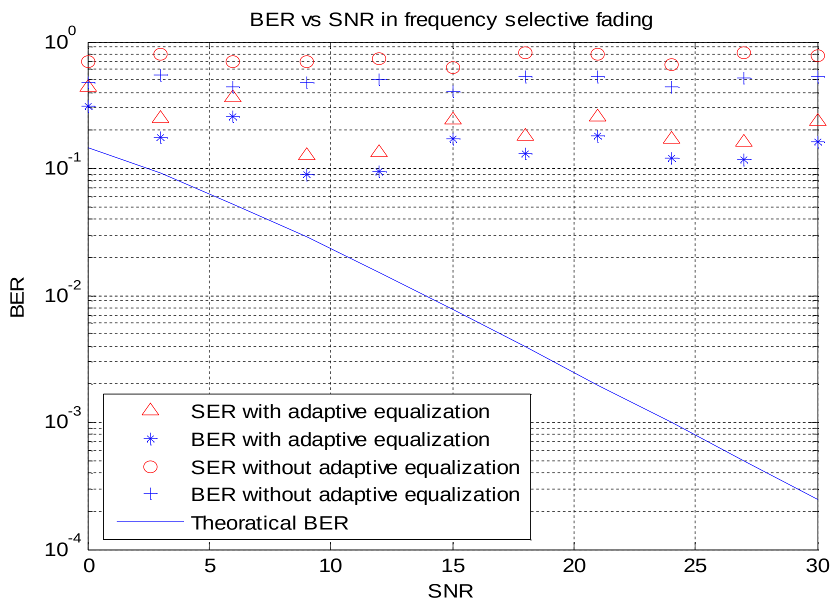
Decision Directed Mode:

The receiver decisions are used to generate the error signal. Decision directed equalizer adjustment is effective in tracking slow variations in the channel response. However, this approach is not effective during initial acqusition .The basic idea is that if the values of the symbols already detected are known and assuming the past decisions are correct, then the ISI contributed by these symbols can be canceled exactly.

FSF with velocity=5:

9.2 FSF for linear equalization in training only mode :

9.2.1 Using data:



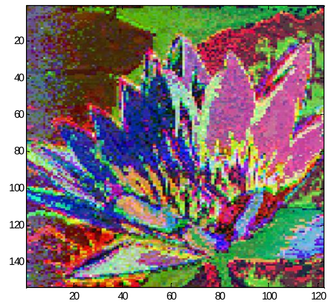
9.2.1a Figure-7: BER of simulation vs. theoretical with LMS in training mode.

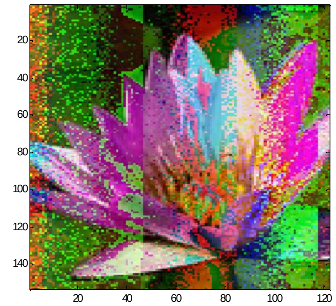
Tc	42.9e-003
Ts	5.0000e-006
Training percentage	0.0800
Number of one time training	686
Number of one time data	7894
Symbols per coherent time	8580
Velocity	5
Stepsize	0.01

We have calculated the training data for each symbol and got 686 training data per symbol.

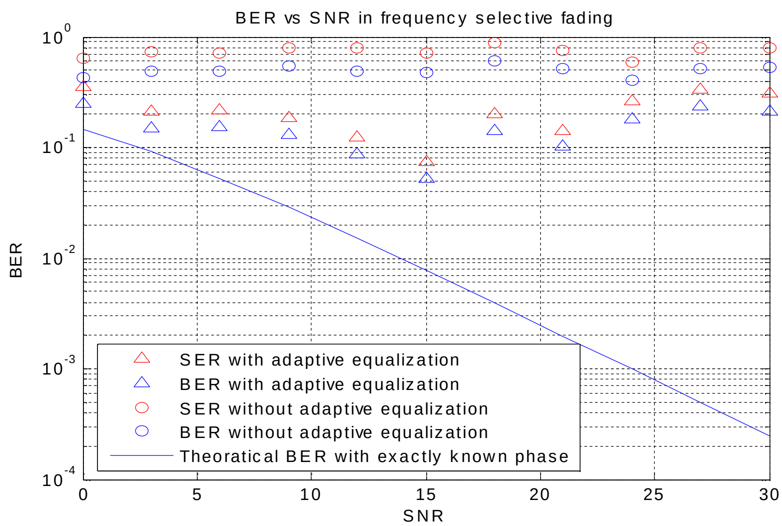
- Tc/Ts = 8580 @ 5km/hr *(.08)= 686 training data

9.2.2 Using image for linear equalization:





Input without using linear equalizer using linear equalizer

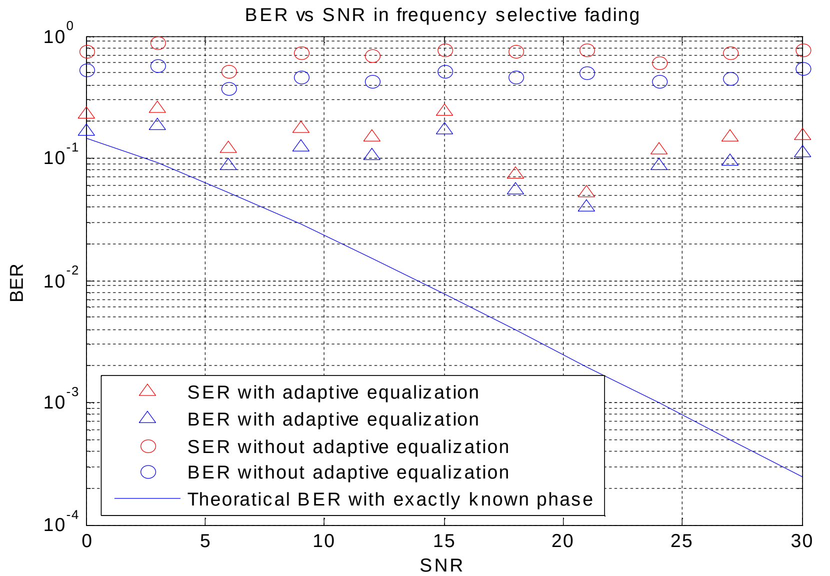


BER vs. SNR graph

9.2.2a Figure 9: Frequency selective fading channel with and without linear equalization

9.3 FSF in decision directed mode for non-linear equalization:

9.3.1 Using data:



9.3.1a Figure-8: BER of simulation vs. theoretical with LMS in DFE mode.

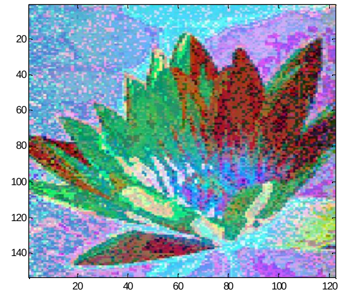
Tc	42.9e-003
Ts	5.0000e-006
Training percentage	0.0800
Number of one time training	686
Number of one time data	7894
Symbols per coherent time	8580
Velocity	5
Stepsize	0.01

We have calculated the training data for each symbol and got 686 training data per symbol.

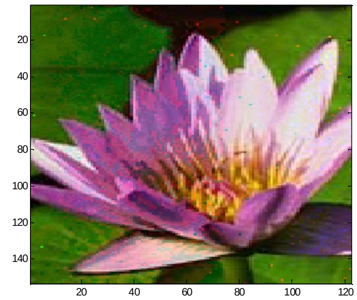
- Tc/Ts = 8580 @ 5km/hr *(.08)= 686 training data

9.3.2 Using image for non-linear equalization:

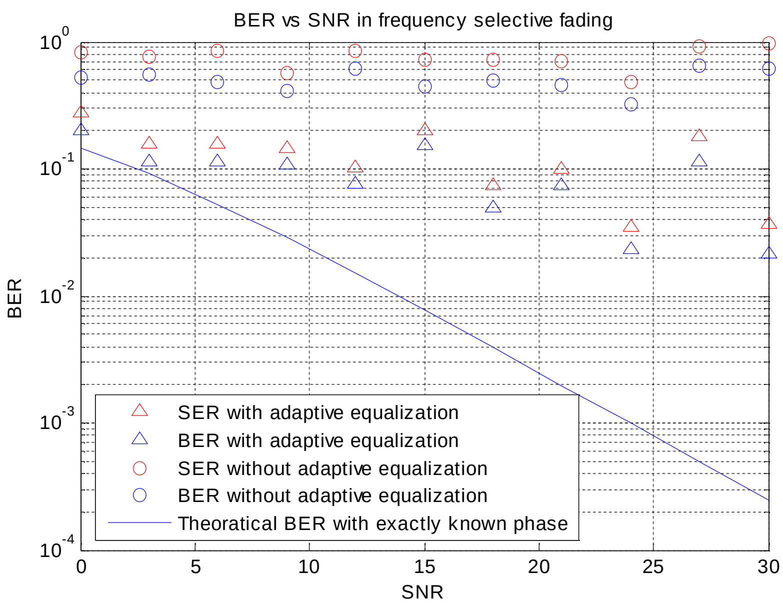
Input



without using DFE



using DFE



BER vs. SNR graph

9.3.2a Figure 10: Frequency selective fading channel with and without non-linear equalization

9.4 Performance of Frequency selective fading channel with and without non-linear equalization:

For BER of simulation vs. theoretical BER performance of simulation result is worse than theoretical BER. The reason is same from above reason addressed in flat fading channel. Different from in flat fading channel, the BER performance is improved dramatically in low SNR, while even degraded in high SNR. This is also reasonable, since in high SNR, phase estimation error and ISI (Inter symbol interference) dominate the BER error, and the estimation error will cause even severe ISI, which cause the BER even worse. In non-linear equalization using DFE the image and data results are better than linear equalization as in DFE both the feedforward and feedback weights are used.

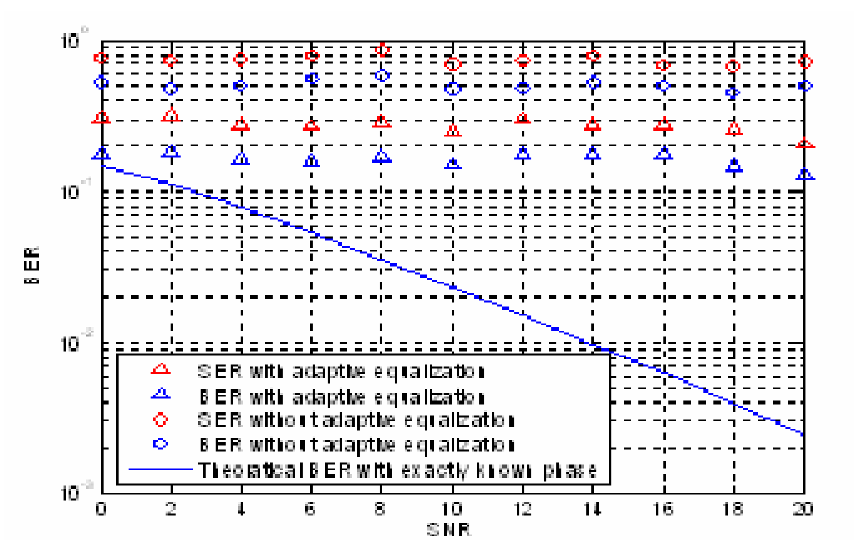
Adaptive equalization

10. Flat fading channel with adaptive equalization:

10.1 Flat fading channel with linear equalization:

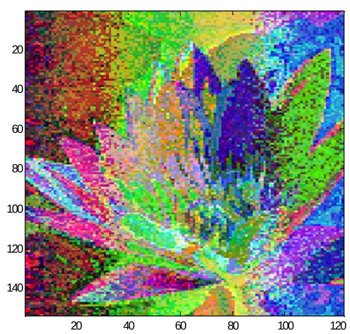
Flat fading channel with linear equalization in training only mode and non-linear equalization in decision directed mode were done in the same way as the frequency selective fading channel described above.

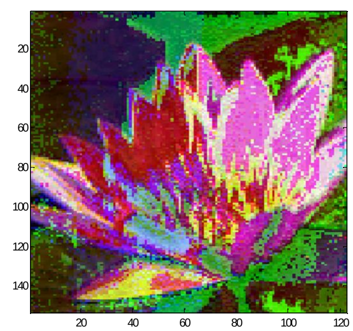
10.1.1 Using data:



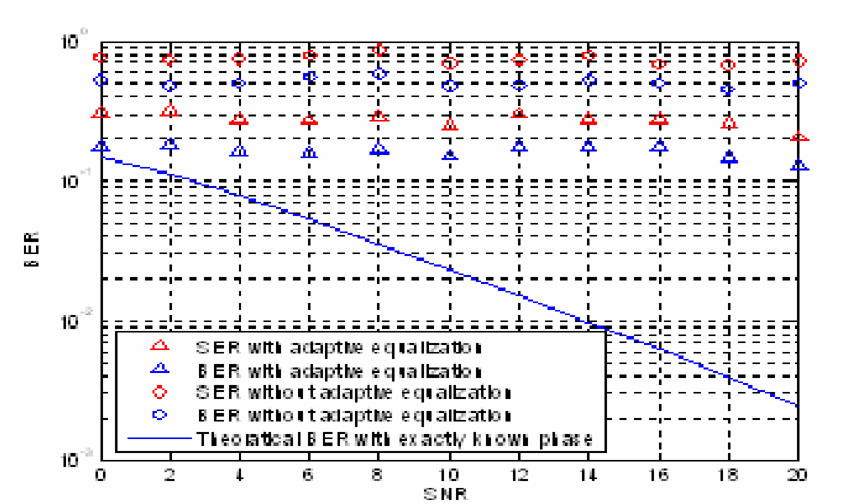
10.1.1a Figure: BER vs. SNR graph

10.1.2 Using image:





Input   without using linear equalizer   using linear equalizer

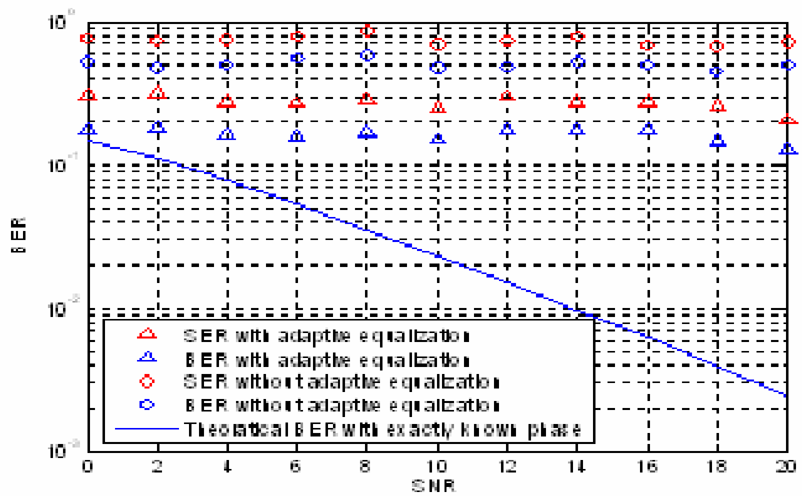


BER vs. SNR graph

10.1.2a Figure 11: Flat fading channel with linear equalization with image

10.2 <u>Flat fading channel with non-linear equalization (DFE):</u>

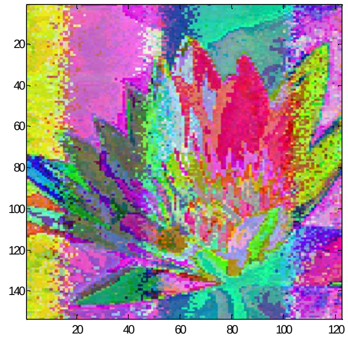
10.2.1 <u>Using data:</u>



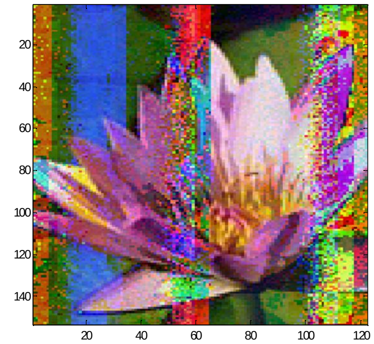
10.2.1a Figure: BER vs. SNR graph

10.2.2 <u>Using image:</u>

Input



without using DFE



using DFE

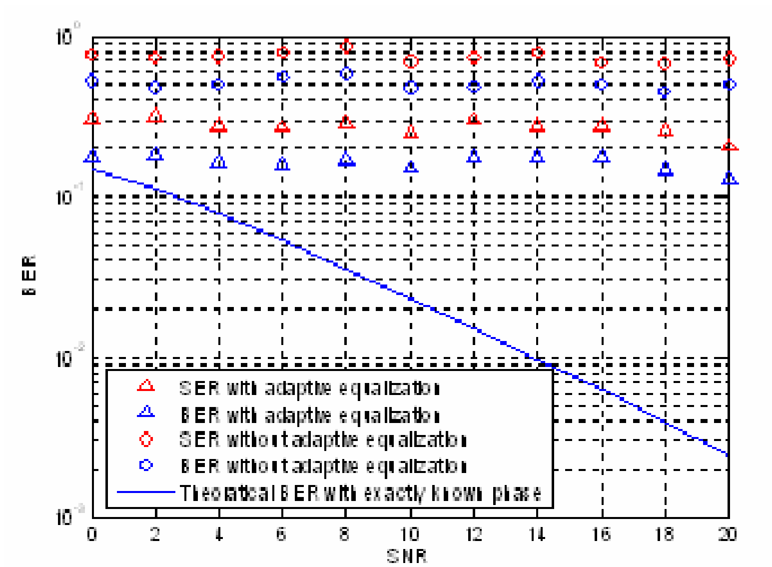


Figure: BER vs. SNR graph

10.2.2a Figure 12: Flat fading channel with non-linear equalization (DFE) with image

10.3 <u>Performance of Flat fading channel with non-linear equalization (DFE):</u>

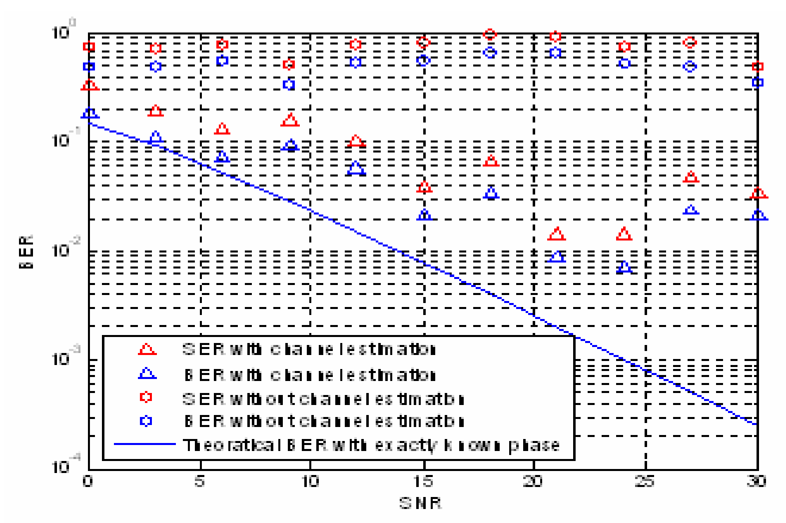
For BER of simulation vs. theoretical BER performance of simulation result is worse than theoretical. The reason is same from above reason addressed in flat fading channel. Different from in flat fading channel, the BER performance is improved dramatically in low SNR, while even degraded in high SNR. This is also reasonable, as in high SNR, phase estimation error and ISI dominate the BER error and the estimation error will cause even severe ISI, which cause the BER even worse. In non-linear equalization using DFE the image and data results are better than linear as in DFE both the feedforward and feedback weights are used.

Channel estimation

11. Frequency selective fading (FSF) channel with Channel estimation:

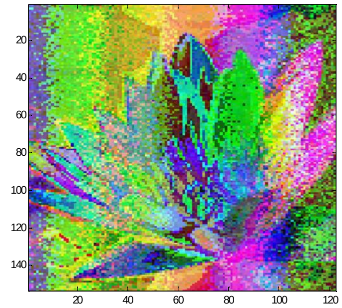
FSF channel with Channel estimation was done in the same way as done in Flat fading channel.

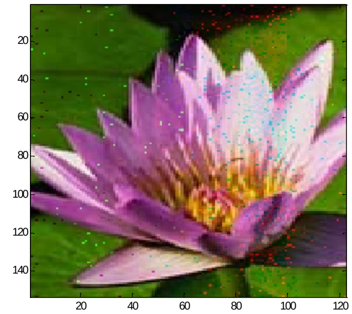
11.1 Using data:



11.1a Figure: BER vs. SNR graph

11.2 Using image:





Input without estimation with estimation

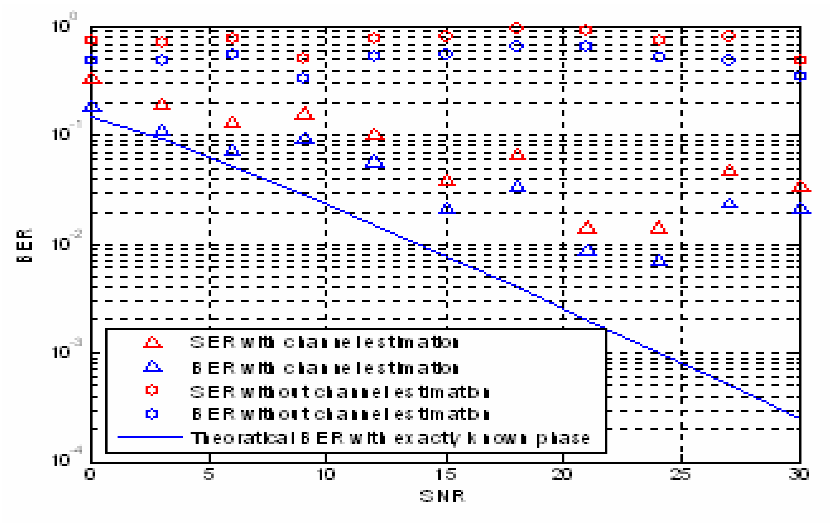


Figure: BER vs. SNR graph

11.2a Figure 13: Frequency selective fading channel with Channel estimation with image

11.3 <u>Performance of Frequency selective fading channel with Channel estimation:</u>

Here the BER and SER plots are shown for both with and without channel estimation. The BER performance of simulation result is worse than theoretical BER. However, due to the time-variant channel, we always have estimation error. For BER of simulation vs. theoretical the BER performance of simulation result is worse than theoretical BER since we do not know exactly the channel phase information and BER performance is improved dramatically in low SNR, while not in high SNR. Since in low SNR, white Gaussian noise dominate the BER error, which can be improved by enhancing SNR; while in high SNR, phase estimation error dominate the BER error, which can not be improved by simply enhancing SNR. For image quality of received vs. adjusted, the received image is plot at SNR = 25dB, we see that other than some random noise, there is some block noise in the image. This is due to the phase estimation error in a coherence time. For BER of Image vs. random data the correlation between images pixels does not affect the BER in flat fading channel. In FSF the result of received image is better than flat with channel estimation.

12. Numerical Data Table:

Method	Channel	Velocity	Data					Image				
			std	ber	ber_without	ser	ser_without	std	ber	ber_without	ser	ser_without
Channel Estimation	FLAT	20	1.120	.0607	.5035	.1082	.7384	1.069	.0598	.4843	.1067	.7255
	FSF	5	1.119	.0402	.4913	.0704	.7422	1.067	.0400	.4849	.071	.7431
Equalization (LINEAR)	FLAT	20	1.120	.1643	.5113	.283	.7603	1.069	.1679	.4758	.2849	.7319
	FSF	5	1.119	.1435	.5234	.2443	.7725	1.067	.0887	.5137	.1553	.7524
Equalization (DFE)	FLAT	20	1.120	.1706	.4938	.2932	.7573	1.069	.1644	.5017	.2829	.7532
	FSF	5	1.119	.1116	.4812	.1569	.7301	1.066	.0957	.5156	.1337	.7768

BER- bit error rate, SER- symbol error rate, STD- standard deviation

We have taken the BER, SER and STD values to compare between flat and frequency selective fading channels. But we have mainly emphasized on BER. It is very difficult to make the correct decisions by just taking and looking at the images and BER vs. SNR graphs. For this reason we have taken the numerical data values based on the computer simulations. Now if we take a comparison between Equalization (DFE) to test the BER effect of the data then the results are:

FLAT	.1706
FSF	.1116

As Flat BER is 0.1706 is greater than FSF BER 0.1116 so FSF is showing the better result.

Again for Channel estimation the BER effect of images are:

FLAT	.0598
FSF	.0400

Here as Flat BER is 0.0598 is greater than FSF BER 0.0400, so again the FSF is showing the better result.

In most of the cases we have found that FSF has less error and thus have the better result than Flat after the channel estimation and adaptive equalization (both linear and non-linear) methods are used. Here we have got the best result in non-linear equalization using DFE in the FSF than all other results.

13. CONCLUSION

In this project, we have tested the effect of two different channel models, flat fading channel and frequency selective fading channel. We have used the GSM values to simulate under urban and Sub-urban environments and tried to reduce the fading effect caused by the channel using two methods: channel estimation and adaptive equalization. In channel estimation for both flat and FSF, the BER and SER plots are shown for both with and without channel estimation and the BER performance of simulation result is worse than theoretical and BER performance is improved dramatically in low SNR. In adaptive equalization the BER performance of simulation result is worse than theoretical and BER performance is improved dramatically in low SNR. In flat fading channel, the image is degraded by random noise and block noise; in frequency selective fading channel, the image is degraded by random noise, block noise, and ISI. In most of the cases we have found that FSF has less error and thus have the better result than Flat after the channel estimation and adaptive equalization methods are used. Here we have got the best result in non-linear equalization using DFE in the FSF than all other results. Here we actually tried to make a model using GSM values works for slow Rayleigh fading channel in multi-path and tried to reduce the effects and compared the results. Finally it can be concluded that the model we tried to build works in multi-path and reduces the fading effect of the channel.

14. FUTURE WORK

This thesis work is done on phase shift keying and we have used quadrature phase shift keying, QPSK modulation. But different modulation techniques such as quadrature amplitude modulation (QAM) and amplitude shift keying (ASK) with different modulation orders can be used in this work. We have used computer simulation to test the work but practical hardware simulation can also be done with this project for wireless and mobile communications.

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