Performance Comparison of AWGN, Flat Fading and Frequency Selective Fading Channel for Wireless Communication System using 4QPSK

Md. Sipon Miah, M. Mahbubur Rahman, T. K Godder, Bikash Chandra Singh and M. Tania Parvin

Abstract—In this thesis paper, 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.

Index Terms—Slow fading, flat fading, frequency selective fading, channel estimation, LMS, RLS, 4QPSK, ISI.

1 INTRODUCTION

MOBILE communications and wireless networks 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. It is well known that the wireless multi-path channel causes an arbitrary time dispersion, attenuation, and phase shift, known as fading, in the received signal. Fading is caused by interference between two or more versions of the transmitted signal which arrive at the receiver at slightly different times. There are many diversity techniques to address fading issue, such as OFDM, MIMO, RAKE receiver and etc. However, it may be still necessary to remove the amplitude and phase shift caused by the channel if we want to apply linear modulation schemes, such as the ones used in WiMAX. 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. 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. The equalization removes the effect of the wireless channel and allows subsequent symbol demodulation. An adaptive equalizer is a time-varying filter which must constantly be retuned. A number of different algorithms can be employed for these modules. In our project, we use LMS (least mean squares) and RLS (Recursive Least Squares). Digital communication systems operating on time varying dispersive channels often employ a signaling format in which customer data are organized in blocks preceded by a known training sequence. The training sequence at the beginning of each block is used to estimate channel or train an adaptive equalizer. Depending on the rate at which the channel changes with time, there may or may not be a need to further track the channel variations during the customer data sequence. Fig.1 shows the flow chart of our MATLAB simulation which is used in this project.

2 WIRELESS MOBILE COMMUNICATION SYSTEMS

In any communication system, there must be an information source (transmitter), a destination (receiver) and a medium to transmit information between the transmitter and the receiver. The block diagram of a basic communication system is given in Fig.1. Message source originates message such as human voice, a television picture or teletype message or data. The message can be electrical and non-electrical. If it is not electrical, the source transducer will convert it into electrical signal. The transmitter may be consists of analog to digital converter, data compressor, source encoder, channel encoder a modulator or any other complicated subsystems.
2.1 Non-cellular wireless mobile communication

In non-cellular (single cell) mobile communication system, the coverage area is not divided into small cells as in cellular system. The coverage area can vary from a small area to a wide one. For small coverage area, the transmitted power, infrastructure cost and complexity are low. TV remote control, garage door opener and cordless phone are few examples of non-cellular wireless communication serving a small coverage area, for wide area coverage, high power transmitter placed at a high elevation is used, a single high power transmitter would be used for a large city. The non-cellular mobile communication system is also being used by small taxi-companies, utility companies, fire, police, medical and emergency personnel and national operators of large vehicle fleets based on land and sea. Wireless local area networks (WLANs) and the evolving Bluetooth technology are also examples of non-cellular wireless communication.

2.2 Cellular wireless mobile communication

In the early mobile radio systems, the objective was to achieve a large coverage area by using a single, high powered transmitter with an antenna mounted on a tall tower, as frequency reuse was not possible, the problem of this system was that the user capacity was very low. For example, the Bell Mobile system in New York city in 1970s could only support a maximum of twelve simultaneous calls over a thousand square miles. Thus the need of higher capacity with limited radio channel brought into the cellular concept. Modern cellular concept began to appear in Bell system proposals during the late 1940s. In cellular case, a coverage area is divided into a large number of small cells, each equipped with a low-power transmitter and each transmitter provides services for a small portion of the total geographic service area. The same frequencies could be reused in different cells. The most important properties of cellular architecture are as below.

- Low power transmitters per cell
- Small coverage area per cell
- Frequency reuse
- Cell splitting to increase capacity

2.3 Cellular Telephone System

A cellular telephone system provides a wireless connection to the PSTN for any user location within the radio range of the system. Cellular systems accommodate a large number of users over a large geographic area, within a limited frequency spectrum. Cellular radio systems provide high quality service that is often comparable to that of the landline telephone systems. High capacity is achieved by limiting the coverage of each base station transmitter to a small geographic area called a cell so that the same radio channels may be reused by another base station located some distance away. A sophisticated switching technique called a handoff enables a call to proceed uninterrupted when the user moves from one cell to another.

A basic cellular system which consists of mobile stations, base stations and mobile switching centers (MSC), the mobile switching center is sometimes called a mobile telephone switching office (MTSO), since it is responsible for connecting all mobiles to the PSTN in a cellular system. Each mobile communicates via radio with one of the base stations and may be handed-off to any number of base stations throughout the duration of a call. The mobile station contains a transceiver, an antenna, and control circuitry, and may be mounted in a vehicle or used as a portable hand-held unit. The base stations consist of several transmitters and receiv-
ers which simultaneously handle full duplex communications and generally have towers which support several transmitting and receiving antennas. The base station serves as a bridge between all mobile users in the cell and connects the simultaneous mobile calls via telephone lines or microwave links to the MSC. The MSC coordinates the activities of all of the base stations and connects the entire cellular system to the PSTN.

A typical MSC handles 100,000 cellular subscribers and 5,000 simultaneous conversations at a time, and accommodates all billing and system maintenance functions, as well. In large cities, several MSCs are used by a single carrier. Communication between the base station and the mobiles is defined by a standard common air interface (CAI) that specifies four different channels. The channels used for voice transmission from the base station to mobiles are called forward voice channels (FVC), and the channels used for voice transmission from mobiles to the base station are called reverse voice channels (RVC). The two channels responsible for initiating mobile calls are the forward control channels (FCC) and reverse control channels (RCC).

Control channels are often called setup channels because they are only involved in setting up a call and moving it to an unused voice channel. Control channels transmitted receive data messages that carry call initiation and service requests, and are monitored by mobiles when they do not have a call in progress. Forward control channels also serve as beacons which continually broadcast all of the traffic requests for all mobiles in the system. Supervisory and data messages are sent in a number of ways to facilitate automatic channel changes and handoff instructions for the mobiles before and during a call. Cellular systems rely on the frequency reuse concept, which requires that the forward control channels (FCCs) in neighboring cells be different. By defining a relatively small number of FCCs as part of the common air interface, cellular phones can be manufactured by many companies which can rapidly scan all of the possible FCCs to determine the strongest channel at any time. Once finding the strongest signal, the cellular phone receiver stays "camped" to the particular FCC. By broadcasting the same setup data on all FCCs at the same time, the MSC is able to signal all subscribers within the cellular system and can be certain that any mobile will be signaled when it receives a call via the PSTN.

### 2.4 Problems in Cellular Mobile Communications

In a cellular system interference is the major limiting factor in increasing capacity. Some of the interference sources are for example. Other base station transmitting in the same frequency band, another mobile user in the same cell, a call in progress in a neighboring cell, impairments caused by the propagation of radio waves, etc. as a result. Different types of system interference are yielded in the network. Among these interferences the most important are the following.

**Co-channel interference (CCI)** this type of interference is caused by the interference between co-channel cells (cells with the same frequency channel) due to the frequency refuse. To reduce CCI, co-channel cells must be separated by a minimum distance to provide sufficient isolation due to propagation distance.

**Adjacent channel interference (ACI)** This other type of interference results when two frequency channels are adjacent in the frequency spectrum and one of them is leaking into the pass band causing interfering into the adjacent channel.

![Fig. 3 Adjacent Channel](image)

ACI is mainly aggravated by imperfect receiver filters. This problem can be minimized with a careful filtering and channel assignments (assigning channels to a cell which is not adjacent in frequency).

**Inter-symbol interference (ISI)** When the signal travels through a channel, objects in an transmission path can create multiple echoes of the signal. These occur at the receiver and overlap in successive slots. This is known as inter-symbol interference equalizers at the receiver can be used to compensate the effect of ISI created by multi-path within time dispersive channels.

**Fading** one consequence of transmitting a signal through a time-varying multi-path channel is to confront at the receiver with a signal fading (amplitude variations in the received signal). Hence not only the propagation delays but also the random impulse responses of the channel will provoke some attenuation and time spread of the signal transmitted.

**Thermal noise** finally, the additive thermal noise is a factor that always corrupts a transmitted signal through a communication channel. Generally this thermal noise is assumed to be an additive white Gaussian noise (AWGN).
3 CHANNEL FADEING TECHNIQUES
The physical medium between the transmitter and receiver is known as channel. This channel results in random delay (random phase shift) with total a factor. Channels may be three types:

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simplex</td>
<td>One way only</td>
<td>FM radio, television</td>
</tr>
<tr>
<td>Half duplex</td>
<td>Two way, only one at a time</td>
<td>Police Radio</td>
</tr>
<tr>
<td>Full duplex</td>
<td>Two way, both at the same time</td>
<td>Mobile systems</td>
</tr>
</tbody>
</table>

3.1 Additive White Gaussian Noise
Zero-mean white Gaussian Noise (WGN) has the same power spectral density AWGN(f) for all frequencies. The adjective ‘white’ is used in the sense that white light contains equal amounts of all frequencies within the visible band of electromagnetic radiation. The autocorrelation function of WGN is given by the inverse Fourier transform of the noise power spectral density GWGN(f):

The autocorrelation function $R_{AWGN}(t) = \frac{N_0}{2} \delta(t)$

3.2 Rayleigh Fading Channels
When information is transmitted in an environment with obstacles (Non Line-of-sight - NLOS), more than one transmission paths will appear as result of the reflection(s). The receiver will then have to process a signal which is a superposition of several different transmission paths. If there exists a large number of transmission paths may be modeled as statistically independent; the central limit theorem will give the channel the statistical characteristics of a Rayleigh Distribution [36]. (Fig 5)

$$P(WGN_i) = \frac{1}{\sigma \sqrt{2\pi}} e^{-\frac{1}{2} \frac{(w_i - \mu)^2}{\sigma^2}}$$

3.3 Multipath Fading
In a radio propagation channel, there are two types of fading; large scale and small scale. Large signal fading is the attenuation caused by the path loss over large distances and shadowing effects and is well represented by log-normal models. Small scale fading occurs in the range of the signal wavelength and is much more random as compared to large scale fading. Small scale fading is mainly a result of multiple multipath components undergoing constructive/destructive interference at any point. In the common case where there is no line of sight (LOS) component between the transmitter and the receiver, the received power follows a Rayleigh distribution and can be seen to have a Rayleigh fading envelope.
3.4 Large Scale Fading
The large scale fading refers to the degradation of the signal strength due to the path loss as a function of the distance between the transmitter and the receiver and shadowing effects caused by the surrounding environmental clutter. The path loss is the gradual loss of received signal power with the distance from the transmitter. Shadowing describes the random effects which occur at different locations which have the same transmitter receiver separation, but different surroundings on the propagation path.

3.5 Shadowing
From the above equation only gives an ensemble average value, which does not take into account the variability in the propagation path between the transmitter and the receiver. Empirical data measurements have shown that the received signal power at a particular distance d is distributed log-normally (normally in dB) about the distance-dependent average received signal power. When the log-normal shadowing is included, the large scale fading at a distance d, can be expressed as:

\[ P_r(d) = P_r(d_0) \left( \frac{d_0}{d} \right)^\gamma 10^X \]

Where X represents a normally distributed random variable with zero mean and variance \( \sigma^2 \). The variance of the log-normal shadowing is calculated based on measurements that are taken over a wide range of locations that have the same transmitter receiver separation but with different environmental clutter. Apart from this simple model of the above equation, there exist various empirical models that take into account the terrain profile of a particular area in the propagation predictions (such as Okumura model [11] and Hata model [12]).

3.6 Small Scale Fading
Small scale fading itself can be subdivided into two other types. One is based on the multipath delay spread and the other on the Doppler shift. Depending on the relative length of the multipath delay spread \( (\sigma_\tau) \) with respect to the OFDM symbol length we can have either Flat Fading or Frequency Selective Fading. Similarly, the relative magnitude of the channel coherence time (as a result of the Doppler shift) with respect to the OFDM symbol duration determines whether the signal undergoes Fast Fading or Slow Fading [10].

3.7 Flat Fading
Flat fading is the name given to the case when the channel coherence bandwidth is larger than the signal bandwidth and hence all frequencies of the transmitted signal experience the same channel condition; i.e., over the signal bandwidth, the channel frequency response is essentially flat; and hence the name Flat Fading. In the time domain, this corresponds to having an expected \( \sigma_\tau \) smaller than the signal symbol period.

3.8 Frequency Selective Fading
On the other hand, if the channel bandwidth is narrower than the signal bandwidth, different frequency bands of the signal are affected differently. The time domain analogue is that the channel \( \sigma_\tau \) is larger than the signal symbol period.

3.9 Fast Fading
In a fast fading channel, the rate of change of the channel is higher than the symbol period and hence the channel changes over one period. In other words, the channel coherence time, \( T_c \), is smaller than the symbol period. \( T_c \) is related to the Doppler spread, \( f_m \), as

\[ T_c = \frac{0.423}{f_m} \]

From this relation it is clear that a high Doppler spread results in a smaller channel coherence time. The coherence time of 0.423 ms corresponding to a \( f_m \) of 1 kHz is clear.

3.10 Slow Fading
As the name suggests, in a slow fading channel, the channel coherence time is larger than the symbol period and hence the channel remains approximately static over a symbol or multiple symbols. From the above equation it is clear that slow fading is usually expected with low Doppler spread values; i.e. with slower moving obstacles and receiver/transmitter. Multipath delay spread based and Doppler spread based fades are completely independent of each other and hence is quite possible to have a flat, fast fading channel or a flat, slow fading channel; and so on.

4 RESULT AND DISCUSSION
I discuss my simulation result by two steps. First I analyze the performance comparison by different parameter setting in each channel. Then I analyze the performance by comparing three different channels under the same parameters setting. All the simulations are based on QPSK modulation with gray code.

4.1 For AWGN channel
A. BER of simulation vs theoretical
As shown in figure 7, The BER performance of simulation result is closely identical to theoretical BER.
PERFORMANCE COMPARISON OF AWGN AND SLOW FADING CHANNEL FOR WIRELESS COMMUNICATION SYSTEM

B. Image quality of received vs original
In figure 8, the received image is plot at SNR = 5dB, we see there are some random noises in the image. From simulation result, the received image quality is almost the same as original at SNR = 10dB.

C. BER of image vs random data
The correlation between image pixels does not effect the BER in AWGN channel.

4.2 For Flat Fading Channel
A. BER of simulation vs theoretical
As shown in figure 9 the BER performance of simulation result is worse than theoretical BER. This is reasonable, since the theoretical BER is based on the assumption that we know exactly the phase information of modulated signal. However, due to the time-variant channel, we always have estimation error for phase information. We also find the BER performance is improved dramatically in low SNR, while not in high SNR. This is also reasonable, 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.
B. BER & constellation equalized vs non-equalized
In figure 13 and figure 14 the constellation is plot at SNR = 15dB, we see both the BER performance and constellation are greatly improved by channel phase estimation.

C. Image quality of received vs adjusted
In figure 6, the received image is plot at SNR = 10dB, 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.

D. BER of image vs random data
The correlation between image pixels does not affect the BER in flat fading channel.

4.3 For frequency selective fading channel

A. BER of simulation vs theoretical
As shown in figure 13, the 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 dominate the BER error, and the estimation error will cause even severe ISI, which cause the BER even worse.

B. BER & constellation equalized vs non-equalized
In figure 13 and figure 14 the constellation is plot at SNR = 15dB, we see both the BER performance and constellation are greatly improved by channel phase estimation.

C. Reset vs continue training result
The BER performances of resetting the state of equalizer come from training result of last coherence time is worse than using the result of last coherence time. The BER is improved by using decision directed mode, since the time-variant property of the channel cause the channel change from estimation result of training data.

D. Training only vs decision directed mode
The BER is improved by using decision directed mode, since the time-variant property of the channel cause the channel change from estimation result of training data.

E. Training only vs decision directed mode
The BER is improved by using decision directed mode, since the time-variant property of the channel cause the channel change from estimation result of training data.

F. LMS vs RLS
The BER performances are almost same for both of them. But during the simulation, we find, LMS need more training data to converge the equalizer comparing to RLS, while latter has more complexity and time consuming.

G. Image quality of received vs original
In figure 15 the received image is plot at SNR = 15dB, we see that other than some random noise and block noise in the image, there are some overlaps in the image. This is due to the white Gaussian noise, phase estimation error in a coherence time, and ISI caused by frequency selective fading channel.
H. BER of Image vs random data
The correlation between image pixels does not affect the BER in frequency selective fading channel, since we use PN code to train the equalizer.

4.4 Comparison among three channels

A. For Image comparison
In figure 16, 17, we may 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.

Fig. 15 (a) without equalization  (b) with equalization

Fig. 17 (a) Original image (b) AWGN channel (c) Flat fading channel (d) Frequency selective fading channel

Fig. 17 (a) AWGN channel (b) Flat fading channel (c) Frequency selective fading channel
deep spectral nulls in the passband. While frequency selective fading channel normally causes the deep spectral nulls, so in our future simulation, we may improve this by add Decision Feedback Equalization (DFE). In this project, we produce two different scenarios by simulate a GSM carrier frequency and bandwidth, and use pilot data to estimate the channel phase. All of these are simulated in MATLAB at present. In our future model, we may integrate our model into GNU radio with USRP hardware support, which will give a practical environment to test our wireless communications simulation and our own algorithm.

5 Conclusion

In this thesis paper, I test the effect of three different channel models, AWGN channel, flat fading channel, and frequency selective fading channel, to the data and image under two scenarios. I also compare and analysis the improvement of channel estimation and adaptive equalization in slow fading channel. Our result is exactly identical to the theoretical analysis. I also improve the receiving data and image quality using 4QPSK modulation techniques because it is three time higher data rate then PSK. I also probable future work, which will introduce more research interests.

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