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Performance Evaluation of OFDM System with Rayleigh, Rician and AWGN Channels

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ABSTRACT

A Orthogonal Frequency Division Multiplexing (OFDM) scheme offers high spectral efficiency and better resistance to fading environments. In OFDM the data is modulated using multiple number of sub-carriers that are orthogonal to each other because of which the problems associated with other modulation schemes such as Inter Symbol Interference (ISI) and Inter Carrier Interference (ICI) are reduced. This paper deals with the analysis of OFDM System utilising different modulation techniques (QAM and BPSK) over Rayleigh, Rician and Additive White Gaussian Noise (AWGN) fading environments with the use of pilot aided arrangement and finally the results are conveyed.

Introduction

Orthogonal Frequency Division Multiplexing (OFDM) is becoming a very common multi-carrier modulation technique for transmission of signals over wireless channels in diverse environments. OFDM divides the high-rate stream into parallel lower rate data and hence prolongs the symbol duration, thus helping to eliminate Inter Symbol Interference (ISI). In an OFDM system the sub-channels overlap with each other to a certain extent as can be seen in figure.1-1in which leads to the reduced use of bandwidth and since these carriers are orthogonal to each other Inter Carrier Interference (ICI) is also reduced [2].

The input data sequence is mapped into symbols, which are distributed and sent over the N parallel sub-channels, one symbol per channel. To permit dense packing and still guarantee that a minimum of interference between the sub-channels is encountered, the carrier frequencies must be chosen carefully. By using orthogonal carriers, which in the frequency domain can be viewed so as the frequency distance between two sub-carriers is given by the distance to the first spectral null.

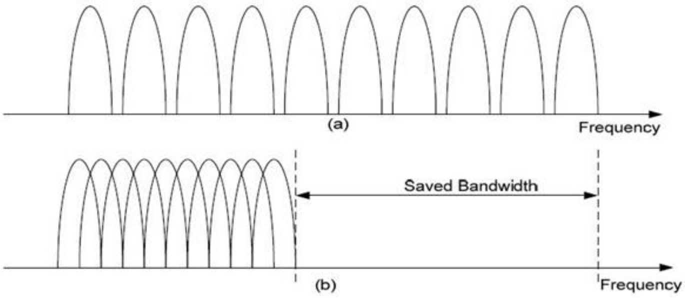

Figure 1-1: Concept of OFDM Signal: (a) Conventional Multicarrier Technique (FDM) (b) Orthogonal Frequency Division Multiplexing Technique

System Model

The concept of using parallel-data transmission and Frequency Division Multiplexing (FDM) was first published in the mid of 1960s. The basic idea was to use parallel data and FDM with overlapping sub-channels to avoid the use of high-speed equalization to combat impulsive noise and multipath distortion and fully utilize bandwidth.

Although the idea of OFDM was conceived in 1960s, it was not realizable until the advent of FFT. With the advent of FFT/IFFT it became possible to generate OFDM using the digital domain for orthogonality of sub carriers. Figure 2-1 shows a block diagram of a discrete time OFDM system, where an N complex-valued data symbol modulates N orthogonal carriers using the IFFT forming. The transmitted OFDM signal multiplexes N low-rate data streams, each experiencing an almost flat fading channel when transmitted. In single carrier systems each symbol occupying an entire bandwidth could be lost due to frequency selective fading, but when transmitted on low data parallel streams, symbol time increases and channel become flat fading [1].

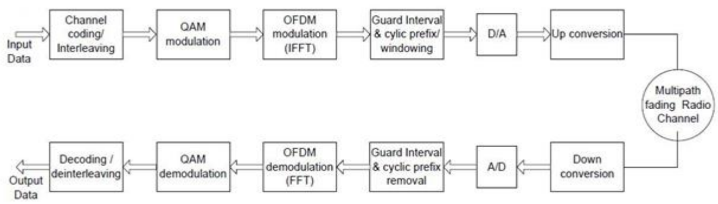

Figure 2-1: System Model of OFDM using FFT and IFFT

- The IFFT and FFT [8] are used for modulating and demodulating individual OFDM sub carriers to transform the signal spectrum to the time domain for transmission over the channel and then by employing FFT on the receiving end to recover data symbols in serial order.
- The second key principle is the cyclic prefix (CP) as Guard Interval (GI). CP keeps the transmitted signal periodic. One of the reasons to apply CP is to avoid Inter Carrier Interference (ICI).
- Interleaving is the third most important concept applied. The radio channel may affect the data symbols transmitted on one or several sub carriers which lead to bit errors. To encounter this issue we use efficient coding schemes [1].

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In OFDM, Guard Interval (GI) is introduced because of multipath propagation as it affects the symbols to delay and attenuate, which causes Inter Symbol Interference (ISI). In GI, Cyclic Prefix (CP) is used to counter Inter Carrier interference (ICI) within an OFDM frame. The CP is simply a copy of the last symbols of the samples placed first, making the signal appear as periodic in the receiver as shown in Figure 2-2.Before demodulating the OFDM signal the CP is removed. By exploiting the structure imposed using CP. Symbol synchronization can be achieved. Due to the carrier orthogonality it is possible to use the Discrete Fourier Transform (DFT) and the Inverse Discrete Fourier Transform (IDFT) for modulation and demodulation of the signal [1]. To obtain high spectral efficiency, there can be different modulation schemes can

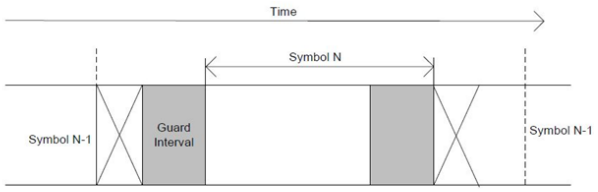

Figure 2-2: Guard Interval (GI) and Cyclic Prefix (CP).

be applied i.e. QPSK, 16-QAM, 64-QAM. We will be using 16-QAM and BPSK.

Channel Environment

This paper mainly deals with the performance of the OFDM system under Rayleigh and AWGN fading environments. Though the total channel is a frequency selective channel, the channel experienced by each subcarrier in an OFDM system is a flat fading channel with each subcarrier experiencing independent Rayleigh fading.

A. Rayleigh fading model

Rayleigh fading is a rational model when there are many objects in the environment that scatter the transmitted signal before it arrives at the receiver. The central limit theorem holds that, if there is sufficiently much scatter, the channel impulse response will be well-modelled as a Gaussian process regardless of the distribution of the individual components [3].

When there are large number of paths, applying Central Limit Theorem, each path can be modelled as circularly symmetric complex Gaussian random variable with time as the variable. This model is called Rayleigh fading channel model [4]. If there is no dominant component to the scatter, then such a process will have zero mean and phase evenly distributed between 0 and 2π radians. The envelope of the channel response will therefore be Rayleigh distributed.

A circularly symmetric complex Gaussian random variable is of the form,

$$Z = X + jY$$

Where real and imaginary parts are zero mean Independent and Identically Distributed (IID) Gaussian random variables. For a circularly symmetric complex random variable,

$$E[Z] = E[e^{j\theta}Z] = e^{j\theta}[Z]$$

The statistics of a circularly symmetric complex Gaussian random variable is completely specified by the variance,

$$\sigma^2 = E[Z^2]$$

The magnitude |Z|, which has a Probability Density Function (PDF) $p(z)$, is called the Rayleigh Random Variable

$$p(z) = \frac{z}{\sigma^2} e^{\frac{-z^2}{2\sigma^2}}, z > 0$$

Rician Fading Model

Rician Fading is a non-deterministic model for the anomaly that occurs when a transmitted signal accidentally cancels itself. The signal arrives at the receiver by several different, and at least one of the paths is changing. Rician fading occurs when one of the paths, typically a line of sight signal, is much stronger than the others. In Rician fading, the amplitude gain is characterized by a Rician distribution. When there isn't any line of sight path occurring between the OFDM transmitter and the receiver than the Rican Fading can be categorised by Rayleigh Fading [5].

Rician Fading [10] channel can be defined using two parameters: K and Ω, where K is called the Rice Factor and it is the ratio between the power in the direct path and the power in the other, scattered, paths and Ω is the total power from both paths and acts as a scaling factor to the distribution. The received signal amplitude not considering the power R is then Rice distributed with parameters:

$$v^2 = \frac{K}{1+K^2}\Omega$$

And,

$$\sigma^2 = \frac{\Omega}{2(1+K)}$$

The resulting Probability Density Function (PDF) is then given by-

$$f(x) = \frac{2(K+1)x}{\Omega} \exp\left(-K - \frac{(K+1)x^2}{\Omega}\right) I_0\left(2\sqrt{\frac{K(K+1)}{\Omega}}x\right)$$

Where $I_0(.)$ Is the 0[th] order modified Bessel function of the first kind. Now if the Rice Factor K is 0 then the Rician Faded Envelope reduces down to Rayleigh faded Envelope.

B. Awgn Channel

An Additive White Gaussian Noise (AWGN) [10] channel adds White Gaussian noise to the signal when it is passed through the channel. In the case of white Gaussian noise the values at any pair of times are identically distributed and statistically independent on each other. AWGN channel is not associated with either fading or any other system parameters. It is just the noise that is added to the OFDM modulated signal when it is travelling through the channel. The channel capacity of AWGN Channel is given by-

$$C = \frac{1}{2}\log\left(1 + \frac{P}{n}\right),$$

where C is the channel capacity.

Simulation Model

System Parameters

OFDM system parameters used in the simulation are indicated in Table I. Moreover, we have chosen the guard interval to be greater than the maximum delay spread in order to avoid Inter-Symbol Interference. Simulations are carried out for different signal-to noise (SNR) ratios and for each value of the Bit Error Rate (BER) is calculated. The simulation parameters to achieve those results are shown in the Table I.

Table 1: Simulation Parameters

Parameters	Specification
FFT Size	64
Number of Sub-Carriers	64
Signal Constellation	QAM & BPSK
Channel Model	Rayleigh, Rician &AWGN
Number of Frames	100
Bits/Frame	96
Cyclic Prefix Length	25%=16

Simulation Results and Discussions

The Rayleigh Fading channel is constructed using the Rayleigh block in MATLAB R2009a using the rayleighchan () function with sampling period of 100μs and Doppler Frequency shift of 10. Then the signal is passed through this channel using the filter () function. The same is done for Rician Fading channel with the channel is constructed using ricianchan () function with the same sampling period and Doppler Frequency shift as above and the Rician Factor as 6.

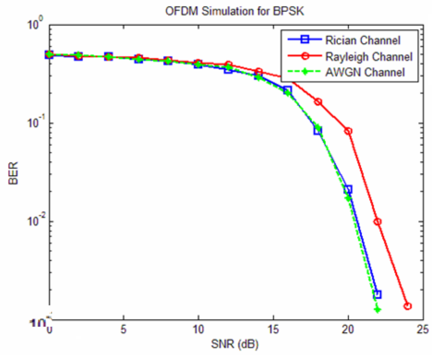

Figure 4-1: BER vs. SNR For 16- QAM Modulation

Figure 4-2: BER vs. SNR for BPSK Modulation

Figure 4-1 represents the BER associated with various SNR values for 16-QAM modulation. The plot evidently shows that the performance of the system is better when there is a Rayleigh Fading Channel compared to Rician and AWGN channel performs the least among them. The BER is very much low for Rayleigh compared to Rician which is moderate and high for AWGN channel.

The next plot Figure 4-2 represents the BER associated with BPSK modulation and the plot shows that BER is high all the fading channels than compared to QAM modulation. So from this we can conclude that the performance of the OFDM system is better if QAM or QPSK is selected as the modulation technique instead of BPSK and OFDM performs better under Rayleigh Fading channel compared to Rician and AWGN Channel as it yields low BER for each SNR value.

Conclusion

In this paper we compare the performance in terms of BER using different modulation schemes on Rayleigh, Rician and AWGN Channel. This system model that is presented in this paper uses BPSK and 16-QAM as sub-carrier modulation technique. We have discussed the advantages of OFDM and the requirement of every block in the system model. The simulation results are provided and from which we can evidently conclude that the QAM gives better performance under Rayleigh channel compared to other modulation scheme's and channels.

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