CHAPTER 1

INTRODUCTION

1.1 PREAMBLE

Wireless communications is a field, which has seen enormous growth in the last several years. The spectacular growth of video, voice and data communication over the Internet, and the equally rapid pervasion of mobile telephony, justifies great expectations for mobile multimedia. Due to this growth of multimedia communication, the users demand high date rate communication. But in wireless environment the spectral resource is scarce. To fulfill the requirements new technologies like Code Division Multiple Access and Orthogonal Frequency Division Multiplexing (OFDM) are a few promising systems for the 4G communication standards.

While present communication systems are primarily designed for one specific application, such as speech on a mobile telephone or high-rate data in a wireless local area network (WLAN), the next generation will integrate various functions and applications. Supporting such large data rates with sufficient robustness to radio channel impairments, requires careful selection of transmission technique. One of the most promising techniques for achieving high data rate transmission in mobile environment is Multi-Carrier Code Division Multiple Access (MC-CDMA) technique.

1.1.1 Limitations of Single Carrier Modulation (SCM) Systems

A single carrier modulation system modulates the information onto one carrier. For digital signals, the information is in the form of bits that are
modulated onto the carrier. At higher bandwidth the duration of one bit or symbol of information becomes smaller and hence the system becomes more susceptible to the loss of information from impulse noise, signal reflections and other impairments. These impairments may impede the ability to recover the information sent. In addition, as the bandwidth used by a single carrier system increases, the susceptibility to interference from other continuous signal sources becomes greater.

In a time dispersive multipath fading wireless channel, the conventional Single Carrier Modulation system introduces Inter Symbol Interference (ISI) which makes an equalizer necessary. If data rate is low, the symbol duration is large, and if large enough as compared to the maximum delay spread of the channel, it is possible to cope with the resulting ISI without any equalization. Severe ISI limits the transmission data rate and ISI problem is usually dealt with by using complex time domain channel equalizers. The limit is given by the computational complexity of the equalizers. Moreover, achieving equalization at several Mega bits per second with compact and low cost hardware is quite difficult in practice.

The limitations of Single Carrier Modulation System can be summarized as follows:

- Frequency Selective Fading
- ISI is comparatively High
- Equalizers are very complex
- Poor Spectral efficiency

1.2 MULTI CARRIER MODULATION (MCM) SYSTEM

MCM technique is an efficient solution for reducing the noise due to the multi path fading which results in Inter symbol Interference (ISI). For the
conventional single carrier modulation systems, MCM technique is being considered as an alternative. The principle behind MCM technique is, to divide the available spectrum in to several sub channels and to assign a carrier to each of the sub channels and distribute the information to be sent among the sub channels. Each subcarrier is modulated separately and transmitted with appropriate frequency spacing. Also each sub carrier has an allowed bit error rate thereby reducing the ISI.

1.2.1 The Concept of MCM

The basic concept behind the Multi Carrier Modulation technique is the principle of dividing the available spectrum into several sub band / sub channel and assigning a carrier to each of them and distributing the information to be sent among the sub carrier / sub band (Figure 1.3). Each sub carrier is modulated separately and then the ensemble is transmitted altogether with appropriate frequency spacing. Each sub carrier has a lower bit rate.

![Figure 1.1 Basic multi carrier transmitter](image)

A proper choice of the basis function allows for their overlapping and subsequently yields a higher spectral efficiency. As the number of sub carriers increases, the spectrum shape becomes asymptotically rectangular. Multi carrier modulation with frequency overlapping basis functions is properly called ‘Orthogonal Frequency Division Multiplexing (OFDM)’. 
OFDM is more popular in wireless context, while in wired environment such as DSL, the term Discrete Multi Tone (DMT) is most commonly employed (Sistanizadeh Chow and Cioffi 1993).

1.2.2 Advantages of MCM

In recent years OFDM has gained a lot of interest in diverse applications. This has been due to its favorable properties like immunity to impulse noise, uniform average spectral density, capability of handling very strong echoes.

The advantages due to multicarrier modulation shall be summarized as

- ISI is comparatively Low
- Channel equalization is simple
- High spectral efficiency
- Flat fading per sub carrier

Figure 1.2 illustrates the benefit of using Multi Carrier Modulation (MCM) compared to Single Carrier Modulation (SCM) in terms of Signal to Noise Ratio (SNR) improvement for a given Bit Error Rate (BER). It is seen that SCM has a much worse performance than OFDM system. By increasing the SNR, after some point, the SCM system no longer improves the overall performance, whereas the OFDM system’s BER performance continues to improve with the increase of SNR. Because of the above listed advantages, Multi Carrier Modulation / Orthogonal frequency Division Multiplexing is being considered as an alternative to Single Carrier Modulation for high data rate applications.
1.2.3 Problems with MCM

Though MCM offers many advantages over SCM, it has the following major problems / drawbacks:

- Compared to SCM systems, MCM exhibits a large Peak to Average Power Ratio (PAPR).

- Multi carrier systems are more sensitive to carrier frequency offset and phase error than single carrier systems.

- Loss of orthogonality between subcarriers leads to interference between sub carriers.
1.3 MULTICARRIER - CODE DIVISION MULTIPLE ACCESS (MC-CDMA) SYSTEM

In MC-CDMA, different users share the same BW at the same time. The data is separated by applying different user specific spreading codes. This is the separation of the user signal carried out in code domain. It applies multicarrier modulation to the symbol rate in order to reduce the amount of ISI per sub channel. This ISI reduction is significant in spread spectrum systems where high clip rate is prevalent.

The principle of MC-CDMA is to map the clips of a spread data symbol in frequency domain over parallel sub channels. MC-CDMA transmits a data symbol of a user simultaneously on several narrow band sub channel. These sub-channels are multiplied by the clips of the user specific spreading codes. MC-CDMA offers flexible system design since the spreading codes length does not have to be chosen equal to the number of sub-carriers in order to reduce the receiver complexities.

The advantages of MC-CDMA system are high spectral efficiency and low receiver complexity and high PAPR (peak to average power ratio) is the disadvantage.

1.3.1 MC-CDMA system implementation

Figure 1.3 illustrates the typical MCCDMA system. The incoming serial data is first copied from serial to form N parallel data streams and grouped into b bits. Each of b bits is spread over frequency domain and formed to be complex number. The complex numbers are modulated in baseband fusion by IFFT and converted back to serial data for transmission. A guard interval consisting of a partial repetition of the output of the IDFT process is inserted between symbols to avoid intersymbol interference (ISI).
caused by multipath distortion. The discrete symbols are converted to analog by low pass filtering and then feed to RF upconverter.

The incoming bit stream is serial to parallel converted (the effect of coding would be better in low data rate systems than higher data rate systems), each branch of parallel data is spreaded by orthogonal spreading codes. Then the spread sequence is modulated by carrier at last the modulated data is sent to Inverse Fourier transformer where the IFFT is applied on the data the advantage of using IFFT is that it is less time consuming than DFT because the number of operations performed in the IFFT blocks is less than the operations performed in the DFT block. After performing the IFFT the transformed signals are again combined to form the serial data. At the receiver the inverse operation is performed that is, first serial data is splited to parallel stream then FFT is performed on each parallel steam then the signal is demodulated and finally the spreading codes is used to despread the signal in order to recover the original data being transmitted the n the parallel streams are combined to for the serial data.

![Diagram](image_url)

**Figure 1.3** Block Diagram of MC-CDMA transmitter and receiver
1.4 SIMULATION OF MC-CDMA BIT ERROR RATE

System performance: To analyze the system performance, we consider three channel models, such as AWGN, Rayleigh fading and Rician fading channel.

**AWGN channel:** This channel is assumed to corrupt the signal by the addition of white Gaussian noise $n(t)$ which denotes a sample function of the additive white Gaussian noise (AWGN) process with zero mean and two sided power spectral density.

\[ \Phi_n(f) = 0.5 N_0 \text{ W/Hz} \]  \hspace{1cm} (1.1)

**Rayleigh fading channel:** Depending on the surrounding environment, several different paths before it reaches the receiver. If there is no line-of-sight between the transmitter and the receiver the attenuation coefficients corresponding to different paths are often assumed to be independent and identically distributed in which path gain has uniformly distributed phase and Rayleigh distributed magnitude. In this channel, the transfer function assumed for the $m^{th}$ user can be represented as

\[ H_m(f_c + F/T_b) = \rho_m e^{j\theta_m} \]  \hspace{1cm} (1.2)

where $\rho_m$ and $\theta_m$ represents the random magnitude and phase of the channel of the user at the frequency $f_c$.

The random magnitude is assumed to be independent and identically distributed (iid) Rayleigh random variables in the interval for all users and subcarriers where the Rayleigh distribution is
Rician fading channel: The model behind the Rician fading is same as Rayleigh fading except that in Rician fading a strong dominant component is present. This dominant component can be for instance LOS.

Refined Rician models also consider

- That the dominant wave can be a phasor sum of two or more dominant signals, e.g. the line-of-sight, plus ground reflection. This combined signal is then mostly treated as a deterministic process.

- That the dominant wave can also be subject to shadow attenuation. This is a popular assumption in the modeling of satellite channels.

Besides the dominant component, the mobile antenna receives a large number of reflected and scattered waves as there is line of sight component, the magnitude factor $\rho_{m,i}$ for $i = 0,1,2\ldots N-1$ assume to have the following Rician distribution which is given by

$$f(\rho_{m,i}) = \frac{\rho_{m,i}}{\sigma_{m,i}} e^{-\frac{\rho_{m,i}^2}{2\sigma_{m,i}^2}} \cdot I_0 \left( \frac{\rho_{m,i}}{\sigma_{m,i}} \right)$$  (1.4)

where $b$ is the line of sight component and $I_0$ is the ordered modified Bessel function which is given by
\[ I_0(x) = \sum_{k=0}^{\infty} \frac{(x/2)^{2k}}{k! \Gamma(k + 1)} \quad \text{for } x \geq 0 \] (1.5)

Figure 1.4 shows the plot of average error probability v/s bit error rate in AWGN, Rayleigh and Rician fading channels for number of sub-carriers 128 as a function of Signal-to-Noise Ratio.

Figure 1.4  Error probability v/s B.E.R. in AWGN, Rayleigh and Rician fading channels for number of sub-carriers 128 as a function of SNR

Figure 1.5 shows the graph to compare BER as the number of interferences in Rayleigh fading channel as a function of Signal-to-Noise Ratio for M Number of users, N- Number of sub-carriers
Figure 1.5  Comparison of BER as the number of interferences in Rayleigh fading channel as a function of SNR

Figure 1.6 shows the graph to compare BER as the number of interferences in Rician fading channel as a function of Signal-to-Noise Ratio for M-Number of users, N - Number of sub-carriers

Figure 1.6  Comparison BER as the number of interferences in Rician fading channel as a function of SNR
Figure 1.7 shows the graph to compare BER as the number of interferences in Rayleigh fading channel as a function of Signal-to-Noise Ratio.

Number of sub-carriers = 128

M = Number of users

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Figure 1.7 Comparison BER as the number of interferences in Rayleigh fading channel as a function of SNR

Figure 1.8 shows the graph to compare BER as the number of interferences in Rician fading channel as a function of Signal-to-Noise Ratio.

Number of sub-carriers = 128

M = Number of users
Figure 1.8  Comparison BER as the number of interferences in Rician fading channel as a function of SNR.

1.5 CLIPPING NOISE

MC-CDMA signals exhibit a fluctuating envelope power and hence when they are subject to non linear amplification, they produce out-of-band spurious emission. The extreme peaks of the signal inevitably suffer from so–called “clipping effects”. When they enter the saturation region of the amplifier resulting in the loss of effective signal transmission power and signal destruction. The gain of the amplifier is reduced to a level where the amplifiers make output level sufficiently high for the signal peaks not to be clipped. The degrees of power envelop variation of a MC-CDMA signal depends on the spreading sequence employed. Therefore the loss of effective transmission power depends on the spreading sequence used.
1.5.1 Effects of Clipping Noise

The major disadvantage of MC systems based on OFDM is their high sensitivity to non-linear amplification. It requires large back-off in the transmitted amplifier and as a consequence, results in inefficient use of power amplifiers. On the other hand using low back-off leads to signal distortion which results in increased performance degradation. In MC communication, spread spectrum techniques are used in conjunction with OFDM. The nonlinear amplification of the signal destroys the properties of the spreading sequences. The orthogonal spreading codes are used to reduce the multiple access interference (MAI). The nonlinearity (NL) destroys the orthogonality and increases MAI. In order to reduce MAI and other interferences, suppression of clipping noise is considered as one of the solution.

1.6 OBJECTIVE OF THE RESEARCH WORK

The objective of our research work is to analyze the problems due to clipping noise in the MC-CDMA signal. The causes of clipping noise and the effect of clipping noise are analyzed. The clipping noise variations with various modulation schemes are also investigated. The Bit error rate (BER) in Additive white Gaussian noise (AWGN) channel, Rayleigh channel and Rician channel with and without clipping noise is computed. As an innovation Global search algorithm based multiuser detector is employed for determination of clipping noise and hence to suppress it.

1.6.1 Motivation of the Research Work

The single carrier modulation (SCM) system is not suitable for transmitting high data rate transmission signals. The problems with SCM system has motivated the researchers to work towards finding a better modulation technique for improving the performance. MC-CDMA system is
considered in many broad band communication systems due to its robustness against channel impairments.

One of the major disadvantages of MC-CDMA system is due to clipping noise. High power amplifiers (HPA) linearly distort the signals which come closer or exceed the saturation level of the amplifier. This distortion causes Inter carrier interference (ICI) and out of band radiation which degrades the system performance in terms of BER. Therefore it is desirable to reduce the clipping noise effects of the MC-CDMA signal.

1.6.2 Scope of the Research Work

The reduction of clipping noise effects can improve many of the following factors

- PAPR reduction capability
- Loss in data rate
- Increase in transmitted power signal
- Reduce the complexity in implementation
- BER degradation

In this research work, performance of MC-CDMA system in terms of clipping noise effects and the analysis of BER are being investigated.

1.7 ORGANISATION OF THE REPORT

The organization of the thesis is as given below

Chapter 1: Introduction

In Chapter 1, the theory of MC-CDMA which is combination of CDMA and OFDM and the technology involved is discussed. The MC-
CDMA system design requirement and system design parameters are investigated.

Chapter 2: Overview of Clipping Noise and Reduction Techniques

This chapter outlines the mathematical modeling of clipping noise and effects of clipping noise on the performance of the system have been discussed. The goal of clipping noise reduction algorithms and the selection criteria for the clipping noise reduction techniques and various types of clipping noise reduction techniques are investigated.

Chapter 3: Clipping Noise Analysis Using Global Search Algorithm Based Multiuser Detector

In this chapter the performance of MC-CDMA system with clipping noise in AWGN, Rayleigh and Rician channels using Global search algorithm MUD has been simulated and BER has been compared.

Chapter 4: Clipping Noise Analysis Using Genetic Algorithm and Sphere Decoding Algorithm Multiuser Detectors

In this chapter the performance of MC-CDMA system under clipping noise using Genetic algorithm and sphere decoding based MUD has been simulated and analyzed in terms of BER.

Chapter 5: Conclusion and Future work

This chapter compares the various technique of clipping noise reduction algorithms presented in the report. Further scope of future work to be carried out in the clipping noise reduction is discussed.