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Performance Evaluation of MC-CDMA System- A Survey

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Abstract: To meet large demand for system capacity, high data rate and widespread services, the next generation wireless communication systems uses Multi carrier code division multiple access (MC-CDMA) as its multiple access scheme. MC-CDMA combines the benefits and limitation of both Code Division Multiple Access (CDMA) as well as Orthogonal Frequency Division Multiplexing (OFDM) techniques. The studies shows that the use of spreading codes with good correlation properties can significantly reduce the interferences such as Multi path interference (MPI) and Multiple access interference (MAI) affecting the system. The main limitation in a MC-CDMA system is the high Peak to average power ratio (PAPR) which in turn reduces the system power efficiency. There are different PAPR reduction techniques such as signal scrambling techniques and signal distortion techniques, which will help to improve the system performance. This paper surveys a brief review of the problems and its available solutions of MC-CDMA system.
Keywords: CDMA, MC-CDMA, OFDM, PAPR, ZCZ.

Introduction

In the fast growing world, the capacity of a wireless communication system has become critical with the increase in the need and rapid growth of mobile users. One solution to this problem is to use multiple access schemes that utilize the limited radio spectrum in a spectrally efficient manner. Both Frequency division multiple access (FDMA) and Time division multiple access (TDMA), used by the 1G/2G technology are limited in either frequency or time. Hence the number of users that can be accommodated is limited. The Code division multiple access (CDMA) technology used by the 2G/3G technology, assigns a pseudorandom code to each users instead of frequency and time slots [1]. Hence the capacity offered by a CDMA system is superior to that of FDMA and TDMA system.However, CDMA system is interference limited. Also, in order to incorporate the new services like multimedia, mobile internet access service, there is a need to provide high spectral efficiency. Orthogonal frequency division multiplexing (OFDM) transmits high data rate streams into several low rate parallel subcarriers, which reduces the effect of inter symbol interference (ISI). Spectral efficiency is enhanced due to the overlapping of subcarriers [2].

The fourth generation (4G) wireless systems aims to reduce the ISI resulting from high data rate transmission and to utilize the finite bandwidth in an efficient way.To achieve this, 4G technology use a multiple access technique known as multi-carrier code division multiple access (MC-CDMA), which combines the advantage of both OFDM and CDMA techniques [3]. MC-CDMA scheme spreads the data symbols in frequency domain and transmitted on different subcarriers, which eliminates the chance of frequency selective fading and improves the bit error rate (BER) performance [2].

Because of the use of CDMA in MC-CDMA structure, the spreading code used to spread the data symbol have significant role in system performance. Here each user is distinguished with respect to the degree of cross correlation between the codes. The cross correlation properties of the spreading code assigned to each user results in multiple access interference (MAI). Hence the BER performance of MC-CDMA system will strongly depend on the MAI resulting in the system. The level of MAI is influenced by the spreading code assigned to each user. Hence codes used should have good correlation properties [4].

The OFDM part in an MC-CDMA structure will create peak to average power ratio (PAPR) that occurs in the system when several subchannels add inphase at the output of the transmitter [5], which will reduce the power efficiency of the system. The effect of high PAPR and Multiple access interference (MAI) can be reduced with the proper use of forward error coding (FEC) scheme with high coding gain [6].

The remainder of this paper is organized as: Section II describes about an overview of MC-CDMA system. Section III and IV focuses on the problems and possible solution of MC-CDMA system. Section V concludes the paper.

Overview of MC-CDMA System

The MC-CDMA scheme is a promising technology for future wireless communication systems. Future wireless communication requires a system supporting a large number of users, which can simultaneously provide high data rate. The MC-CDMA is a type of multiple access that utilize the benefits of both CDMA and OFDM schemes. The multi carrier part reduces the multipath fading and ISI, whereas the spread spectrum technology utilize the limited spectrum in an efficient way.The high data rate transmission will make a resistive channel. The multi carrier part will overcome this problem by transmitting high data rate data into low rate parallel subcarriers. The overlapping of carriers provides high spectral efficiency. The Fig 1 shows the power spectrum of the transmittedMC-CDMA signal.

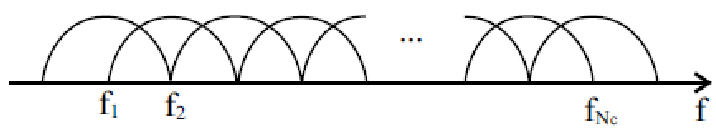

Figure 1: Power spectrum of MC-CDMA signal [7]

Compared to the other multicarrier technique, in a MC-CDMA scheme the original data symbols are first spread with a pseudorandom sequence, followed by the modulation on different carriers. That is, in a MC-CDMA system the chips of same symbol are modulated on different carriers. Hence the spreading is said to be done in frequency domain. Compared to DS-CDMA, in MC-CDMA the codes that is used to distinguish each users are modulated in frequency domain, hence the need of complex rake receiver is avoided.The Fig 2[7] shows the block diagram of a MC-CDMA system.

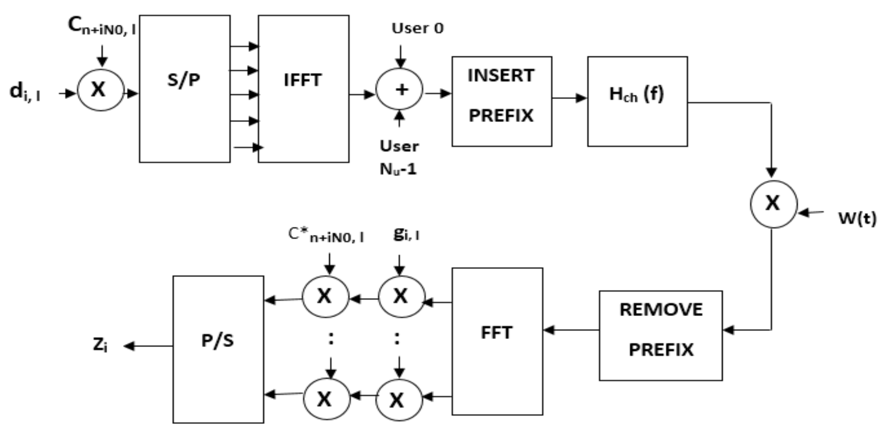

Figure 2: Block Diagram of Multi Carrier-Code Division Multiple Access system [7]

The Fig 2 shows that the data sequence d is first multiplied with a spreading sequence Cn+iNc,where n=0, 1…Nc-1. Cn+iNc denotes the n^{th} chip during the i^{th} symbol interval and Nc denotes the spreading factor. After spreading, the data symbols are transmitted on different orthogonal subcarriers in parallel. The spread data symbols are modulated on different orthogonal subcarriers with the help of N point inverse fast fourier transform (N-IFFT). Similar to an OFDM system, the MC-CDMA system reduces the interference between the successive symbols by cyclically extending the FFT block with cyclic prefix of N_p samples. The Fig 3 [7] shows the mapping of chips on the subcarriers.

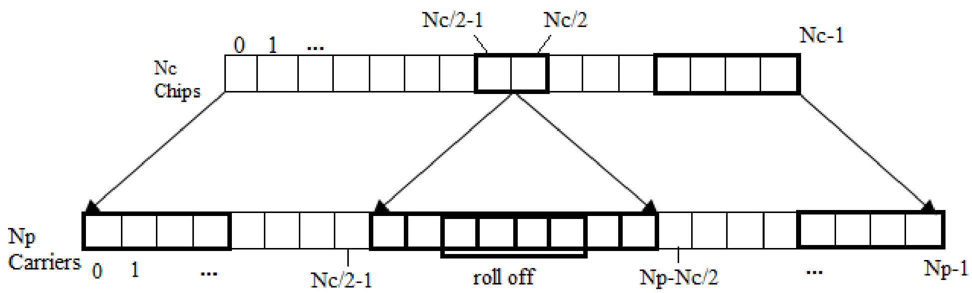

Figure 3: Mapping of chips on the carriers [7]

The signal is then transmitted through a channel having transfer function H_{ch} (f) and the signal received at the receiver is affected by additive white gaussian noise (AWGN) w(t) having power spectral density $N_0/2$. At the receiver the cyclically added N_p samples are removed from each FFT block. The remaining N samples are further processed which consists of N-point FFT and one tap equalizer g_{in} which rotates the FFT output. The equalizer output are then again multiplied with the corresponding spreading code and are summed to obtain the estimated output $Z_{i,}$ from which a decision is made about the data symbol.
The figure 4 shows the BER comparison of Multicarrier DS CDMA scheme,MC-CDMA scheme with MMSEC, two subcarrier MT-CDMA scheme with 2 finger rake receiver and DS-CDMA scheme with 2 finger rake receiver. The figure clearly shows that MC-CDMA performs better than the other schemes.

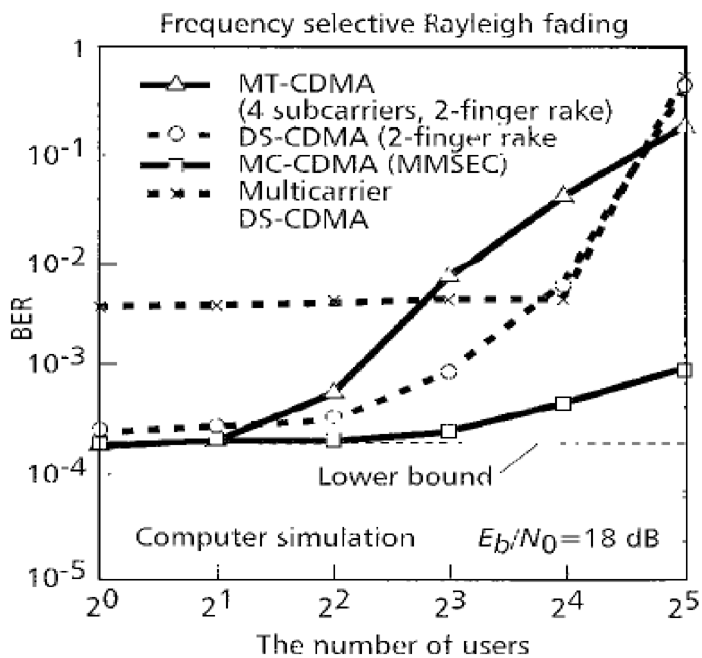

Figure4: Bit error rate comparison [16]

Compared to other multiple access schemes the main benefits of a MC-CDMA system includes high spectral efficiency, robustness to channel fading, flexible system design, high frequency diversity etc. However since MC-CDMA is a multi-carrier scheme, its performance is limited due to high PAPR, which occurs due to the combination of large number of independent subcarriers.

Problems in an MC-CDMA System

The important limiting factor in every communication system is the interference affecting the system. The MC-CDMA system is a combination of both CDMA and OFDM, hence it will have the drawbacks of both the schemes.
A. Interference affecting the system
The performance of a CDMA system will depend on the interference affecting the system, so that it is known as an interference limited system. The interference affecting the system can be multi path interference (MPI) due to multi path delays and multiple access interference (MAI) due to multiple access delays. Both MPI and MAI causes self-interference as well as multi-user interference (MUI) that degrade the performance and capacity of CDMA systems [8]. The MPI occurs when the signal from the transmitter travels through two or more path to the receiver under the right condition. These two or more signal components will interfere resulting in MPI.
The MAI is one of the major factor that limits the performance and capacity of CDMA systems. It is actually the interference between the direct sequence users which occur due to the random time offset between the signals. Due to MAI, the design of orthogonal code waveforms become difficult.
B. Peak to average power ratio
The OFDM scheme used in a MC-CDMA system is capable of providing improved quality of service at high data rates. At high data rates single carriers are more susceptible to fading and multipath propagation, however multicarrier techniques eliminates the need for complex equalizers by maintaining high data rate transmission [9]. The OFDM scheme transforms a wideband channel in to a narrowband channel and the use of narrow band signals will reduces frequency selective multipath fading because narrow band signals are less sensitive to fading and inter

symbol interference (ISI).However in a multicarrier system, at the output of the transmitter several subcarriers add in phase which creates high PAPR. The PAPR of a MC-CDMA signalx (t) is actually defined as the ratio of maximum power of a sample in a given OFDM symbol to the average power of that OFDM symbol.

$$\text{PAPR} = \frac{\max[|x(t)|\text{^}2]}{E[|x(t)|\text{^}2]} \quad \ldots (1)$$

Due to high PAPR, the RF power amplifiers should be operated in a very large linear region, if not the signal peaks will move into a nonlinear region of the power amplifier which will result in signal distortion [10].This signal distortion may result in intermodulation among the subcarriers. Hence power amplifiers should be operated with large back offs which may result in costly transmitter and poor amplification.Therefore it is essential to reduce the PAPR.

Solutions to Reduce the Problems in a MC-CDMA System

The CDMA scheme used in a MC-CDMA system is interference limited. Therefore, the performance and capacity it can handle will depend on the interference affecting the system.

A. Interference cancellation techniques

The user capacity of a system is mainly limited due to the domination of interference affecting the system. There are several ways to improve the user capacity by using optimum detection, interference cancellation (IC) methods, or methods such as decorrelating receiver. The use of multi user algorithms improves the performance of the system, however the complexity increases exponentially with increase in the number of users and code length. In IC techniques, it attempts to remove the multiple user interference from each user's received signal prior to making data decisions. IC cancellation techniques can be mainly classified as serial or successive and parallel cancellation techniques. In serial cancellation techniques, the interference caused by the remaining users is removed from each user in succession. However in order to achieve this, a specific geometric power distribution must be assigned to each user. Another disadvantage of this scheme is that there is a delay in accomplishing the interference cancellation of all users in the system. In parallel processing the interference produced by the remaining users accessing the channel is simultaneously removed from each user [17].

B. Use of efficient spreading sequence

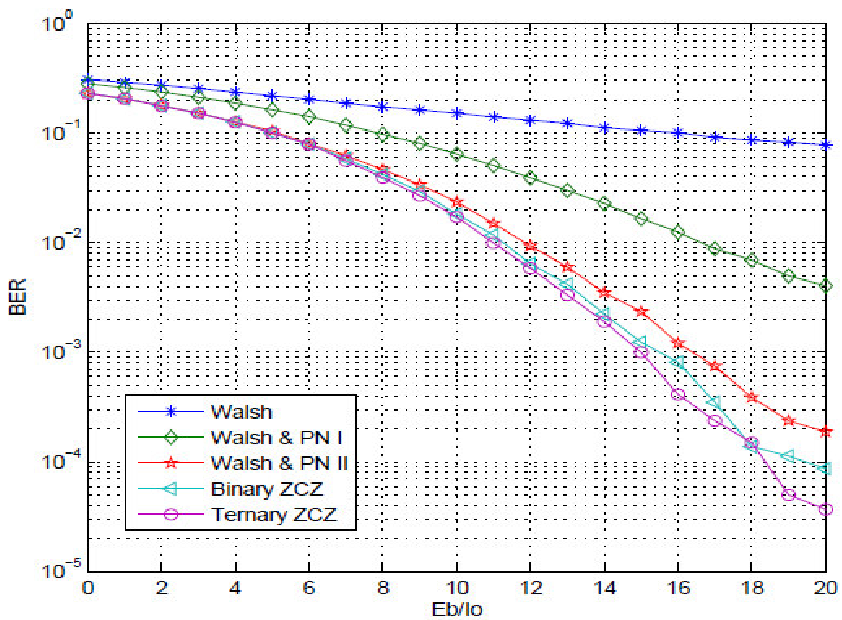

Figure 5: Bit error rate verses signal to noise ratio over Multipath Rayleigh fading channel [8]

The interferences such as MPI and MAI are closely related to the Auto-correlation function (ACF) and Cross-correlation function (CCF) of the spreading sequence used to spread the data sequence. Hence the use of spreading sequence with good correlation properties can replace the need of complicated interference cancellation techniques. The commonly used spreading sequences are Pseudo noise sequence, Walsh codes, Gold codes etc. The spreading sequence set that have ideal impulsive ACF and zero CCF can significantly reduce the interference affecting the system. But such ideal sequences are difficult to design. A set of spreading sequence known as zero correlation zone

(ZCZ) sequence are defined to be a sequence set with zero correlation zone at out of phase state [8]. Hence, if all the multi path and multiple access delays are within this zero correlation zone, then the use of ZCZ sequences in the system can effectively eliminate MPI and MAI. The Fig 5 shows the BER performance of MC-DS-CDMA system using different codes.

Both binary and ternary codes are a type of ZCZ code in which ternary ZCZ sequence have longer zero correlation zone and large family size. The figure clearly shows that ZCZ code performs better than other spreading codes. Among binary and ternary ZCZ code, the performance of the system using ternary ZCZ code is superior to the system using binary ZCZ code.

C. PAPR reduction techniques

Also compared to a CDMA system, the use of narrow band signals in an MC-CDMA system makes the system less sensitive to ISI and multipath fading. However, in a multi carrier system the transmitted signal exhibit high PAPR which reduces the efficiency of high power amplifier and degrades the system performance.Hence to improve the system performance, it is required to reduce the PAPR. There are different PAPR reduction techniques, which are mainly classified as signal scrambling techniques and signal distortion techniques [10]. Partial transmit sequence (PTS), selected mapping (SLM), Block coding techniques etc., are signal scrambling techniques and peak windowing, envelope scaling, peak reduction carrier etc., are signal distortion techniques.The table 1 shows the amount of PAPR reduction for different PAPR schemes [11].

Table 1: Peak to average power ratio reduction for different schemes [11]

PAPR Scheme	PAPR Reduction in dB
Amplitude Clipping	2.0 to 3.0
Clipping and Filtering	3.9
Companding (MC-CDMA)	3.5 to 6.5
SLM (OFDM)	3.5
PTS (OFDM)	4.3
Block Coding	3.7
DCT	1.0
DWT	2.0

The PAPR reduction techniques should be selected by considering the following factors such as, it should create only few harmful side effects such as in-band distortion, out-of band radiation, reduced BER degradation, low implementation complexity etc.[10]. However, most of the PAPR reduction techniques reduces PAPR at the cost of loss in data rate, increases complexity and transmit signal power etc. Md. KisluNoman, et.al [12] highlight that PTS is a special case of SLM and also the performance of system using PTS is superior to that of the one using SLM. However the use of both PTS and SLM increases the implementation complexity at the receiver.

The system using an excellent coding technique can reduces PAPR and consequently improve the system performance in terms of BER. K Rasadurai , et.al [6] prove that by using efficient forward error coding (FEC) scheme having high coding gain such as Turbo code (TC) and Low density parity code (LDPC) provide better BER performance with reduced PAPR.The Fig 6 shows the BER comparison of a MC-CDMA system using turbo code, LDPC code, uncoded data, and convolutional code data with QAM modulation with AWGN channel [15].

The figure clearly depicts that the LDPC coded MC-CDMA system behaves better than any other coded schemes. Hence the use of block coding technique with a code having high coding gain will help to reduce PAPR with low complexity.

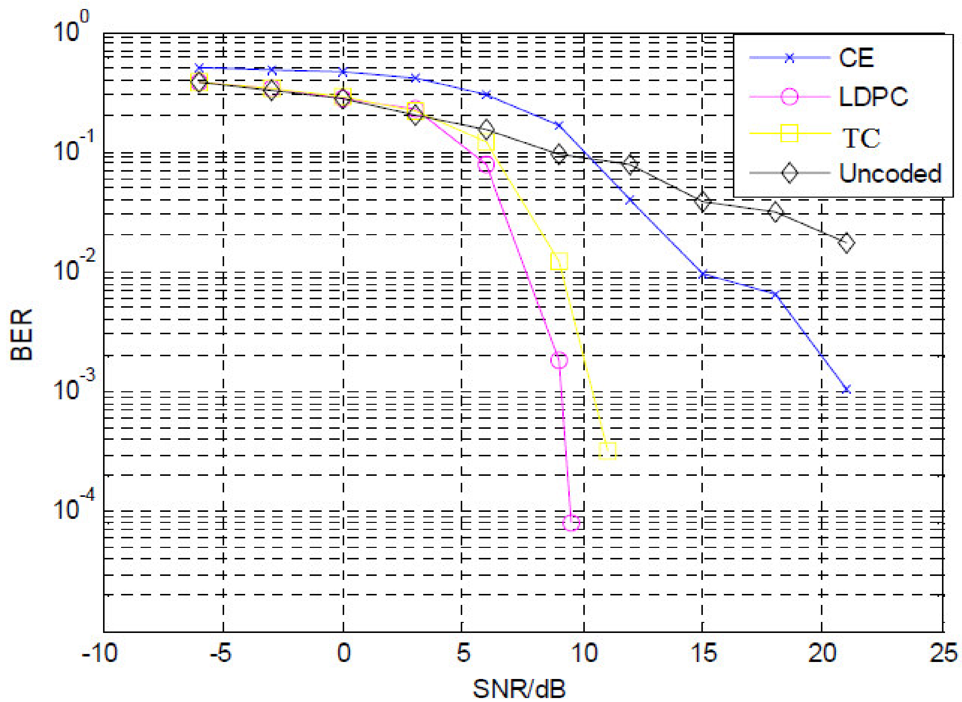

Figure 6: Coded Multi Carrier-Code Division Multiple Access performance for Rayleigh Fading channel [15]

Conclusion

In this paper, we have done an intensive survey of the works done by various researchers on MC-CDMA system and the studies shows that MC-CDMA have both the benefits and limitations of both CDMA and OFDM scheme. The CDMA part makes the system interference limited and the OFDM part reduces the system performance due to high PAPR. Survey [8] points out that the problem due to MPI and MAI can be significantly reduced with the use of spreading code with good correlation properties. The author also suggest a spreading code known as ZCZ code which can reduce both MPI and MAI, if the multi path and multiple access delays are within the zero correlation zone. The studies shows that the PAPR resulting in the system can be effectively reduced with the proper use of PAPR reduction techniques. We are working on the block coding technique with a code having high coding gain such as Turbo code and LDPC code to reduce PAPR and expecting a significant improvement on the system performance with reduced complexity.

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