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Multicarrier CDMA with OFDM for Data-Centric Applications and Performance Analysis

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Abstract— In 4G wireless communication systems, Multicarrier Code Division Multiple Access (MC-CDMA) is one suitable choice to achieve high data rate. MC-CDMA is the combination of CDMA and OFDM schemes, resulting in to getting the advantage of both the schemes. In this paper the BER performance analysis of MC-CDMA using different spreading codes, modulation techniques, channel models, with and without receiver diversities are carried out. Hence achieving increased BER performance and thereby increasing the total capacity by mitigating the effect of Multipath Interference (MI) and Multiple Access Interference (MAI) within MC-CDMA systems.

Index Terms— AWGN,BER,BPSK,CP,FFT,IFFT,MAI,MC-CDMA,MI,MRC,NGN,OFDM,QPSK.

1 Introduction

OVER the decade the focus of wireless communication has shifted from voice to multimedia and data. It became a challenging task to accommodate more users in a limited spectrum. In its evolution from analog first generation technology (1G) to digital second generation technology(2G),General Packet Radio Service (GPRS) and Enhanced Data for GSM Evolution (EDGE), enhanced the data capability of GSM platform . The technology counterpart CDMA evolved from IS-95A to IS -95 B and CDMA-2000. The introduction of WCDMA technology is termed as third generation technique (3G) which ensures 2Mbps throughput for user as per IMT-2000 standard [7]. Wider bandwidth is required to support a higher data rate in a single carrier transmission. To overcome the frequency selectivity of the wideband channel experienced by single-carrier transmission, multiple carriers can be used for high rate data transmission. Since the subcarriers are maintaining orthogonality among themselves the Inter-carrier Interference (ICI) can be suppressed leading to distortion less transmission. Orthogonal Frequency Division Multiplexing (OFDM) [13] is a multi-carrier transmission technique. It is a low-complexity technique to efficiently modulate multiple sub-carriers by using digital signal processing.

To achieve high data rate Multi-carrier code division multiple access (MC-CDMA) is one suitable choice for NGN CDMA based wireless communication system. MC-CDMA is a combination of CDMA and OFDM schemes and is one of the promising 4G techniques. The principle of OFDM-CDMA is to map the chips of a spread data symbol in frequency direction over several in the parallel sub-channels. OFDM-CDMA inherits merits of OFDM and DS-CDMA [1], which has a fine performance. Capacity planning is one of the major issues in designing of wireless communication system. The main objective of this paper is to increase the BER performance and thereby increasing the total capacity by mitigating the effect of Multipath Interference (MI) and Multiple Access Interferences (MAI) using MC-CDMA. The digital modulation considered as (QPSK) in conjunction with Spread Spectrum. The spreading modulation used is the orthogonal Gold codes. The channel model used is Average White Guassian noise (AWGN). Diversity technique used in the receiver is MRC (Maximal Ratio Combining) which will reduce MI. *Eb/No* Vs *BER* plot for 64 point IFFT/FFT based OFDM is also plotted for different noise models like AWGN, Rayleigh fading etc. For an effective interference system performance improvement of OFDM is done by introducing the concept of Cyclic prefixing (CP), which will reduce MAI. Also compairing the BER performance of this system with MC-CDMA system using walsh hadamard code instead of goldcode, BPSK instead of QPSK, Rayleigh fading channel instead of AWGN channel,without receiver diversities.

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2 Spreaind Codes

The MC-CDMA orthogonal spreading codes are one of the major elements within the whole CDMA system. The CDMA orthogonal spreading codes are combined with the data stream to be transmitted in such a way that the bandwidth required is increased and the benefits of the spread spectrum system can be gained. Figure1.shows the concept of CDMA is based around the fact that a data sequence is multiplied by a spreading code or sequence which increases the bandwidth of the signal. Then within the receiver the same spreading code or sequence is used to extract the required data. Only when the required code is used, does the required data appear from the signal. The process of extracting the data is called correlation. When a code exactly the same as that used in the transmitter is used, then it is said to have a correlation of one and data is extracted. When a spreading code [10] that does not correlate is used, then the data will not be extracted and a different set of data will appear. This means that it is necessary for the same spreading code to be used within the transmitter and receiver for the data to be extracted.

2.1 Using Walsh-Hadamard code

The Walsh–Hadamard code is used to define individual communication channels. It is usual in the CDMA literature to refer to codewords as “codes”. Each user will use a different codeword, or “code”, to modulate their signal. Because Walsh–Hadamard codewords are mathematically orthogonal, a Walsh-encoded signal appears as random noise to a CDMA capable mobile terminal, unless that terminal uses the same codeword as the one used to encode the incoming signal. Orthogonal codes are easily generated by starting with a seed of 0, repeating the 0 horizontally and vertically, and then complementing the 1 diagonally [4]. This process is to be continued with the newly generated block until the desired codes with the proper length are generated. Sequences created in this way are referred as “Walsh” code. The Walsh code is used to separate the user in the forward CDMA link. In any given sector, each forward code channel is assigned a distinct Walsh code.

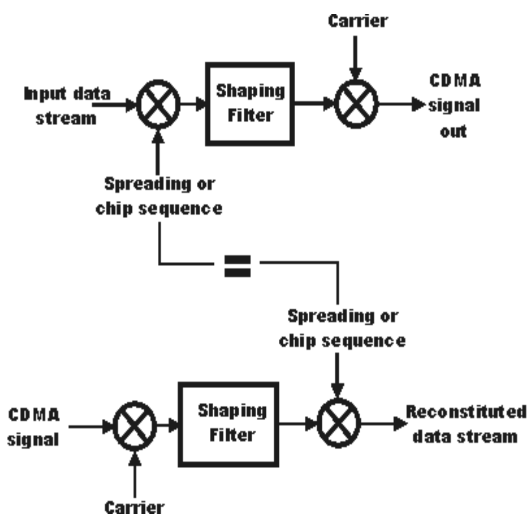

Fig.1. CDMA system showing use of spreading codes

2.2 Gold codes

Orthogonal codes must have good correlation properties to mitigate MAI. W-H code has poor correlation properties and it behave diversely resulting in a large number of BER levels thereby putting some users at disadvantage. When mobile-to-base links cannot be precisely coordinated, particularly due to the mobility of the handsets, a different approach is required. Since it is not mathematically possible to create signature sequences that are both orthogonal for arbitrarily random starting points and which make full use of the code space, unique "pseudo-random" or "pseudo-noise" (PN) sequences are used in *asynchronous* CDMA systems.

A PN code is a binary sequence that appears random but can be reproduced in a deterministic manner by intended receivers. These PN codes are used to encode and decode a user's signal in Asynchronous CDMA in the same manner as the orthogonal codes in synchronous CDMA (shown in the example above). These PN sequences are statistically uncorrelated, and the sum of a large number of PN sequences results in *multiple access interference* (MAI) that is approximated by a Gaussian noise process (following the central limit theorem in statistics). Gold codes are an example of a PN suitable for this purpose, as there is low correlation between the codes. If all of the users are received with the same power level, then the variance (e.g., the noise power) of the MAI increases in direct proportion to the number of users. In other words, unlike synchronous CDMA, the signals of other users will appear as noise to the signal of interest and interfere slightly with the desired signal in proportion to number of users. Signals become more sensitive to non linearities of transmitter for high peak average to power ratio. In uplink PAPR can be reduced by Golay code [12].

3 MULTICARRIER CDMA

The most important objectives in the 4th generation wireless mobile communication systems are to enable the integration of existing technologies in a unified platform, to take care of the severe Inter-Symbol Interference (ISI), to provide high speed data transmission rate in a spectrally efficient manner with utilizing the available limited bandwidth and to achieve low cost and reduced complexity receivers and their signal processing solutions for high quality communication. Multicarrier techniques on multi-path fading environment can be one of the best solutions to achieve the above performance. Due to the limitations of Orthogonal Frequency Division Multiplexing (OFDM) and Code Division Multiple Access (CDMA), Multi-Carrier Code Division Multiple Access (MC-CDMA) [9] which is a multiple access scheme generated by the combination of OFDM and CDMA has received much attention. Each user symbol in the frequency domain is spreaded by the MC-CDMA. In other word, each user symbol is phase shifted according to a code value and carried over multiple parallel sub-carriers. However, the code values differ per sub-carrier and per user. All sub-carrier signals are merged at the receiver and undo the code shift. Then the receiver separates signals of different users. So, the network can accommodate many users within a given frequency band. It has many other advantages like robustness to channel dispersion, high frequency spectrum efficiency and high data transmissions.

3.1 OFDM Based Multicarrier Transmission

In the last years wireless communications have experienced a fast growth due to the high mobility that they allow. However, wireless channels have some disadvantages, like multipath fading, that make them difficult to deal with. A modulation that efficiently deals with selective fading channels is orthogonal frequency division multiplexing (OFDM)[9], which consists on *N* orthogonal subcarriers generated and modulated in frequency domain. Figure 2. shows the OFDM model.

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Multicarrier transmission splits the high-rate data stream into *N* substreams of lower data rate. Classical parallel-data systems divide the available bandwidth into *N* non overlapping subchannels. Each subchannel is modulated with a separate symbol and then the *N* subchannels are frequency multiplexed. This way interchannel interference is eliminated but it leads to poor spectral efficiency. In order to use the spectrum more efficiently it was proposed to use overlapping subchannels, but in overlapping subchannels it is necessary to eliminate crosstalk between subcarriers, which means that the different modulated subcarriers have to be orthogonal to each other.

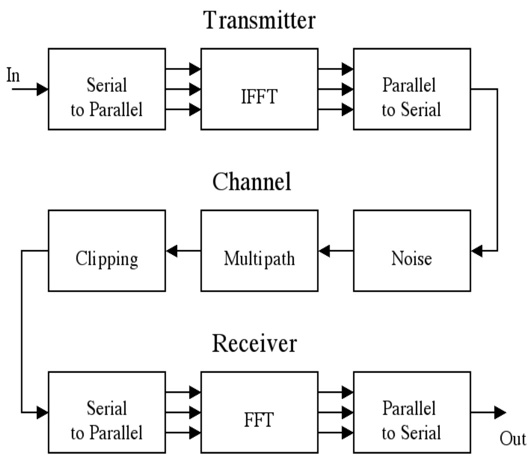

Fig.2. OFDM Model

Orthogonal means that there is a precise mathematical relationship between the frequencies of the carriers of the system.The fact that the subcarriers are orthogonal allows the usage of the Fourier transform without introducing intercarrier interference (ICI). The advancements in digital signal processing and very large scale integrated circuits allow efficient and cost-effective implementation of the fast Fourier transform (FFT) operations making OFDM an attractive solution for wireless channels.

4 System Model

4.1 Transmitter Model

Figure 3. shows the simulation model of MC-CDMA transmitter. Randomly generated user data are randomized and output of randomizer is fed to forward error correction (FEC) block where randomized data are coded by Reed Solomon and convolutional encoder. FEC code has high gain and adopted in WCDMA and WiMAX standards. Viterbi algorithm is used for decoding the convolutional coding. Output of FEC code is interleaved and modulated. For modulation, QPSK is used. Modulated output is spreaded by Gold spreading code in frequency domain then transmitted simultaneously on *Nc* parallel subcarriers.

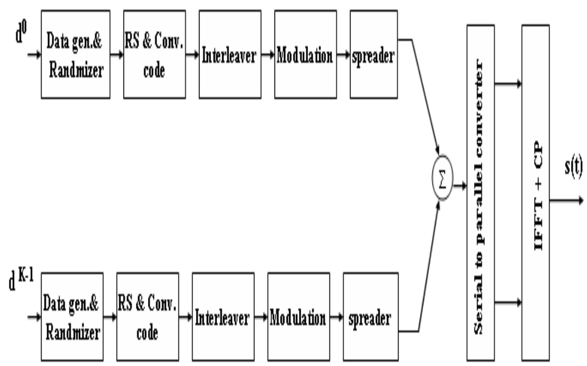

Fig.3. MC-CDMA Transmitter Model

These parallel subcarriers are orthogonal to each other and can be generated by using Inverse Fast Fourier transform (IFFT). After this cyclic prefix is used as a guard interval to minimize the effect of inter carrier interference (ICI). Now parallel to serial converter (P/S) converts parallel data into serial data stream and transmit over channel. The transmitted baseband signal for the *kth* user is given by

$$s_k(t) = 2P_k \sum_{i=-\infty}^{\infty} \sum_{n=1}^{N_c} d_k(i)\, p_{T_b}(t - iT_b)\, a_k(n) \cos(w_n t + \theta_{k,n}) \quad (1)$$

Where *K* is the number of the active user, *i* is the number of the information symbol *Nc* is the total number of subcarrier, *Pk* is the transmitted power of *kth* user, *dk(i)* is the ith binary data sequence of *kth* user, *ak(n)* is the spreading sequence on nth subcarrier of *kth* user, *wn* is the carrier frequency and α *k,n* is the phase of the nth subcarrier for *kth* user which is independent and identically distributed over [0, 2∏] interval .

p Tb is the rectangular symbol pulse waveform defined as

$$p\ Tb = 1 \quad \text{For } 0 \le t \le Tb$$
$$= 0 \quad \text{Otherwise} \quad (2)$$

4.2 Channel Model

The channel is assumed additive white Gaussian (AWGN) on each subcarrier. Complex equivalent of this channel is described as,

$$Y(n) = V(\theta)s(n) + G(n) \quad (3)$$

Where, V (θ) is the array manifold vector and G (n) is AWGN with zero mean and two-sided power spectral density given by No/2.

4.3 Receiver Model

Receiver model of MC-CDMA is shown in Figure 4.

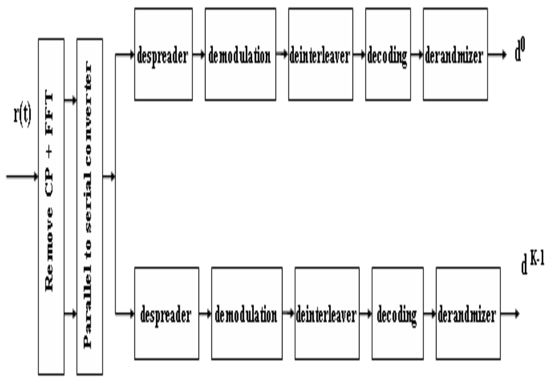

Fig.4. MC-CDMA Receiver Model

At receiver first convert serial data into parallel by serial to parallel converter (S/P) then remove the cyclic prefix and take the Fast Fourier Transform (FFT) of received signal. After that despread and demodulate the users signal. The output of demodulator passes through the channel decoder. The decoded output is derandomized and obtained the users data.

4.4 Receiver Diversity

Antenna diversity is especially effective at mitigating the multipath situations. This is because multiple antennas offer a receiver several observations of the same signal. Each antenna will experience a different interference environment. Thus, if one antenna is experiencing a deep fade, it is likely that another has a sufficient signal. Collectively such a system can provide a robust link

In this paper, considering maximal-ratio combining as a receiver diversity technique for mitigating the effect of MPI. The properties of maximal-ratio combining are,

- All paths cophased and summed with optimal weighting to maximize combiner output SNR
- Optimal technique to maximize output SNR
- A means of combining the signals from all receiver branches, so that signals with a higher received power have a larger influence on the final output.

5 Performance Analysis

BER Vs Eb/No Performance Analysis was done for the transceiver .Bit Error rate is averaged for finite number of iteration and mean value is taken. The performance of Receiver diversity block is tested with and without diversity component. The performance of the Maximal Ratio Combiner is being tested. Similarly unitary codes are defined as orthogonal codes which are allocated on a unitary basis. ie, One code is allocated per user at a time. The orthogonal unitary codes are being analysed for their BER performance.

6 Simulation Results

Proposed implementation of MC-CDMA transceiver described was simulated using MATLAB Version 7.10 R2010a.

Each block of MC-CDMA transmitter and receiver is individually coded. Reed Solomen and convolution code is used as a channel coding. Figure 5&6. shows the BER vs SNR analysis for MC-CDMA using Walsh Hadamard coding with 64 point FFT based OFDM as the multicarrier technique. They are analysed without receiver diversity shown in Figure 5. &with receiver diversity shown in Figure 6. It achieved BER level of between 10^0 and 10^{-1} in the case of without receiver diversity and achieved BER level of between 10^{-1} and 10^{-2} in the case of with receiver diversity .

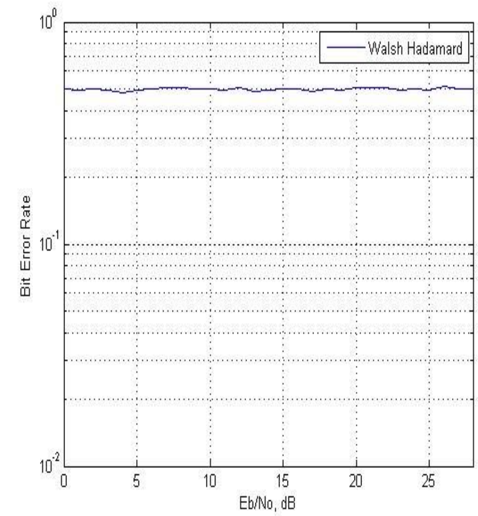

Fig.5. MC-CDMA system without receiver diversity and using Walsh-Hadamard code as spreading code.

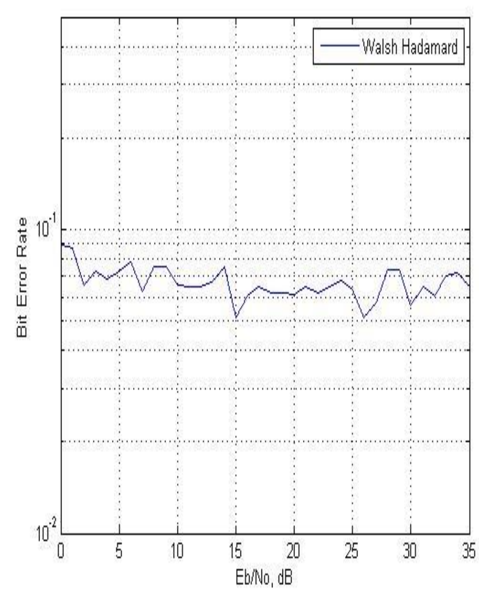

Fig.6. MC-CDMA system with receiver diversity and using Walsh-Hadamard code as spreading code.

Figure 7. shows BER vs SNR analysis for MC-CDMA using Gold coding with 64 point FFT based OFDM as the multicarrier technique. It adopted with Cyclic prefix and Maximal Ratio Combining for reducing interferences. Hence achieved improved BER level of about 10^{-3} and capacity, than the system using walsh hadamard code as spreading code.

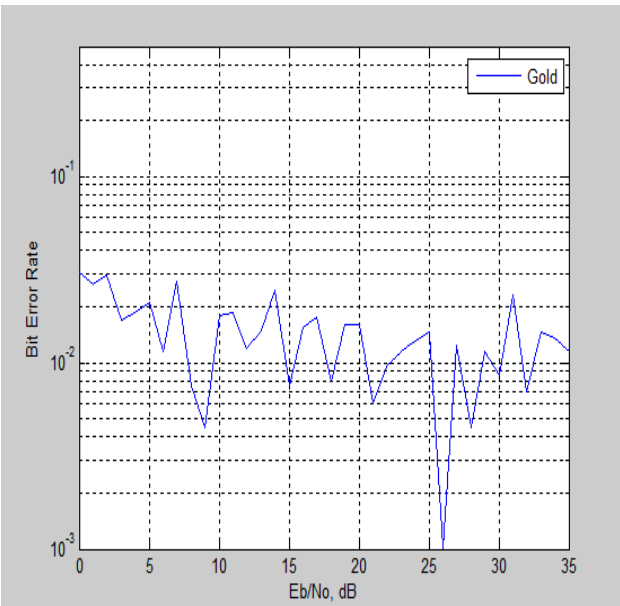

Fig.7. MC-CDMA system with MRC as receiver diversity and gold code as spreading code.

7 Conclusion

In this paper, analysed the MC-CDMA system over additive white guassian channel. Improved BER performance will increase the capacity of the system. MAI and MPI may reduce the performance of the system. So, orthogonal gold codes are introduced for mitigating MAI and maximal-ratio combining diversity techniques are used to mitigate the effect of MPI. Cyclic prefixing is also introduced for mitigating ISI. From simulation results, it is observed that BER performance is significantly improved with orthogonal gold code. Compared the performance among the BPSK, QPSK modulation techniques and its shown that QPSK can provide substantial performance improvement over BPSK. By the use of these parameters, achieved BER performance at the level of 10^{-3} and due to this, high data rate with increased capacity can be obtained.

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