Performance analysis of Multi Carrier CDMA System with DCT-OFDM

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Abstract

In this paper, a precise method for calculating the bit-error rate (BER) of a discrete cosine transform (DCT)-based orthogonal frequency-division multiplexing (OFDM) system on additive white Gaussian noise (AWGN) channels for a Multicarrier-CDMA (MC-CDMA) is derived and its BER performance will be compared with the FFT based MC-CDMA. These accurate results are used to examine and compare the BER performance of a DCT-MC-CDMA system and the conventional Fast Fourier transform (FFT)-based MC-CDMA system in an AWGN environment. Some signaling formats, such as phase-shift keying (PSK),binary phase-shift keying(BPSK), Quadrature Phase shift keying(QPSK) and 16-ary quadrature amplitude modulation (QAM), Differential Phase Shift Keying(DPSK) modulation are considered. As DCT requires less computation than FFT we can reduce MC-CDMA design complexity by exploiting DCT characteristics.

Keywords: *Bit-error probability (BEP) analysis, discrete cosine transform (DCT), fading channels, intercarrier interference (ICI), orthogonal frequency-division multiplexing (OFDM).*

I. INTRODUCTION

Multicarrier communication based on Multi carrier Code Division Multiplexing Access (MC-CDMA) principles are increasingly being deployed in broadband wireless communication standards such IEEE 802.11 (Wi-Fi) and IEEE 802.16 (WiMax)[1-3]. In recent years orthogonal frequency division multiplexing (OFDM)[1] and code division multiple access (CDMA) systems [4] have gained considerable attention due to their use in high speed wireless communication. Both OFDM and CDMA have unique features, for example, the former is good in bandwidth utilization, and the later has multi-user potential. Orthogonal frequency division multiplexing-code division multiple access (OFDM-CDMA) [5],[6] attempts to combine these features, so that we can attain higher data rates for multiple users simultaneously. In order to achieve a high spectral efficiency and to combat the frequency selectivity of the channel OFDM is employed. OFDM efficiently grip multiple modulated carriers tightly together, reducing the required bandwidth but keeping the modulated signals orthogonal so they do not interfere with each other.

However, the complex exponential function set is not the only orthogonal basis that can be used to construct baseband multicarrier signals [7], a single set of sinusoidal functions can be used as an orthogonal basis and this scheme can be synthesized using a discrete cosine transform (DCT). Hence, we will denote the scheme as DCT-MC CDMA, and the conventional CDMA system as FFT-MC-CDMA in this paper. Conceptually, OFDM is a specialized FDM, the additional constraint being the entire carrier signals are orthogonal to each other. In OFDM, by choosing the sub-carrier frequencies they satisfy the property of orthogonality. This simplifies the design of both the transmitter and the receiver. A separate filter design for each sub-channel is not required as in conventional FDM. The orthogonality also gives high spectral efficiency [8], with a total symbol rate near the Nyquist rate for the equivalent baseband signal. One key principle of OFDM is that since low symbol rate modulation schemes [9],[10] (i.e., where the symbols are relatively long compared to the channel time characteristics) suffer less from intersymbol interference caused by multipath propagation; it is advantageous to transmit a number of low-rate streams in parallel instead of a single high-rate stream. Since the duration of each symbol is long, it is possible to introduce a guard interval between the OFDM symbols, thus eliminating the ISI. The guard interval also eliminates the need for a pulse-shaping filter, and it reduces the sensitivity to time synchronization problems.

Here, OFDM in its primary form is considered as a digital modulation technique, and not a multi-user channel access method, since it is developed for transferring one bit stream over one communication channel using one sequence of OFDM symbols. However, OFDM can be combined with multiple access using time, frequency or coding separation of the users. In orthogonal frequency-division multiple access (OFDMA) [11], multiple access is achieved by conveying different OFDM sub-channels to different users. OFDMA supports distinguished quality of service by assigning different number of sub-carriers to different users in a analogous fashion as in CDMA, and thus complex packet scheduling or Media Access Control schemes can be avoided.

Particularly, for real-valued modulation formats, such as BPSK and pulse amplitude modulation (PAM), in the absence of a quadrature modulator, DCT-MC CDMA can completely avoid the in-phase/quadrature-phase (IQ) imbalance problem addressed in [12] inherent in conventional FFT-based CDMA systems. As far as fast implementation algorithms are concerned, the fast DCT algorithms proposed in [13] and [14] can provide fewer computational steps than FFT algorithms.

In this paper, we will first give a BER analysis for a DCT-MC-CDMA system operating in the presence of white noise over an AWGN channel. We show that DCT-MC CDMA gives greater signal-to-interference ratio (SIR) than FFT-MC-CDMA in this case. We then derive exact expressions for the BER of DCT-MC CDMA systems in an AWGN channel, and compare the BER performance of the DCT-MC CDMA system with the conventional FFT-MC CDMA system by using the obtained BER performance expressions. Our results indicate that in the presence of noise, the BER performance of DCT-MC CDMA is superior to that of FFT- MC CDMA due to the energy-compaction property [15] of the DCT; that is, the signal energy is concentrated in a few low-index DCT coefficients, while the remaining coefficients are zero or negligibly small. Having shown better BER performance of DCT-MC-CDMA over an AWGN channel we further consider the bit-error rate (BER) performance of DCT-MC CDMA by simulation in Rayleigh fading environments.

The remainder of this paper is organized as follows. In Section II, the system model is given and then we introduce the analysis of FFT-MC CDMA system and DCT-MC CDMA. The BER analysis for FFT/DCT-MC CDMA systems with different modulation formats in the presence of white noise, performance comparisons with FFT-MC CDMA and some discussion are presented in Section III. Finally, we draw our conclusions in Section IV.

II. SYSTEM MODEL

A. *Implementation of MC CDMA with FFT*

A generic bit interleaved MIMO system with n_T transmit antennas, n_R receive antennas ($n_R \geq n_T$) and a certain SNR was described. Fig. 1 is a detailed block diagram for a DCT/FFT-MC CDMA system including modulators in the presence of additive white Gaussian noise. It becomes a FFT- system when the IDCT and DCT modules are replaced with the IFFT and FFT modules, respectively.

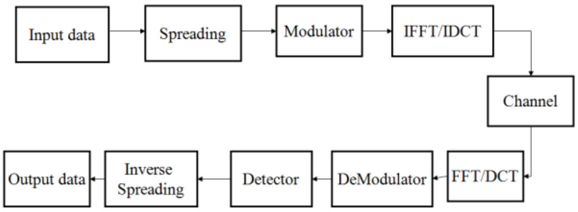

Figure 1.block diagram of DCT-MC CDMA

The MC-CDMA based system consists of an OFDM baseband CDMA transmitter and an OFDM based CDMA receiver.

The discrete Fourier transform (DFT) converts a finite list of equally spaced samples into the list of coefficients of a finite combination of complex sinusoids, ordered with frequencies, with same sample values. The input samples are complex numbers, and the coefficients with respect to output are complex as well. The output sinusoid frequencies are integer multiples of a fundamental frequency, whose equivalent period is the length of the sampling interval. The combination of sinusoids obtained by taking DFT is periodic with that same period. These implementations usually employ efficient fast Fourier transform (FFT) algorithms; so much so that the terms "FFT" and "DFT" are often used interchangeably.

The sequence of N complex numbers x_0, $x_1,x_2,\ldots x_{N-1}$ is transformed into an N-periodic sequence of complex numbers $X_0,X_1,X_2,\ldots X_{N-1}$ according to the DFT formula:

$$X_k = \sum_{n=0}^{N-1} x_n * e^{-j2\pi kn/N}$$

(1) Notice that this new sequence X_i repeats after N terms, so $X_0=X_N$, $X_1=X_{N+1}$ and so on. In this context, it is common to define ω to be the N^{th} primitive root of unity, ω=e2πi/N, to obtain the following form:

$$X_k = \sum_{n=0}^{N-1} x_n * \omega^{-kn}$$

(2)

The transform is sometimes denoted by the symbol F, as in X=F(X) or F(X).It can also provide uniformly spaced samples of the continuous DTFT of a finite length sequence (Sampling the DTFT). It acts like a matched filter for that frequency. It is the discrete analogy of the formula for the coefficients of a Fourier series:

$$x_n = \sum_{n=0}^{N-1} x_k * e^{j2\pi kn/N}$$

(3)

which is the inverse DFT (IDFT).

B. *Implementation of MC CDMA with DCT*

A discrete cosine transform (DCT) expresses a finite sequence of data points in terms of a sum of cosine functions oscillating at different frequencies. Formally, the discrete cosine transform is a linear, invertible function

$f: R^N \rightarrow R^N$(where R denotes the set of real numbers), or equivalently an invertible N × N square matrix:

$X_k = \sum_{n=0}^{N-1} x_n \cos\left[\frac{\pi * (n+\frac{1}{2})K}{N}\right]$ k =0,…..,N-1

(4)

This transform is exactly equivalent (up to an overall scale factor of 2) to a DFT of 4N real inputs of even symmetry where the even-indexed elements are zero. That is, it is half of the DFT of the 4N inputs y_n, where $y_{2n}=0$, $y_{2n+1}=x_n$ for 0≤ N<n, $y_{2n}=0$, and $y_{4N-n}=y_n$ for 0<n<2N. IFFT AND IDCT converts the long single sequence signal to multi carrier signals. It converts time domain sequence into frequency domain sequence.

III. IMPLEMENTATION WITH DIFFERENT MODULATION FORMATS

Input data given to the MC-CDMA system here we are using Random generator as the Input source. Spreading actually performs the interleaving of input data sequence. Modulator is used to represent the input data in predefined format. In communication system number of modulation techniques are available they are QAM, BPSK, DPSK etc.

A. Phase Shift Keying

Any digital modulation scheme uses a finite number of distinct signals to represent digital data. A limited number of phases are used in PSK each assigned a distinctive pattern of binary digits. Generally, each phase encodes an equal number of bits. Every pattern of bits forms the symbol that is represented by the exact phase. The demodulator, designed particularly for the symbol-set used by the modulator determines the phase of the received signal and maps it back to the symbol it represents, thus recovering the original data. This requires the receiver to be able to compare the phase of the received signal to a reference signal. The probability that a single sample taken from a random process with zero-mean and unit-variance Gaussian probability density function will be greater or equal to x. It is a scaled form of the complementary Gaussian error function:

$Q(X) = \frac{1}{\sqrt{2\pi}}\int_x^{\infty} e^{-t^2/2}\,dt = \frac{1}{2}\operatorname{erfc}\left(\frac{x}{\sqrt{2}}\right)$, $x \geq 0$

(5)

In reality, transmission is always corrupted by noise whatever may be the type of channel assumed. The simplest mathematical model of the radio channel is the additive white Gaussian noise (AWGN) channel. The error-rates quoted here are those in additive white Gaussian noise (AWGN).

B. Binary Phase Shift Keying

BPSK is the simplest form of phase shift keying (PSK). It uses two phases which are separated by 180° and so can also be termed 2-PSK. Usually the constellation points are exactly positioned, and in this they are shown on the real axis, at 0° and 180°. This modulation is the most robust of all the PSKs since it takes the highest level of noise or distortion to make the demodulator reach an inaccurate assessment. It is, however, only able to modulate at 1 bit/symbol and so is not fitting for high data-rate applications.

The bit error rate (BER) of BPSK in AWGN can be calculated as

$P_b = Q\left(\sqrt{\frac{2E_b}{N_0}}\right)$ or $P_b = \frac{1}{2}\operatorname{erfc}\left(\sqrt{\frac{2E_b}{N_0}}\right)$

(6) QPSK uses four points on the constellation diagram, equispaced around a circle. With four phases, QPSK can encode two bits per symbol, with gray coding to minimize the bit error rate (BER) sometimes misperceived as twice the BER of BPSK.

C. Quadrature amplitude modulation (QAM)

In Quadrature amplitude modulation (QAM) both an analog and a digital modulation scheme is employed. It conveys two analog message signals, or two digital bit streams, by changing the amplitudes of two carrier waves, using the amplitude-shift keying (ASK) digital modulation scheme or amplitude modulation (AM) analog modulation scheme. The two carrier waves, usually sinusoids, are out of phase with each other by 90° and are called quadrature carriers or quadrature components. The modulated waves are summed, and the resulting waveform is a combination of both phase-shift keying (PSK) and amplitude-shift keying (ASK), or phase modulation (PM) and amplitude modulation(AM).

In determining error rates for QAM it is given by

$Q(x) = \frac{1}{\sqrt{2\pi}}\int_x^{\infty} e^{-\frac{1}{2}t^2}\,dt, x \geq 0$

(7)

Q(x) is related to the complementary Gaussian error function by:$Q(x) = \frac{1}{2}\,erfc\left(\frac{1}{\sqrt{2}}x\right)$, which is the probability that x will be under the tail of the Gaussian PDF towards positive infinity.

IV. BER ANALYSIS

In this section, the exact BER performance of a DCT-MC CDMA system in the presence of additive white Gaussian noise is evaluated. The analysis is restricted to BPSK, DPSK, and 16-QAM, but our method can be used for other modulation formats. We will compare the performances of a subcarrier FFT-MC CDMA system and a subcarrier

DCT MC CDMA system using the exact BER analysis results obtained in the preceding section.

To ensure the reliability of the computer simulation, codes are generated to obtain each BER value in Figs. 2-7. The comparisons are based on the same signal-to-noise ratio (SNR) per bit, where the average energy per bit is in the case of QAM. Fig. 2 shows the BER performance of a subcarrier FFT MC CDMA system and Fig. 3 shows the BER performance of a subcarrier DCT-MC CDMA system, both with BPSK modulation.

These results clearly show that DCT-MC CDMA is comparable to FFT. The performance of

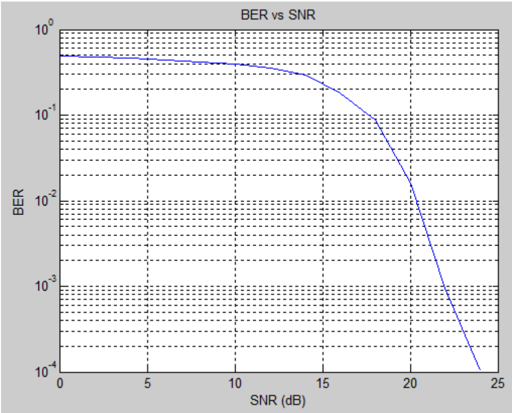

Fig 2. BER VS SNR curve for FFT multicarrier system with BPSK modulation

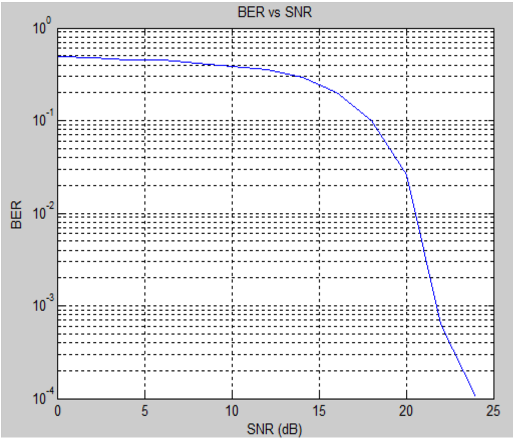

Fig 3 BER VS SNR curve for DCT multicarrier system with BPSK modulation

DPSK-modulated FFT-MC CDMA with additive white Gaussian noise is compared with the performance of DPSK-modulated DCT MC CDMA with white Gaussian noise in Figures 4-5.

In the case of, the BER performance for the two systems are quite similar. The performance of two systems with QAM signaling is shown in Fig. 6-7. The comparability of DCT-MC CDMA over FFT-MC CDMA can be clearly seen. There by we can expliot the computational complexity redution with the help of DCT over FFT in MC-CDMA implementation.

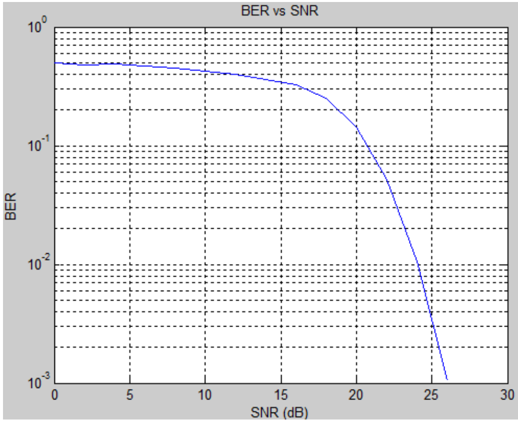

Fig 4. BER VS SNR curve for FFT multicarrier system with DPSK modulation

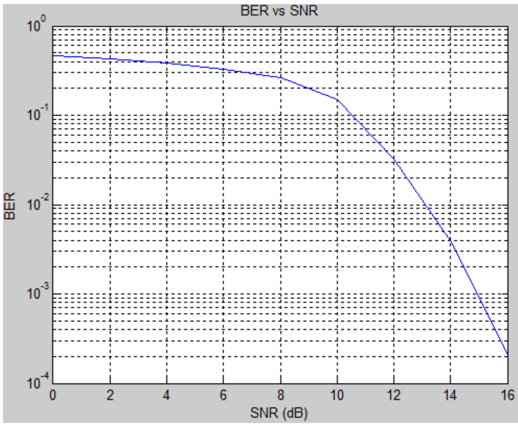

Fig 6. BER VS SNR curve for FFT multicarrier system with QAM modulation

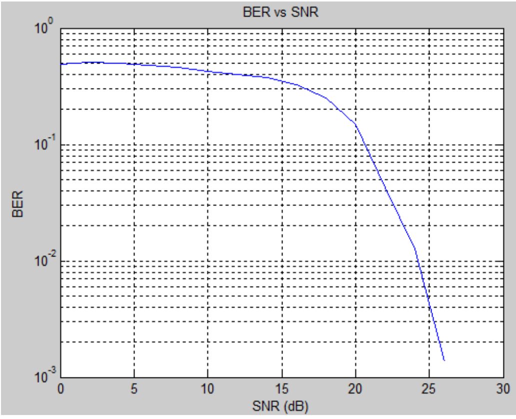

Fig 5. BER VS SNR curve for DCT multicarrier system with DPSK modulation

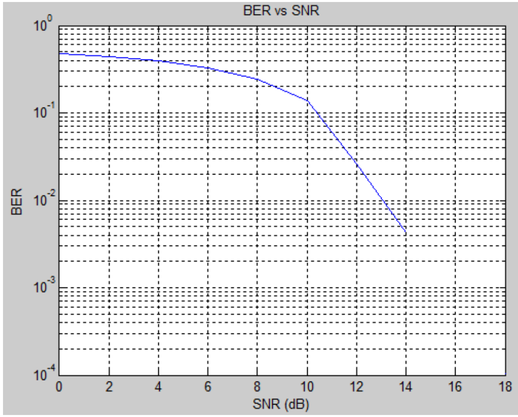

Fig 7. BER VS SNR curve for FFT multicarrier system with QAM modulation

Table 1 Performance comparison of BER for Different modulation formats with FFT/DCT

SNR	BER for BPSK DCT	BER for BPSK FFT	BER for DPSK DCT	BER for DPSK FFT	BER for QAM DCT	BER for QAM FFT
0	0.4934375	0.493229167	0.489895833	0.488333333	0.472604167	0.470625
2	0.4803125	0.476875	0.49375	0.4971875	0.44625	0.453541667
4	0.466979167	0.468229167	0.478958333	0.4778125	0.388958333	0.394583333
6	0.44875	0.4365625	0.473125	0.4728125	0.3290625	0.314791667
8	0.419791667	0.411354167	0.458229167	0.443958333	0.256354167	0.262083333
10	0.393541667	0.3834375	0.426354167	0.433125	0.1396875	0.146458333
12	0.350833333	0.355104167	0.408854167	0.3846875	0.0240625	0.041145833
14	0.305416667	0.279270833	0.362083333	0.3653125	0.003541667	0.005
16	0.2059375	0.221875	0.313020833	0.3215625	0	0.000208333
18	0.1028125	0.081145833	0.23375	0.245416667	0	0
20	0.023854167	0.018229167	0.161979167	0.157395833	0	0
22	0.001979167	0.001458333	0.051875	0.0584375	0	0
24	0.000104167	0.000104167	0.01125	0.011770833	0	0
26	0.000000000	0.00000000	0.000520833	0.001354167	0	0

V. CONCLUSION

The increasing demand for the development of wireless communication systems for high data rate transmission and high quality information exchange leads to the new challenging subjects in the telecommunication research area. The MC CDMA systems with DCT are able to achieve a better BER performance as compared to the MC CDMA with FFT with less computational complexity. Simulations and measurements were presented to show the capability for several MC CDMA systems. It could be shown that the reliability and capacity significantly increase with increasing the number of transmit and receive antennas. From the study and overview of MC CDMA systems, it is clear that MC CDMA systems offer significant gains in performance over traditional wireless communication systems. For this reason, CDMA technology is poised to play an important role in the next generation mobile communication systems and standards.

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