WAVELET BASED MULTICARRIER CODE DIVISION MULTIPLE ACCESS COMMUNICATION FOR WIRELESS ENVIRONMENT

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ABSTRACT

This paper presents the study on Wavelet transform based Multicarrier Code Division Multiple Access (MC-CDMA) system for a downlink wireless channel. The performance of the system is studied for Additive White Gaussian Noise Channel (AWGN) and slowly varying multipath channels. The bit error rate (BER) versus Signal to Noise ratio (SNR) is used as a performance measure using simulation done on computer. Comparison of the simulated results with the theoretical limit of a BPSK modulated signal shows that this system performs near the theoretical limit for both AWGN and slowly varying Flat fading channel. Also, a comparison with the Discrete Fourier Transform (DFT) based system was made for AWGN channel and the result shows that even in the absence of a guard interval, the wavelet based system performs equally with the DFT.

INTRODUCTION

MC-CDMA systems were introduced in an attempt to combine Direct Sequence CDMA (DS-CDMA) principles with Multicarrier Modulation (MCM), while preserving the main advantages of both. The goal of combining these two transmission techniques is to obtain a bandwidth efficient multiple access system with good performance under conditions of Multipath transmission, and also allow a relatively simple receiver implementation. This modulation also provides multiple access mechanisms in the sense that different users can use the same set of subcarriers but with a different spreading sequence that is orthogonal to the sequences of all other users [1].

The MC-CDMA schemes are generally categorized in to two main groups: one method combines frequency domain spreading and is usually referred to as MC-CDMA. The second one combines time domain spreading and MC-CDMA, and is called Multicarrier Direct Sequence CDMA (MC-DS-CDMA). In this work MC-CDMA is considered.

MCM, also called Orthogonal Frequency Division Multiplexing (OFDM) for wireless channels, solves the problem of Intersymbol Interference (ISI) encountered during transmission at high data rates over multipath channels, since the time duration of the signal waveform representing one symbol is increased compared to a single-carrier system. This is achieved by dividing the available bandwidth into a number of overlapping frequencies but that are mathematically orthogonal subcarriers; and the data can be transmitted across multiple narrowband channels which suffer only from flat fading.

CDMA, a technology that is being widely chosen for third-generation mobile phone network, allows multiple radio subscribers to share the same frequency band at the same time by assigning each user a unique code. The technology makes very efficient use of limited spectral resources and allows robust communication over time varying radio channels. Basically, CDMA is based on spread spectrum technique.

The combination of MCM and CDMA into MC-CDMA appears to be very attractive in mobile communications. The MCM can be implemented by using Discrete Fourier Transform (DFT) that provides orthogonal basis between subchannels. Recently, another method known as Discrete Wavelet Transform (DWT) has been proposed to replace the DFT for MCM both for wired and wireless applications [1].

The DFT-based system, however, has some drawbacks. In a high rate DFT-based system addition of cyclic prefix is required to eliminate ISI. This results in the reduction of bandwidth efficiency amounting to about 20% [2]. Other drawbacks of the DFT-based system are the difficulty encountered in subcarrier synchronization in fading channels and pronounced sensitivity to frequency offset compared to that of a single carrier. Maintaining good synchronization would require pilot tones that add to further reduction in bandwidth efficiency. [2]

A wavelet-based system can be used instead of DFT for multicarrier modulation. Wavelet transform has a property of time-frequency multiresolution [1]. By the choice of an appropriate wavelet function and scaling function this system can achieve optimum resolution as required. The use of discrete wavelet multitone can result in lower interchannel interference, more robustness against multipath fading and lower the effect of narrow band interference or jamming signal [2]. Thus the wavelet-based MC-CDMA system is capable of providing higher spectral efficiency and more capacity.

This paper presents a Wavelet based MC-CDMA (W-MC-CDMA) for the downlink channel of a cellular system. The paper is structured as follows. First, a brief description of the nature and characteristics of Discrete Wavelet Transform are given; then the system and channel models used in the study are presented. Finally, the performance of W-MC-CDMA on the channels characterized earlier are presented, discussed and conclusions drawn from the results.

Basics of Wavelets

DWT is used to represent a continuous time signal in terms of shifted and scaled versions of a prototype wavelet function *ψ(t)* known as the basic (or mother) wavelet function. The DWT and the Inverse Discrete Wavelet Transform (IDWT) of a signal $s(t)$ are respectively given by [1,3-8]:

$$s_{mn} = \int_{-\infty}^{\infty} s(t) 2^{m/2} \psi(2^m t - n) dt \tag{1}$$

$$s(t) = \sum_{m=-\infty}^{\infty} \sum_{n=-\infty}^{\infty} s_{mn} 2^{m/2} \psi(2^{m/2} t - n) \tag{2}$$

where m, n are integers and s_{mn} are called the wavelet coefficients. It can be shown that the dilated and translated wavelets $\psi_{mn}(t) = 2^{m/2} \psi(2^m t - n)$ are orthogonal to each other, i.e.

$$< \psi_{m,n}(t), \psi_{j,k}(t) >= \int_{-\infty}^{\infty} \psi_{j,k}(t) \psi_{m,n}(t) dt = \delta_{j-m} \delta_{k-n} \tag{3}$$

For any wavelet, there exist corresponding scaling functions $\phi_{mn}(t)$, which are also generated from a mother scaling function $\phi(t)$. The scaling functions also satisfy the orthogonality relation along translation such that

$$< \phi_{j,k}(t), \phi_{j,n}(t) >= \delta_{k-n} \tag{4}$$

For any $j \le m$,

$$< \psi_{j,k}(t), \phi_{m,n}(t) >= 0 \tag{5}$$

These relations form the basis of the wavelet transform application in communications. There exist many families of wavelets and scaling functions that satisfy the above conditions [3].

Mallat and Meyer demonstrated a simple way of calculating wavelet function (Fast wavelet transform, FWT). Their work established a connection between continuous time wavelet and digital filter-bank. Also Daubechies developed a systematic technique for generating finite-duration orthonormal wavelets with FIR filter banks [6, 7].

In this work, a generalization of wavelet called wavelet packets are used, and the family of wavelets considered are the Daubechies wavelets of order 4 and 10. [1]

SYSTEM MODEL

Channel Model [1, 5]

Noise and interference

Noise is usually modeled as Additive White and Gaussian (AWGN). Given the transmitted signal $s(t)$, the received signal $r(t)$ can be represented as:

$$r(t) = s(t) + n(t) \tag{6}$$

where $n(t)$ is a zero-mean AWGN, with power spectral density of $\frac{N_0}{2}$.

In general, cellular mobile radio communication systems rely on frequency reuse, where the same radio frequency band serves users in geographically separated cells. Also in CDMA systems, multiple numbers of users use the same frequency band within a cell. This introduces *Co-Channel Interference* coming from the cells using the same carrier frequency. There is also *Adjacent Channel Interference* due to partial spectral overlap between neighboring radio channels.

Mathematically, interferences are modeled to be additive, as in Eq. (7).

$$r(t) = s(t) + n(t) + I(t) \qquad (7)$$

where $r(t)$, $s(t)$ and $n(t)$ are as in Eq. (6), $I(t)$ is the interfering signal. In this work, a total of 20 active users *all with equal average energy* are considered.

Small scale fading

In a wireless mobile communication system, a signal may travel from transmitter to receiver over multiple reflective paths, giving rise to the phenomenon often referred to as *multipath propagation*. The effect can cause fluctuations in the received signal's *amplitude, phase*, and *angle of arrival*, resulting in multipath fading. Generally, multipath fading manifests itself in two ways, namely: *Time-spreading* of the signal (or signal dispersion) and *Time-variant* behavior of the channel.

Flat fading vs. frequency selective fading

Time dispersion (*excess delay*) represents the signal propagation delay that exceeds the delays of the first arrival of signal at the receiver. For a single transmitted impulse, the time T_m, between the first and last received component represents the maximum excess delay during which the multipath signal power falls to some threshold level below that of the strongest component. Viewed in frequency domain, we can define a *coherence bandwidth*, f_0, *as* a statistical measure of the range of frequencies over which the channel passes all spectral components with approximately equal gain and linear phase. Excess delay and coherence bandwidth are approximately related by

$$f_o \approx \frac{1}{T_m} \qquad (8)$$

In a multipath environment the time dispersion causes signal fading which can be classified as either *Flat* or *Frequency Selective Fading*. For a narrow-band transmission where the signal bandwidth is much less than coherence bandwidth, fading introduces very little or no frequency distortion; the received signal is then said to have undergone flat fading. On the other hand, if the signal bandwidth is greater than the coherence bandwidth of the channel, different frequency components of the signal will be affected differently by the channel. This is refereed to as frequency-selective fading. In time domain, this frequency selective fading leads to Inter-Symbol Interference (ISI).

Fast fading vs. slow fading

The time-varying nature of the channel is caused by relative motion between a transmitter and receiver, or by movement of objects within the channel. The *Coherence Time* T_c is a measure of the expected time duration over which the response of the channel is essentially invariant. The time varying behavior of the channel causes a Doppler shift. The Doppler shift f_d is a measure of the spectral broadening of the signal caused by the relative motion of the receiver with respect to the transmitter. The magnitude of the frequency shift is given by:

$$f_d = \frac{v}{\lambda} \qquad (9)$$

where v is the relative velocity, and λ is the signal wavelength.

The Doppler Shift determines whether the channel can be described as *Slow Fading or Fast Fading*. In a fast fading channel, the *coherençe time* T_c, of the channel is smaller than the symbol duration of the transmitted signal ($T_s > T_c$). In a *Slow Fading* channel, the channel impulse response changes at a rate much slower than the transmitted baseband signal, and the symbol period of the signal is much smaller than the coherence time of the channel ($T_s << T_c$).

For mobile radio applications, the channel is time-variant because the relative motion between the transmitter and receiver results in propagation path changes. The rate of change of these propagation conditions determines the rate at which fading impairments occur on the channel. In this work, two Doppler frequencies of 50 Hz and 120 Hz are considered. For a mobile frequency of around 900 MHz, these frequencies correspond to average vehicle speeds of 50 Km/hr and 150 Km/hr respectively.

Small scale fading is generally modeled to have a Rayleigh distribution. The received signal for flat fading, time-varying channel is given by:

$$r(t) = \alpha(t)s(t) + n(t) + I(t) \tag{10}$$

where $r(t)$, $s(t)$, $n(t)$ and $I(t)$ are as in Eq. (7), and, $\alpha(t)$ represents the envelop due to the flat fading channel. The distribution of $\alpha(t)$ follows that of a Rayleigh distribution. In this work, the energy of $\alpha(t)$ is normalized to unity so that it does not contribute to SNR computation.

The received signal for a two-ray ISI channel model is given by

$$r(t) = \beta_0\alpha_0(t)s(t) + \beta_1\alpha_1(t)s(t-\tau_1) + n(t) + I(t) \tag{11}$$

where β_0 and β_1 are the amplitudes of the main ray and the secondary ray respectively. The secondary component with a factor of β_1 and delayed by τ_1 corresponds to the first significant interfering (delay) term. In all of the trials, the two paths are assumed with equal energy and the sum of $E\{\beta_1^2\alpha_1(t)^2\}$ and $E\{\beta_0^2\alpha_0(t)^2\}$ are set to unity so that the channel has an average power gain of one. This is done to ensure that the average signal energy at the input and output of the channel remains the same.

Laboratory Simulation of Fading Signals [1]

Filtered Gaussian Noise

The simplest fading signal simulator is to use low-pass filtered white Gaussian noise as shown in Fig. 1. If the Gaussian noise has zero mean, this method produces a Rayleigh fading signal; otherwise a Ricean signal is produced. The attenuation factor $\alpha(t)$ will be the magnitude of the sum of $\alpha_I(t)$ and $\alpha_Q(t)$.

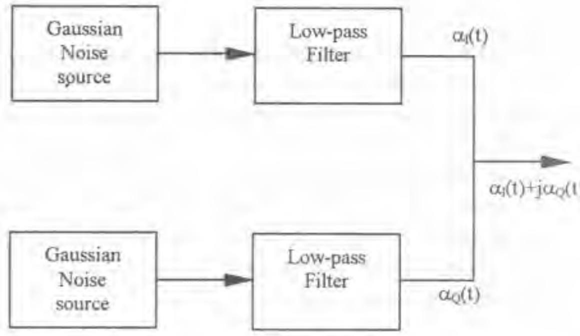


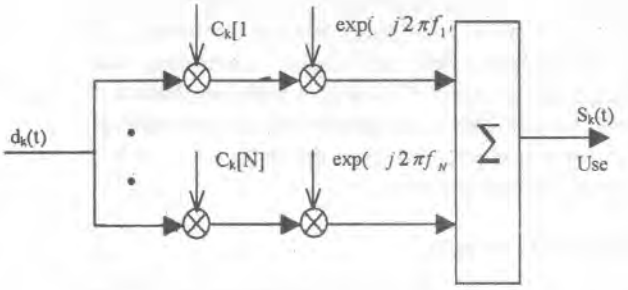
Figure 1 Fading simulator that uses low-pass filtered white Gaussian noise

Transmitter Model [1]

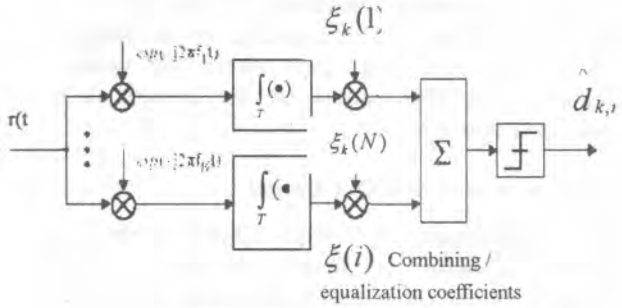
Conventionally, MC-CDMA is a modulation technique where a single symbol is transmitted on multiple narrow band subcarriers. As shown in Fig.2a, a single data symbol is replicated into N parallel copies. The i^{th} branch (sub-carrier) of the parallel stream is multiplied by a chip $C_k[i]$, where k denotes the k^{th} user and i denote the i^{th} chip interval. The data spread by the code then modulates the sub-carriers and summed. The subcarriers are made orthogonal to each other, and for efficient implementation DFT is used to modulate the data on subcarriers.

Wavelet-based MC-CDMA (W-MC-CDMA) system has gained popularity in literature recently. Due to very high spectral containment properties of wavelet filters, wavelet based MCM can combat narrowband interference. The classic notion of a guard band does not apply to wavelets; hence there is an increase in data rates than those of DFT implementations. In the implementation of the wavelet-based system, the key element in the characterization of the system is the filter set design in both the analysis and synthesis parts. One of the optimization results of multicarrier system is the use of perfect reconstruction quadrature mirror filters types which is often referred to as wavelet discrete multitone (DWMT).[11,12]

Shown in Fig. 3 is the basic model of the transmitter implemented in this work. The input data symbols from each user are assumed to be BPSK modulated digital baseband signal, and spread by the respective codes of each user.



a) MC-CDMA transmitter



b) MC-CDMA receiver

Figure 2 MC-CDMA schemes

In the down link channel of a CDMA system, the base station transmits simultaneously to each mobile station. Hence, the spread data are summed at chip level; serial to parallel (S/P) converted and are then used to modulate the sub-carriers by using Inverse Discrete Wavelet Packet Transform (IDWPT) before transmission over the channel.

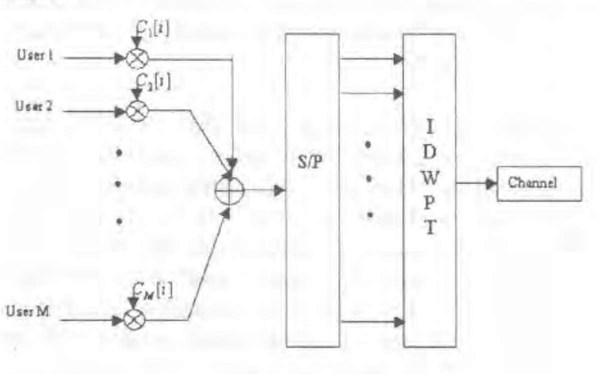


Figure 3 Transmitter Model

Receiver model [1]

The receiver model of W-MC-CDMA system implemented in this work is shown in Fig. 4. The inverse process of what has been described in the section above is performed. The signals corresponding to each sub-carrier at baseband are extracted using a digital Discrete Wavelet Packet Transform (DWPT). The data are then de-spread using the same spreading code used at the transmitter, summed and a decision made to reconstruct the original data and the Bit Error Rate (BER) computed.

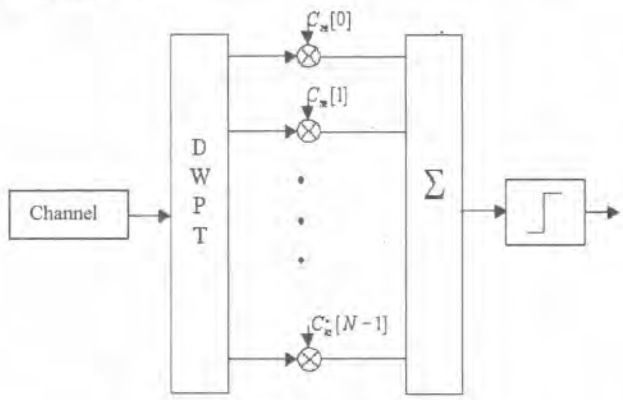


Figure 4 Receiver Model

Spreading and De-spreading

As stated earlier, CDMA is based on spread spectrum (SS) technology. The two most popular SS schemes are: *Direct sequence spread spectrum*, (DS-SS) and *Frequency hopping* Spread spectrum (FHSS).

Direct Sequence Spread Spectrum (DS-SS) is the most common version of SS in use today, due to its simplicity and ease of implementation. In DS-SS, the carrier (data signal) is modulated by the PN code sequence, in which the code bit rate is much larger than the information signal bit rate. These systems are also called *Pseudo-Noise* systems, and the code bits are called *chips*.

Figures 5 and 6 show the basic idea behind DS-SS systems. Let the information signal be $D(t)$, transmitted at frequency f, and let the spreading sequence be $P_N(t)$, with frequency f_c. The transmitted signal $s(t)$ is:

$$S(t) = D(t)P_N(t) \tag{12}$$

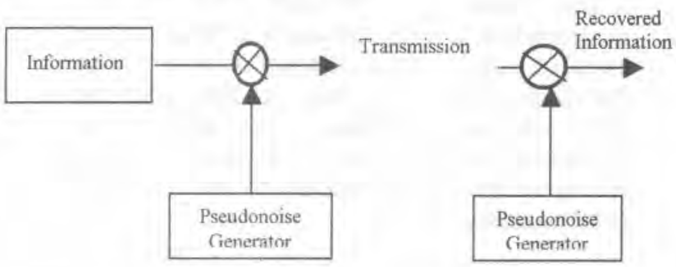


Figure 5 Block Diagram of a DS system

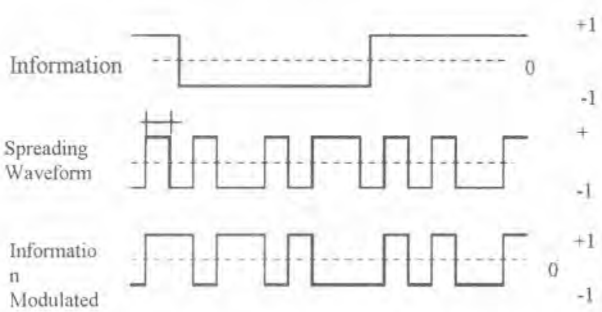


Figure 6 Direct sequence signal

When the signal is correlated with the spreading sequence at the receiver, the received signal will be recovered exactly (assuming that there is synchronization between the sent and received spreading sequences), i.e.

$$S(t)P_N(t) = D(t)P_N(t)P_N(t) = D(t) \tag{13}$$

This is because the product of the PN sequence with itself is 1. Now, if we allow interference $I(t)$ and noise $n(t)$ with finite power distributed evenly across the frequency band, the received signal at the input to the receiver, $Y(t)$, is :-

$$Y(t) = D(t)P_N(t) + n(t) + I(t) \tag{14}$$

When this signal is correlated with the spreading sequence, the data signal portion of $Y(t)$ is de-spread giving us the original $D(t)$. However, the effect of multiplying $I(t)$ and $n(t)$ with $P_N(t)$ spreads the signals out to have bandwidth f_c, whereas the signal $D(t)$ now has returned to its original frequency f. So a filter following the signal correlation can recapture the signal $D(t)$ with a reduced amount of noise power. The noise power that can pass through the filter is decreased by a factor f_c / f, which is called processing gain.

Simulation Results

The data rate considered for simulation is 10Kbps, and a processing gain of 32, and 20 active users are assumed. The BER versus Signal to Noise Ratio (SNR) is used as a performance measure. The Doppler frequencies considered are 50Hz and 120 Hz. Both the flat and ISI channels are assumed to be slowly varying at least within the symbol duration. All BER results are the average of 5 independent trials.

Performance in AWGN Channel

The performance of W-MC-CDMA system in AWGN channel is shown in Fig. 7. For comparison, the theoretical performance of a BPSK modulated signal on an AWGN channel is also plotted. The curves indicate that the performance of W-MC-CDMA is essentially identical with that of the theoretical limit of a BPSK modulated signal on an AWGN channel, for both Daubechies N=4 and N = 10 wavelets.

For comparison of the wavelet based result of this work with that of a DFT based system, the result from [10] which was realized using Gold code of length 63, 1 and 63 active users, 512 subcarriers, with a guard interval equal to symbol duration over the AWGN channel is considered and reproduced in Fig. 8.

From Fig. 8 it can be seen that the DFT based system the results for 1 and 63 users are indeed very close. One can thus safely assume that it behaves in almost the same way for 20 users, the number of users considered in this work. Also comparing this DFT based result with the DWT based for 0, 2, 4, 6 dB, no appreciable difference is observed. Hence, a wavelet based system with no guard interval performs equally well compared to the Fourier based system with guard band. The absence of guard interval obviously implies that an increased rate of transmission can be achieved.

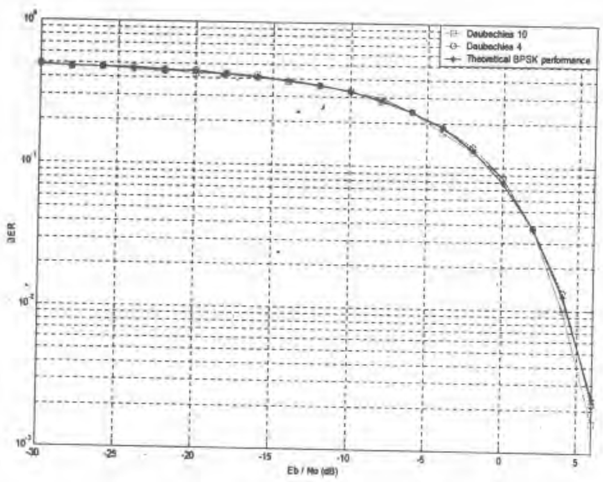


Figure 7 BER vs. E_b / N_o in AWGN channel

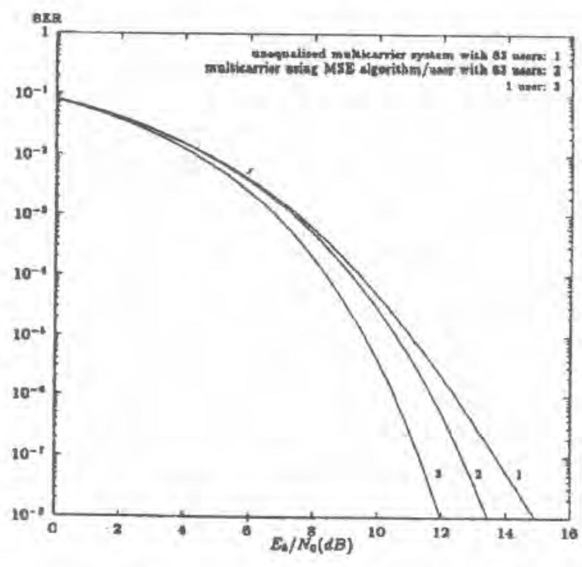


Figure 8 Performance on AWGN channel using DFT realization [8]

Performance on Flat fading channel

W-MC-CDAM performance for flat fading channels was also investigated. Figure 9 depict the BER for flat-fading channel of Doppler frequencies 50 Hz and 120 Hz and compares this with the theoretical performance of BPSK modulated signal in a flat fading channel.

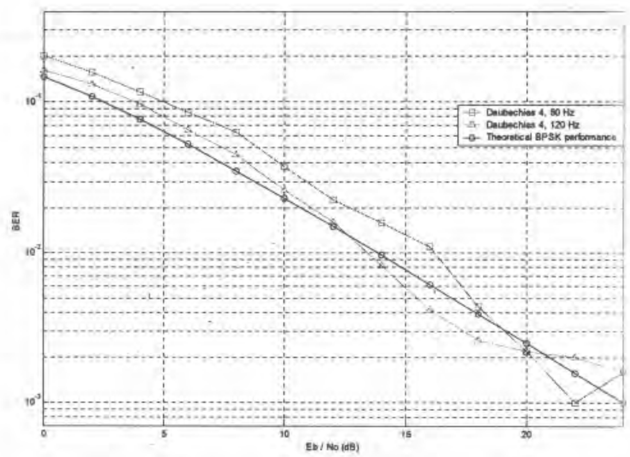


Figure 9 BER vs. E_b / N_o in flat fading channel

We see that the variation of the performance of the considered system with the theoretical limit is small, which could be attributed to the inevitable limitations in simulation. Hence, we can safely say that the system operates near the theoretical limit of BPSK both for 50 Hz and 120 Hz Doppler.

Performance in ISI Channels

For this simulation, we used a two-ray channel model, where the paths are assumed to have equal energy (i.e. $\beta_0 = \beta_1 = 0.707$). Figs. 10 depict the performance of the system for frequency selective channel.

Finally, for ease of comparison of the performance of AWGN, flat fading, and ISI channels the corresponding results are plotted in Fig. 11. We note from channel model Eqs. (7), (10) and (11) that whether the channel is called flat or ISI, it still incorporates the AWGN and the interference.

For flat fading, it is the impact of multipath signal modeled as $\alpha(t)$ that causes the performance degradation when compared to the AWGN channel. And for ISI, it is $\alpha(t)$ and the delayed version of the signal that cause the degradation compared to the flat fading channel.

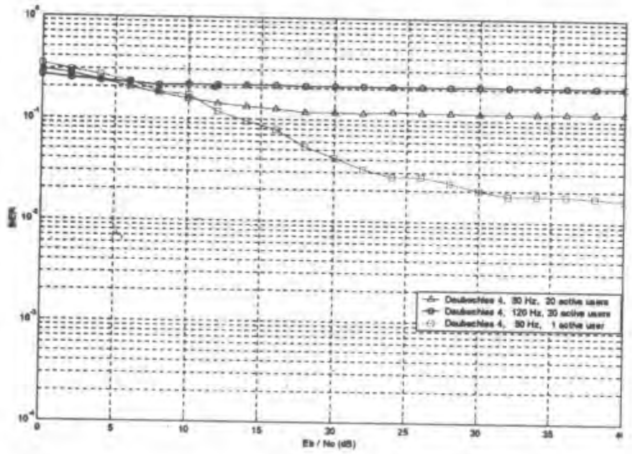


Figure 10 BER vs. E_b / N_o in ISI channel. The excess delay of the channel is assumed to be of one chip duration.

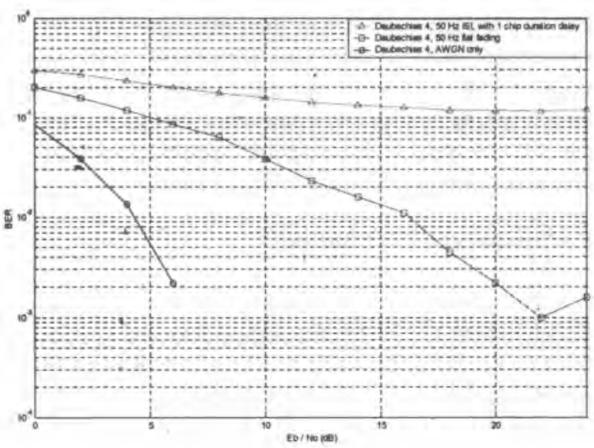


Figure 11 BER vs. E_b / N_o in AWGN, flat and ISI channel

CONCLUSION

In this paper, the performance of W-MC-CDMA system is seen for different channel models. From the above discussion, it can be concluded that the performance of W-MC-CDMA is almost identical to the theoretical performance for BPSK modulation both in AWGN and flat fading channels. Comparison with the DFT based system shows that the DWT based system with no guard interval, performs equally well, which could help to increase transmission rate of a system. The BER for ISI channel is relatively high (from 1-30%) depending on the number of active users. Finally, from the comparison made in Figure 7, the performance of the system is better for purely AWGN and worse for ISI channel.

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