IJDACR
ISSN: 2319-4863

International Journal of Digital Application & Contemporary Research
Website: www.ijdacr.com (Volume 5, Issue 3, October 2016)

Rake Receiver based MC-CDMA Scheme in Rayleigh Fading Channel using Different Equalization Techniques

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Abstract –**In this paper, we propose an MC-CDMA model using Rake Receiver and different equalization techniques (ZF, MMSE, EGC and MRC) are used. Rake receiver using different number of fingers has been considered for performance evaluation. Simulation has been carried out using MATLAB 2010a. Additionally, we examine its BER v/s SNR graph for different types of equalizers in Rayleigh fading channel. Simulation results show that the proposed technique outperforms existing multicarrier systems.**

Keywords –**2G, 3G, 4G, CDMA, MC-CDMA.**

I. Introduction

Three major multiple access schemes exist: frequency division multiple access (FDMA), time division multiple access (TDMA) and code division multiple access (CDMA) [1].

Based on the combination of OFDM and DS-CDMA, a multicarrier code division multiple access (MC-CDMA) is proposed [2]. Unlike DS-CDMA, which spreads the original data stream into the time domain, MC-CDMA spreads the original data stream into the frequency domain by initially converting the input data stream from serial to parallel then multiplying this stream by the spreading chips in different OFDM subcarriers, the result of which is MC-CDMA signal which takes on the advantages of both DS-CDMA and OFDM.

The advantages of MC-CDMA are:

- The capacity is interference limited [3] and any techniques that reduce interference are capable of increasing the capacity of MC-CDMA.
- The signal is robust to frequency selective fading and can support high data rate transmission.
- Bandwidth is used more efficiently as the spectra of subcarrier overlap [4].
- Since the received signal is combined in the frequency domain, an MC-CDMA receiver can employ all the received signal energy scattered in the frequency domain [5]. This is a significant advantage over DS-CDMA, where part of the signal energy can be lost due to insufficient number of fingers in the RAKE receiver.
- The transmitter and receiver signals can be implemented using FFT, which does not increase the degree of complexity.

The main objective of this paper is to develop an approach to minimize the effect of multipath fading in Rayleigh fading environment using Multicarrier CDMA (MC-CDMA) with RAKE receiver and different combining schemes viz; Equal Gain Combining (EGC), Maximal Ratio Combining (MRC), Zero-Forcing (Z-F) and Minimum Mean Square Error (MMSE) Equalization.

II. Proposed Methodology

Transmitter for MC-CDMA

In the transmitter for the MC-CDMA, data from k users are spread using different spreading sequences of length L and they are mutual. This is explained by the following equations:

U_k is the k^{th} user with data rate $1/T_d$. The spreading code is $Ck_0, Ck_1, \dots Ck_{L-1}$. After spreading of each user and combining, the signal is $Sk_0, Sk_1, \dots Sk_{L-1}$

$$S = \sum_{k=0}^{k-1} s_k = (s_0, s_1 \dots\dots s_{L-1})^T \qquad (1)$$

Where,

$$S = CU$$
$$U = (U_0, U_1 \dots\dots U_{L-1})^T$$
$$C = (C_0, C_1 \dots\dots C_{L-1})^T \qquad (2)$$

The combined signal is send to serial to parallel converter and each data element is given a specific slot of frequency using IFFT. Then the output is joint to create an OFDM symbol.

Now the received OFDM symbol can be given as fallow:

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$$r = \sum_{k=0}^{k-1} H_k S_k + \eta = (R_0, R_1 \ldots\ldots R_{L-1}) \quad (3)$$

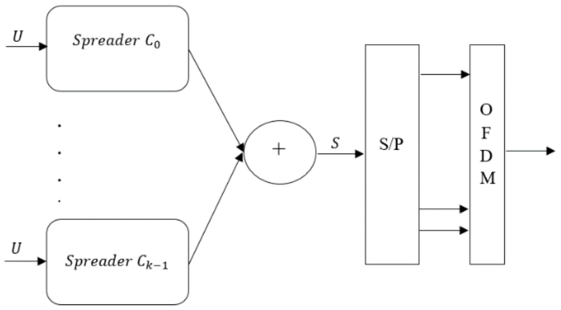

Figure 1: Transmitter configuration of MC-CDMA system

The 'r' is the received OFDM symbol yet a signal component from the client. It is additionally to be noted that 'r' will have all 'k' clients information and each one spreading code doled out to every client in the transmitter will be utilized again as a part of the receiver to get the single signal component from 'r'. The quantity of spreading codes are equivalent to number of clients. In any case the OFDM symbol length is the extent of the spreading code.

$$r = XS + \eta = (R_0, R_1 \ldots\ldots R_{L-1})$$
$$X = HC \quad (4)$$

X is termed as system matrix.

Receiver (Rake Receiver)

The rake receiver consists of multiple correlators, in which the receive signal is multiplied by time-shifted versions of a locally generated code sequence. The intention is to separate signals such that each finger only sees signals coming in over a single (resolvable) path. The spreading code is chosen to have a very small autocorrelation value for any nonzero time offset. This keeps away from crosstalk between fingers. In practice, the circumstances is less perfect. It is not the full periodic autocorrelation that determines the crosstalk between signals in different fingers, but rather two partial correlations, with contributions from two consecutive bits or symbols. It has been attempted to find sequences that have satisfactory partial correlation values, but the crosstalk due to partial (non-periodic) correlations remains substantially more difficult to reduce than the effects of periodic correlations.

The rake receiver is designed to optimally detect a DS-CDMA signal transmitted over a dispersive multipath channel. It is an extension of the concept of the matched filter.

In the matched filter receiver, the signal is correlated with a locally generated copy of the signal waveform. If, however, the signal is distorted by the channel, the receiver should correlate the incoming signal by a copy of the expected received signal, rather than by a copy of transmitted waveform. Thus the receiver should estimate the delay profile of channel, and adapt its locally generated copy according to this estimate.

In a multipath channel, delayed reflections interfere with the direct signal. However, a DS-CDMA signal suffering from multipath dispersion can be detected by a rake receiver. This receiver optimally combines signals received over multiple paths.

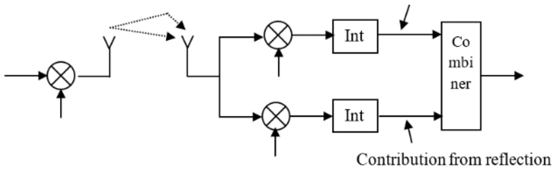

Figure 2: RAKE Receiver

Rake receiver gathers the energy received over the various delayed propagation paths. According to the maximum ratio combining principle, the SNR at the output is the sum of the SNRs in the individual branches, provided that,

- Only AWGN is present (no interference)
- Codes with a time offset are truly orthogonal

Signals arriving with the same excess propagation delay as the time offset in the receiver are retrieved accurately, because,

$$\sum_{n=1}^{N} c_1^2(nT_c + t_d) = \sum_{n=1}^{N} c_1^2(nT_c) = N \quad (5)$$

This reception concept is repeated for every delayed path that is received with relevant power. Considering a single correlator branch, multipath self-interference from other paths is attenuated here, because one can choose codes such that,

$$\sum_{n=0}^{N} c_1(nT_c) c_1(nT_c + t_d) \cong 0 \quad (6)$$

Fading Channels

In wireless communication, the signal can be attenuated with time while propagating over a certain media. In wireless communication fading is mostly due to multipath propagation or shadowing which affects the wave propagation [6]. Multipath propagation occurs when a radio signal takes two or more different paths after it is transmitted from the antenna and before its reception on the receiving antenna. There are different ways of modelling a wireless communication channel that can help in modelling the important statistical properties of real world communication systems and can also give an idea of the signal amplitudes of the transmitted signals that can be expected at the receiver side. There are different fading models that can be used to estimate the fading over a channel, e.g. Nakagami fading, Rician fading, Log-normal shadow fading, Weibull fading Rayleigh fading, etc.

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Rayleigh Fading Channel

The Rayleigh Fading Channel is mostly applied in cases when there is no LOS (Line of Sight) between the transmitter and the receiver. The channel also mix the AWGN noise to the signal samples after it suffers from Rayleigh Fading. Let the received signal "y" is given as:

$$y = hx + n \tag{7}$$

Where; n is AWGN (Additive White Gaussian Noise) with zero mean & unit variance; h is the Rayleigh Fading response with zero mean & unit variance; x is the transmitted signal. The transmitted symbols x can be obtained from the received signal y by the process of equalization as given below:

$$\bar{y} = \frac{y}{h} = \frac{hx+n}{h} = x + z \tag{8}$$

Where $\hat{y}$ is the estimation of the received signal.

The hypothetical BER for BPSK modulation framework over Rayleigh fading channel (with AWGN noise) is given by:

$$P_b = 1/2\left(1 - \sqrt{\frac{E_b/N_0}{1+E_b/N_0}}\right) \tag{9}$$

The hypothetical BER for BPSK modulation system over an AWGN channel is given as:

$$P_b = 1/2\left(erfc\sqrt{\frac{E_b}{N_0}}\right) \tag{10}$$

Detection Techniques

Zero-Forcing

Zero-Forcing (ZF) technique is the simplest MIMO detection system, where filtering matrix is built using the ZF performance based criterion. The limitation of ZF scheme is the susceptible noise enhancement and loss of diversity order due to linear filtering. ZF can be implemented by using the inverse of the channel matrix H to produce the estimate of transmitted vector $\tilde{x}$.

$$\begin{aligned}\tilde{x} &= H^{\dagger}r \\ &= H^{\dagger}(Hx) \\ &= x \end{aligned} \tag{11}$$

Where $(.)^{\dagger}$ denotes the pseudo-inverse. However when the noise term is taken into account, the post-processing signal is given as fallow:

$$\begin{aligned}\tilde{x} &= H^{\dagger}R \\ &= H^{\dagger}(Hx+n) \\ &= x + H^{\dagger}n \end{aligned} \tag{12}$$

With the addition of the noise vector, ZF estimate, that is $\tilde{x}$ consists of the decoded vector x plus a combination of the inverted channel matrix and the unknown noise vector. As the pseudo-inverse of the channel matrix may have high power when the channel matrix is ill-conditioned, the noise variance is accordingly improved and the performance is corrupted. To alleviate for the noise improvement introduced by the ZF detector, the MMSE detector was proposed, where the noise variance is taken into account in the construction of the filtering matrix G.

Minimum Mean Square Error

Minimum Mean Square Error (MMSE) approach alleviates the noise enhancement problem by taking into consideration the noise power when constructing the filtering matrix using the MMSE performance-based criterion. The vector estimates produced by an MMSE filtering matrix becomes,

$$\tilde{x} = [[(H^H H + (\sigma^2 I))^{-1}]\, H^H]\, r \tag{13}$$

Where σ^2 is the noise variance. The added term ($1/SNR = \sigma^2$, in case of unit transmit power) offers a trade-off between the residual interference and the noise enhancement. Specifically, as the SNR raises large, the MMSE detector converges to the ZF detector, but at low SNR it prevents the worst Eigen values from being inverted. At low SNR, MMSE becomes Matched Filter,

$$[(H^H H + (\sigma^2 I))^{-1}]\, H^H \approx \sigma^2 H^H \tag{14}$$

At high SNR, MMSE becomes ZF:

$$(H^H H + (\sigma^2 I))^{-1}]\, H^H \approx (H^H H)^{-1} H^H \tag{15}$$

Maximal Ratio Combining

Maximal ratio combining (MRC) overcomes the limitations of selection combining: it combines the input signals in all diversity branches. MRC has been considered as the optimal combining technique in the presence of additive white Gaussian noise (AWGN) because of its capacity to boost the instantaneous output SNR. This is demonstrated as below. Assume a system with N_d diversity branches, the instantaneous output SNR is given by [7].

$$SNR = \left(\frac{E_b}{N_0}\right)\frac{\left|\sum_{i=1}^{N_d}\mu_i\beta_i e^{j\theta_i}\right|^2}{\left|\sum_{i=1}^{N_d}\mu_i\right|^2} \tag{16}$$

Where E_b is bit energy; N_0 is noise spectral density, μ_i is the combining weight and β_i and θ_i are the magnitude and phase of the received signal respectively.

To obtain the maximum instantaneous output SNR, Cauchy-Schwarz inequality is applied, giving the maximum value as [7].

$$\begin{aligned} SNR &\le \left(\frac{E_b}{N_0}\right)\frac{\left|\sum_{i=1}^{N_d}\mu_i\right|^2\left|\sum_{i=1}^{N_d}\beta_i e^{j\theta_i}\right|^2}{\left|\sum_{i=1}^{N_d}\mu_i\right|^2} \\ &= \left(\frac{E_b}{N_0}\right)\sum_{i=1}^{N_d}\beta^2{}_i = \sum_{i=1}^{N_d} SNR_i \end{aligned} \tag{17}$$

The only condition to reach this maximum value is to set [7].

$$\mu_i = c\beta_i e^{-j\theta_i}\, for\ i = 1,2, \ldots .N_d \tag{18}$$

Where c is some arbitrary complex constant. Therefore, according to (18), in MRC, the magnitude of the combining weight is proportional to the magnitude of the received signal, and the

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ISSN: 2319-4863

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phase of the combining weight is the negative value of the phase of the received signal.

The maximum SNR in equation (17) also suggests that MRC can produce an output SNR equal to the sum of the individual SNRs in each diversity branch. It follows that MRC can offer the advantage of producing an acceptable output SNR even when none of the SNR in individual branches is acceptable [1].

Equal Gain Combining

Although MRC has the ability to maximize the instantaneous output SNR, in certain cases it is difficult to track the magnitude and phase of the received signal in order to produce a time varying combining weight [7]. Equal gain combining (EGC) provides a more convenient solution whereby the combining weights in all branches are equal to a constant.

With constant gain, EGC cannot maximize the instantaneous output SNR. Hence it is not optimal and its performance is inferior to MRC. However, EGC still has the ability to exploit the signals in all diversity branches, allowing it to give better performance than selection combining.

III. SIMULATION RESULTS

Simulation is carried out using MATLAB 2010a:

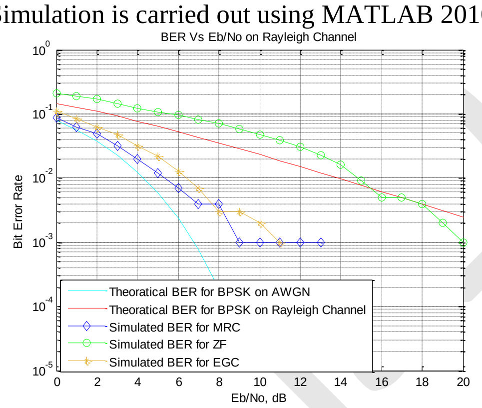

Figure 3: Comparative analysis of BER for MC-CDMA system for 16 subcarriers

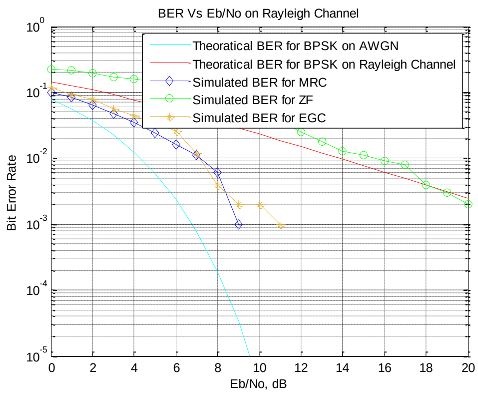

Figure 4: Comparative analysis of BER for MC-CDMA system for 32 subcarriers

IV. CONCLUSION

In order to support multiple users with high speed data communications, the MC-CDMA technique is used to address these challenges. This paper is based on MC-CDMA systems and more specifically on algorithms that could provide a comprehensive method to eliminate the harsh channel conditions. We have analysed the performance of MC-CDMA model for different types of equalizers (ZF, MMSE, MCR and EGC). From the results we conclude that the performance of MMSE is better than other equalization techniques.

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