Performance of the MIMO-MC-CDMA System with MMSE Equalization

N. Tamilarasan1, L. Nithyanandan2
1 Assistant Professor – Sri Ganesh College of Engineering and Technology, Puducherry. Email: neithalarasu@gmail.com
2 Associate Professor - Pondicherry Engineering College, Puducherry

Abstract—Multipath fading and spectral crowding are the major challenges in dealing higher data rate in future broadband wireless communication system. Multi-carrier Modulation like Multicarrier code division multiple access (MC-CDMA) can tackle the problem and provide higher data rate for future wireless communication system. However, through a frequency selective fading channel, the subcarriers in MC-CDMA signal have different amplitude levels and phase shifts which result in loss of the orthogonality among users and generates Multiple access interference (MAI). To combat the MAI, various amplitude and phase equalizing techniques such as Maximum Ratio Combining (MRC), Equal Gain Combining (EGC), Orthogonal Restoring Combining (ORC), Threshold Orthogonal Restoring Combining or Minimum Mean Square Error (MMSE) may be used. Out of these MMSE offers better performance since the MMSE criterion is applied independently on each subcarrier. Further improvement in performance is possible through space–time block coding, which offers maximum diversity gain and multiplexing gain. This paper combines MC-CDMA with MMSE equalization and space–time block coding which proves to be a powerful physical layer solution in combating delay spread and inter symbol interference (ISI).

Index Terms—MC-CDMA, MIMO, Equalization, MMSE, ISI.

I. INTRODUCTION

To meet continuing growth of the customer demand in wireless communication it is necessary to use available spectrum efficiently to the extent possible. The combination of multicarrier modulation and code-division multiple-access schemes can offer good spectral efficiency, high data rate transmission, multiple access and interference rejection capabilities as well as robustness against multipath propagation. Its basic principle is that the total transmission bandwidth is divided into many narrowband sub channels, and each data symbol is spread in the frequency domain.

ISI caused by multipath fading of wireless channels lead to distortion of signal, causing bit errors at the receiver. ISI has been recognized as the major obstacle to high-speed data transmission over wireless channel. Equalization is a technique to combat ISI [1-3]. Several combining and equalization techniques for MC-CDMA signals have appeared in the literature [4-7]. As analyzing is done in the down-link of a cellular radio system and the computation is made in the mobile unit, a low complexity scheme is required. In single user communication system, conventional EGC and MRC can achieve better performance in Gaussian and Rayleigh fading channels, respectively. However, in a multi-access MC-CDMA system, frequency diversity reduces the orthogonality of spreading codes and results in the MAI [8]. Since in downlink, the system is assumed to be synchronous, the information associated with different users undergoes the same channel effect. However, at the receiver side, the orthogonality between spreading sequences is degraded by the fading or noise. Hence, the choice of equalization becomes a critical point impacting the trade-off between the residual amount of multiple access interference and the increase in thermal noise.

S. Kaiser [1], has derived the approximation of the bit error rate (BER) for MC-CDMA with MRC, EGC and MMSE. However, it is based on the law of large numbers; the spreading code length must be sufficiently large. In [4], the BER performance of MC-CDMA with MRC and EGC has been simulated over a Rayleigh fading channel with correlated envelopes and phases. However, it is observed that both EGC and MRC have very poor performance due to the orthogonality loss between the spreading sequences. The orthogonality loss results in a high error floor making these techniques difficult for practical use. In addition, K. Zhang and Y. Guan [5], proposed a lower bound and a tight approximation on the BER of MC-CDMA with ORC. When ORC is used, the error floor is eliminated but the error probability is still poor especially at low signal to noise ratio due to the noise enhancement.

Among the various equalization methods for MIMO and MC-CDMA, MMSE is considered to be a good solution for data recovery since it can effectively reduce the ISI and utilize the diversity of the frequency-selective channel [9]. As mentioned before, however, most of the results are concentrated on MRC and EGC, and the analytical results on MMSE are well matched only when the spreading code length is sufficiently large [1]. In addition, in the channel-coded system, a large spreading code does not improve performance but only increases system complexity.

In future wireless communication spectral efficiency is the major challenge. To increase the data rate without bandwidth expansion, MIMO is attractive [10], [11]. The combination of MC-CDMA with MMSE along with MIMO is very effective for solving the ISI problem by converting the frequency selective nature of the MIMO channel to flat fading [12-14]. Each pair of transmit and receive antennas
IV. SYSTEM MODEL

Consider a MC-CDMA system with \( N \) users, having \( N_c \) subcarriers, the transmitted signal corresponding to the \( k \)th user with BPSK modulation can be expressed [15] as

\[
s_k(t) = \sum_{i=-\infty}^{\infty} \frac{2 E_k}{N_c T_s} \sum_{n=1}^{N_c} b_i n c_{k,n} u_{k,n}(t - i T_s) \cos(\omega_n t)
\]

where \( E_k \) and \( T_s \) are the bit energy and symbol duration respectively, \( u_{k,n}(t) \) represents a rectangular waveform with amplitude 1 and pulse duration \( T_s \), \( b_{i,n} \) is the \( i \)th transmitted data bit of user \( k \), \( c_{k,n} \) is the spreading code, \( \omega_n = 2\pi f_0 + 2\pi(n-1)\Delta f \) is the radian frequency of the \( n \)th subcarrier, and the frequency spacing is \( \Delta f = 1/T_s \).

The received signal \( r(t) \) after cyclic prefix removal is given by

\[
r(t) = \eta(t) + \sum_{i=-\infty}^{\infty} \sqrt{\frac{2 E_{\eta}}{N_c T_s}} \sum_{n=1}^{N_c} \sum_{k=1}^{N} h_n b_{i,n} k (t - i T_s) \cos(\omega_n t + \phi_n)
\]

where \( h_n \) is the subcarrier flat fading gain, \( \phi_n \) is the subcarrier fading phase (\( (h_n, \phi_n) \) are common to all users), and \( \eta(t) \) is AWGN with single-sided power spectral density \( N_o \). After phase compensation, the receiver performs amplitude correction described by \( \alpha_i (i = 1, \ldots, N_c) \), called equalizer coefficient. In the literature, different equalizer coefficient expressions for MMSE have been proposed for MC-CDMA systems [16-18]. After demodulation the received signal on the \( n \)th subcarrier is given by

\[
y_n = \int_{0}^{T_s} r(t) \cos(\omega_n t + \phi_n) dt = D_n + I_n + \eta_n
\]

Where \( D_n \) is the desired signal and \( I_n \) is the multi-user interference Components and \( \eta \) is the noise component with zero mean and variance \( N_o T_s/4 \).

Denoting \( \alpha_n \times c_{1,n}, \alpha'_n = [\alpha_1, \alpha_2, \ldots, \alpha_{N_c}] \), \( Y = [y_1, y_2, \ldots, y_{N_c}]^T \).

After equalization and de-spreading, the decision variable

\[
U = Y' \alpha
\]

where

\[
\alpha' = R_{YY}^{-1} R_{bYY}
\]

Let \( \eta = [\eta_1, \eta_2, \ldots, \eta_{N_c}]^T \), \( b = [b_1, b_2, \ldots, b_{N_c}]^T \), \( C_d \) is a \( N_c \times N_c \) matrix with \( k \)th column being the spreading code for \( k \)th user, and \( H \) is a diagonal matrix with \( n \)th diagonal element equals to \( h_n \).

\[
Y = \sqrt{\frac{E_{\eta} T_s}{2 N_c}} H C_d b + \eta
\]

Then the matrix \( R_{bYY} \) is

\[
R_{bYY} = E \left[ b_1 \times \left( \sqrt{\frac{E_{\eta} T_s}{2 N_c}} H C_d b + \eta \right) \right]
\]

\[
= \frac{E_{\eta} T_s}{2 N_c} E \left[ b_1 H C_d b \right]
\]

The matrix \( R_{YY} \) is

\[
\frac{E_{\eta} T_s}{2 N_c} H C_d C_d^T H + \frac{N_c T_s}{4} I_{N_c}
\]

Where \( I_{N_c} \) is an identity with \( N_c \times N_c \). Substituting (6) and (7) into (4), the set of equalizer coefficients for MMSE scheme for downlink as

\[
\alpha = \frac{1}{\sqrt{\frac{2 N_c}{E_{\eta} T_s} \left( H C_d C_d^T H + \frac{N_c T_s}{4} I_{N_c} \right)^{-1}}} \cdot h
\]

Where \( \alpha = [\alpha_1, \alpha_2, \ldots, \alpha_{N_c}]^T \) and \( h = [h_1, h_2, \ldots, h_{N_c}]^T \)
III. SIMULATION RESULT

Simulation is performed using MATLAB version 9.1 with BPSK/QPSK modulation and the simulation parameter is shown in Table 1. The system is tested using 16, 64 and 128 subcarrier (SC). To understand the impact of MIMO and equalization simulations are carried out for 2x2, 3x3 and 4x4 transmitting and receiving antenna respectively, with and without MMSE equalization.

**TABLE I. SIMULATION PARAMETER**

<table>
<thead>
<tr>
<th>Spreading Code</th>
<th>Walsh-Hadamard Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of subcarriers</td>
<td>16, 64 &amp; 128</td>
</tr>
<tr>
<td>Channel</td>
<td>Rayleigh fading</td>
</tr>
<tr>
<td>Modulation</td>
<td>BPSK &amp; QPSK</td>
</tr>
<tr>
<td>Antennas</td>
<td>2x2, 3x3 &amp; 4x4</td>
</tr>
<tr>
<td>Equalization Technique</td>
<td>MMSE</td>
</tr>
</tbody>
</table>

Figures 3, 4 and 5 show the BER performance of MIMO-MC-CDMA with (line graphs) and without (legend graphs) MMSE for BPSK modulation, with different antenna configuration and 16, 64 and 128 SC respectively. From the graphs it is evident that the system with MMSE performs better due to the reduction of ISI. It can also be inferred that the increase in number of transmitting and receiving antennas and increase in number of subcarriers improve the performance due to the diversity and multiplexing gain.
Figures 6, 7 and 8 show the BER performance of MIMO-MC-CDMA with and without MMSE for QPSK modulation. Comparing figures 3, 4 and 5 with figures 6, 7 and 8, the latter figures show slightly lesser performance, because of the higher order modulation used. From the simulation results it is quite clear that whatever is the modulation used the system with MMSE performs better.

**CONCLUSION**

The EGC, MRC and ORC are suitable for single carrier communication. If it is used in multi-carrier system, it reduces the orthogonality of user thus creating additional interference in the receiver. Hence, in this paper the performance of MIMO-MC-CDMA signals in frequency selective fading channels with MMSE is analyzed. From the simulation results, it is inferred that the system with MMSE reduces the BER of MIMO MC-CDMA in the Rayleigh fading channel as ISI is drastically reduced.

**REFERENCES**


