

Minimization Of Inter Carrier Interference Using Iterative Technique for Mimo-Ofdm

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Abstract – In orthogonal frequency division multiplexing – multiple input multiple output (OFDM-MIMO) systems, in multipath fading channels the time period of an OFDM block is not constant. As a result, the sub-carriers lose their orthogonality and create intercarrier interference (ICI). Lot of research has been carried out to cancel or mitigate the effects of ICI in OFDM-MIMO systems but these methods are computationally complex. Here we use a low-complexity based frequency-domain algorithm to cancel the ICI created in time-varying multipath channels. Simulation with BPSK and QPSK demonstrates the performance of our algorithm in comparison to channels with ICI and no ICI. The results are also compared with zero forcing equalization algorithm which is the algorithm used presently in the OFDM-MIMO systems. Based on Fast Fourier Transform, iterative linear MSE has been implemented to maximize the output signal to noise/interference ratio in the MMSE estimates during iterative detection. It shows that 15 db signal to noise gain is achieved when bit error rate is 10^{-9} .

Keywords: Time-varying multipath channels, Inter carrier interference (ICI), minimum mean square error, multiple- input multiple- output .

I. Introduction

In multipath fading channel, the received signal undergoes frequency-selective fading. If the symbol period is not too large as compared to the delay spread of the channel, the current symbol will affect the subsequent symbol as well. This process is known as inter-symbol interference (ISI). For a single-carrier system, as the data rate increases the ISI will also rise significantly. To avoid this problem multiple carriers are used for high rate data transmission. Multi-carrier systems can be regarded as a type of orthogonal frequency division

Multiple access (OFDMA) method as they transmit different symbols with orthogonal sub-channels in parallel form. The computationally efficient fast Fourier transform (FFT) is used to transmit data parallelly over a large number of orthogonal subcarriers. OFDM-MIMO systems are being used in the latest generation of wireless mobile communications for achieving high-speed data transmission and efficiency. The subcarrier signals are overlapped in spectrum. As long as there is

orthogonality between the sub-channels, there is no ICI thereby creating distortion less transmission channel. [1]

A guard interval is used before each transmitted data block to eliminate ISI. ICI may also occur if the length of the guard interval is shorter than the spread delay of the multipath channel.[2] Such ICI can be easily eliminated by copying the guard interval part of the next OFDM symbol and adding it to the head part of the current OFDM symbol as shown in figure 1.

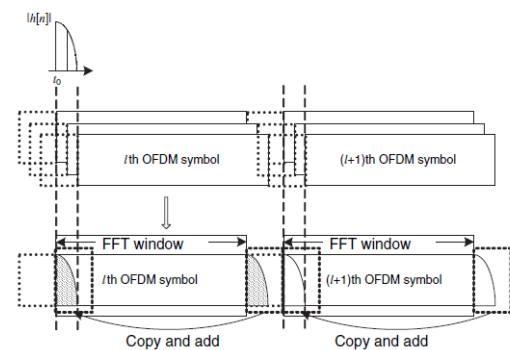


Fig 1 Copying and adding the guard interval of the next symbol into the head part of the current symbol to prevent ICI [3]

There are basically two types of noise created by the carrier signal – the phase noise and the carrier frequency offset (CFO). The CFO is caused by Doppler frequency shift in the multipath channel. The subcarrier frequency component is affected by other subcarrier frequency components and this also leads to ICI. Actually the CFO can be divided into two parts integer CFO (IFO) and fractional CFO (FFO). The IFO does not disturb the orthogonality of the subcarriers and hence no ICI is created but in case of FFO, the orthogonality among the subcarriers is disturbed which leads to ICI. [4]

Traditional OFDM systems assume that the path remains static during the symbol duration. This even holds true if the symbol duration is much smaller than the spread delay of the channel. But in some high speed applications such as underwater acoustic channels, the channel will be changing its coherent time so fast that it is possible to have the symbol duration always lesser than it. In a time-varying channel if the OFDM symbol period is longer, then the orthogonality among the subcarriers at the receiver is destroyed and this creates ICI. This is especially true in case of fast fading

channels. The problem becomes graver in case of multiple-input multiple-output systems because on each subcarrier of a specific receiver, the signals and ICI from all transmitters get missed up. [5]

To cancel the effects of ICI caused by this variation, different methods such as polynomial cancellation coding (PCC), self-cancellation scheme, time domain filtering, minimum mean-squared error (MMSE) etc. have been presented. Some of these approaches have good performance but are computationally expensive. Such methods can't be used in high rate data transmissions. The other methods don't demonstrate better performance. There are two major problems associated with ICI cancellation – estimation of the time variance in the channel by appropriate modeling and equalization. The model should be able to achieve balance between accuracy and complexity. The equalization implies that the receiver should be able to estimate the transmitted signal from the signal which is polluted by ICIs from various transmitters.

Multiple input multiple output technology is uses more number of antennas to make use of reflected signals to provide gains in channel throughput. MIMO is used in mainly new technologies these days to provide spectral efficiency combined with improved link reliability.[6]

The purpose of using MIMO-OFDM is it is the dominant air interface for 4G and 5G broad band wireless communications and it is the foundation for most advanced wireless networks . the main use of OFDM is Fast Fourier Transforms (FFT) may be used to simplify implementation and convert signals from time domain to frequency domain.

In this work, after analyzing the symbol energy distribution over sub-channels and the method of ICI generation, a frequency-domain partial MMSE method with lesser complexity is presented to mitigate the effects of ICI. This method is implemented in the receiver so that the subcarrier with the largest SINR than all the other undetected symbols is identified by using the MMSE detector on it and its neighbouring subcarriers.

The rest of the paper is detailed as follows: Section II gives the system model; section III explains the energy distribution over the symbols, section IV describes the proposed ICI cancellation scheme. The simulation results are presented in section V and section VI derives the conclusion.

II. System Model

In this section, we present the transmission model of MIMO-OFDM systems in linear time-varying channels over multipath fading channels. For MIMO-OFDM system, we have M number of transmitters and N

number of receivers. The OFDM symbol length is K. The l-th channel tap between the m-th transmitter and the n-th receiver at time slot t by $h_{l,m,n}^{(t)}$, $l=0, 1, \dots, L-1$, where L is the channel length. So for linear time-varying channel model in one frame, $h_{l,m,n}^{(t)} = h_{l,m,n} + \delta_{t-l} \alpha_{l,m,n}$, where $h_{l,m,n} = \frac{1}{K} \sum_{t=l}^{l+K-1} h_{l,m,n}^{(t)}$ is the time invariant part and $\alpha_{l,m,n}$ is the time varying factor of its l-th channel tap. $\delta_i = \frac{i}{K} - \frac{K-1}{2K}$ Indicates the time-varying step. For MIMO-OFDM, by regarding each pair of transmitter m and receiver n as a SISO-OFDM link, the time-domain signal received at the nth receiver from the mth transmitter is given by

$$y_{m,n} = (H_{m,n} + A_{m,n}B)x_m \quad (1)$$

where x_m is the time domain signal transmitted from m-th transmitter, $H_{m,n}$ is a K x K circulant matrix with the first column to be $[h_{0,m,n}, h_{1,m,n}, \dots, h_{L-1,m,n}, 0, \dots, 0]^T$, $A_{m,n}$ is a K x K circulant matrix such that its first column is $[\alpha_{0,m,n}, \alpha_{1,m,n}, \dots, \alpha_{L-1,m,n}, 0, \dots, 0]^T$, B is a diagonal matrix such that $B = \text{Diag}([\delta_0, \delta_1, \dots, \delta_{K-1}]^T)$.

The frequency domain equation for the signals is given as

$$Y_{m,n} = (H_{m,n} + A_{m,n}B)X_m \quad (2)$$

where $Y_{m,n} = F_K y_{m,n}$ and $X_{m,n} = F_K x_{m,n}$ are the received and transmitted frequency domain symbol domain vectors. $H_{m,n} = F_K H_{m,n} F_K^H = \text{Diag}(\{H_{m,n,k}\}_{k=1}^K)$ and $A_{m,n} = F_K A_{m,n} F_K^H = \text{Diag}(\{A_{m,n,k}\}_{k=1}^K)$ are diagonal matrices as per the characteristics of the circulant matrix. $\{H_{m,n,k}\}_{k=1}^K$ and $\{A_{m,n,k}\}_{k=1}^K$ are the K-point DFT of $[h_{0,m,n}, h_{1,m,n}, \dots, h_{L-1,m,n}, 0, \dots, 0]^T$ and $[\alpha_{0,m,n}, \alpha_{1,m,n}, \dots, \alpha_{L-1,m,n}, 0, \dots, 0]^T$ respectively. In this B is a pre-calculated matrix.

The ICI components reside in $A_{m,n}$, and the time invariance components reside in $H_{m,n}$. For SISO-OFDM, ICI compensation can be easily achieved by using Equation (2). But for MIMO-OFDM systems it becomes too complicated as the signal from one transmitter gets mixed with interference from other transmitters. This makes calculation of $A_{m,n}$ too hard.

The signal received at the n-th receiver is the superposition of the received signals from the various transmitters and contaminated by noise.

$$Y_n = \sum_{m=1}^M Y_{m,n} = \sum_{m=1}^M (H_{m,n} + A_{m,n}B)X_m + V_n \quad (3)$$

V_n is the frequency domain noise vector at the n-th receiver. Assuming that it follows Gaussian distribution $V_n \sim \mathcal{N}(0_{1 \times K}, \delta^2 I_{K \times K})$.

By vectorizing all received signals, transmitted signals and the frequent domain noise vectors, we get

$$Y = [Y_1^T Y_2^T \dots Y_N^T]^T \quad (4)$$

$$X = [X_1^T X_2^T \dots X_M^T]^T \quad (5)$$

$$Z = [Z_1^T Z_2^T \dots Z_M^T]^T \quad (6)$$

Which results in

$$Y = \begin{bmatrix} H'_{1,1} & H'_{2,1} & \dots & H'_{M,1} \\ H'_{1,2} & H'_{2,2} & \dots & H'_{M,2} \\ \vdots & \vdots & \ddots & \vdots \\ H'_{1,N} & H'_{2,N} & \dots & H'_{M,N} \end{bmatrix} X + V \quad (7)$$

With $H'_{m,n} = H_{m,n} + A_{m,n}B$

II. Symbol Energy Distribution

In order to analyse the distribution of energy over symbol and the ICI on one subcarrier we represent the signal as

$$Y_m = H_{m,m}X_m + \sum_{n=0, n \neq m}^{N-1} H_{m,n}X_n + W_m,$$

with $0 \leq m \leq N - 1$

In this equation the first term in ICI free while the second term which considers the sum of all signals consists of ICI.[8] So the energy of the transmitted signal leaked into the mth subcarrier is

$$P_{m,n} = E[|H_{m,n}X_n|^2] = E_s E[H_{m,n}H_{m,n}^*] \\ = \frac{E_s}{N^2} \sum_{k=0}^{N-1} \sum_{l=0}^{v-1} \sum_{k'=0}^{N-1} \sum_{l'=0}^{v-1} \left(E(h_{k,l}h_{k',l'}^*) e^{\frac{j2\pi(l-k-l'+k')n}{N}} e^{-\frac{j2\pi(k-k')(n-m)}{N}} \right)$$

Here the superscript * represents the conjugate operation. Using this equation the energy of the transmitted signal distributed to subcarriers n-L to n+L can be expressed as

$$\phi_L = \sum_{q=-L}^L P_q \\ = \frac{E_s}{N^2} \sum_{k=0}^{N-1} \sum_{k'=0}^{N-1} \left[J_0(2\pi f_d(k' - k)T_c) \sum_{q=-L}^L e^{-j2\pi(k' - k)q/N} \right]$$

The normalized form of this distribution is depicted in the figure given below. It can be observed from this figure that most of a symbol's energy is spread over itself and its several neighbour subcarriers. More than

99% of the X_n 's energy is distributed on itself and two adjacent subcarriers..[9]

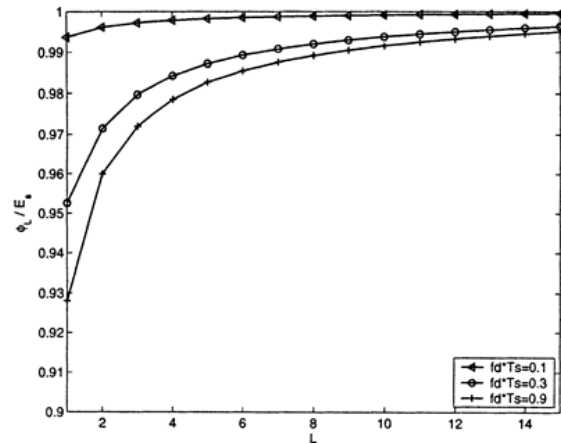


Fig 2 Normalized energy distribution over symbol [9]

III. Proposed Method

First the symbols with highest SINR are detected by using the MMSE detector on all subcarriers of an ofdm block.

While calculating the MMSE, it should be computationally inexpensive.

$$\arg \max_k \frac{|H_{k,k}|^2 E_s}{E_s \sum_{n,n \neq k} |H_{k,n}|^2 + \sigma^2}$$

Step 1: All the predicted SINRs of the undetected symbols in an OFDM block are calculated. From these the symbols with the largest SINR are calculated.

Step 2: This symbol is detected based on partial MMSE. By assuming $K=2L+1$, we define p_k as a K-dimensional column vector, and let p_{ki} denote its i th element. By equation (3) the transmitted block is detected by partial MMSE detector

$G_k = (H_k^K H_k + \sigma^2 I_k)^{-1} H_k^H$, where I_k denotes the K-dimensional identity matrix. We obtain

$$\hat{X}_k = G_k Y_k = G_k H_k X_k + G_k W_k$$

Step 3: \hat{X}_k = hard decision of \hat{X}_k

Step 4: Update the received signal vector Y and the channel matrix

Step 5: Repeat step 1 to 4 until all symbols are detected completely.

IV. Simulation Results

We demonstrated the simulation for time-varying multipath channels with 64 number of subcarriers and the length of cyclic prefix to be 6 samples. BPSK modulation is used and the bit energy is $E_b = E_s/2$. A tap delay line with two paths and an exponential delay power spectrum is simulated. The relative delay of first path is zero and for second path is 5 samples. These are the results with $L=3$ and $L=5$ respectively. The results are compared with Zero force equalization method.

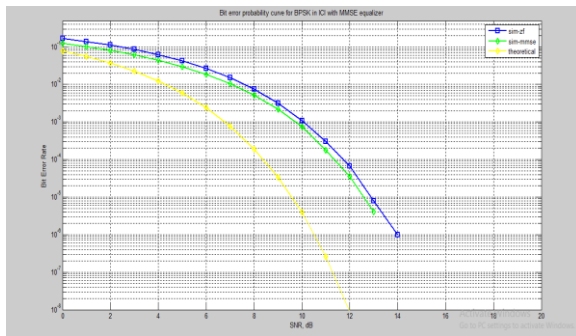


Fig 3

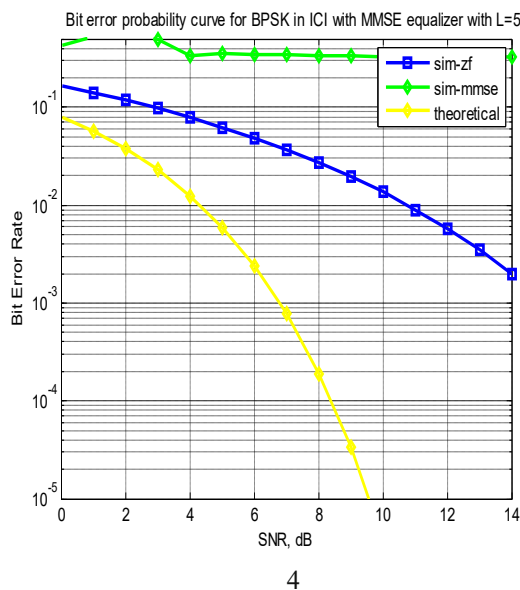


Fig 4

The below figure shows the SNR vs BER plot of the proposed method using the iterative technique for 2,3,4,5 iterations respectively in BPSK and QPSK modulation techniques.

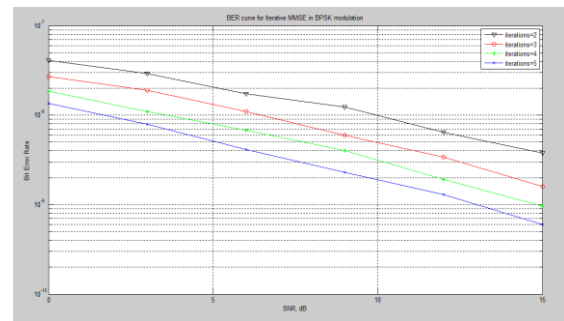


Fig 5

5. BER curve for minimization of ICI for various iterations in BPSK modulation.

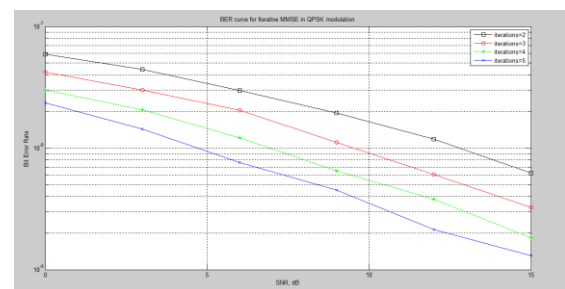


Fig 6. BER curve for minimization of ICI for various iterations in QPSK modulation.

VI. Conclusion

In this work, the symbol energy distribution and the ICI was analyzed. The effect of these based on time varying multipath channels was observed and a method was proposed to mitigate the effect of ICI with least computational complexity. The algorithm is implemented over MIMO-OFDM systems with BPSK and QPSK constellation. Based on Fast Fourier Transform, iterative linear MSE has been implemented to maximize the output signal to noise/interference ratio in the MMSE estimates during iterative detection in BPSK and QPSK modulation techniques for 2,3,4&5 iterations by increasing number of iterations bit error is reduced. Finally we achieved a negligible bit error rate in both modulation techniques and in BPSK we observed a less BER compared to QPSK modulation technique.. By using iterative MMSE technique at prescribed signal to noise gain we achieved 10^{-9} bit error rate .

VII. References

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