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Simulation of Time-Domain LMMSE Channel Estimation for MIMO-OFDM Systems using Sliding Window Concept

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Abstract: ***In this paper, we designed time domain linear minimum mean square estimator for Multiple Input Multiple Output Orthogonal Frequency Division Multiplexing (MIMO-OFDM) systems. MIMO-OFDM system undergoes interference due to multiple antennas, channel conditions, noise etc. In order to mitigate these interferences and improve the signal quality at receiver side we use channel estimation techniques. The TD-LMMSE channel estimation technique is used so that the received signal has less error and could be approximated to the transmitted signal. Furthermore, we are using sliding window concept along with TD-LMMSE for MIMO-OFDM and on the basis of simulation results it is observed that the proposed system shows improved results when compared with SISO-OFDM systems.***

Keywords: Channel Estimation, Interference, MIMO-OFDM, SISO-OFDM, Sliding Window, TD-LMMSE

1. Introduction

In the modern broadband wireless communication, MIMO-OFDM systems are widely used because of their improved performance in terms of link reliability, high data rates and capacity. In MIMO-OFDM system, channel estimation is essential for reliable transmission and reception of data. Channel variation causes a loss of orthogonality among the subcarriers of an Orthogonal Frequency Division Multiplexing (OFDM) symbol and leads to inter-carrier interference (ICI) and degradation in performance. Also, the digital signal is degraded by Inter-symbol interference (ISI) and additive white Gaussian noise (AWGN). MIMO transmission greatly improves the capacity of wireless communications. MIMO increases the channel capacity, which means more through-put and thus increasing the bitrate. Since OFDM can convert a frequency selective channel into parallel flat fading channels, it is natural to combine MIMO with OFDM to provide high rate data transmission over frequency selective channels. However, channel estimation in MIMO-OFDM systems is a challenging task due to the presence of multiple antennas. To restrain these problems, appropriate selection of channel estimation technique is necessary.

In this paper, LMMSE technique is adopted as it provides rapid channel tracking, it smooth out the error which is essential for MIMO systems. LMMSE channel estimation interpolates channel in time as well as frequency domain. One of the disadvantages of LMMSE estimators is their dependence on the a priori knowledge of the channel autocorrelation. Without such knowledge, the application of LMMSE estimation is not possible. The complexity of LMMSE estimation is mainly caused by the inverse of the channel covariance matrix, which is usually large in a high mobility environment. The complexity can be reduced by using a low rank approximation of the channel covariance matrix [1]. The paper is basically design of a time varying LMMSE filter that can emulate a sliding window channel estimation technique for OFDM systems. When implemented on a limited number of time domain OFDM blocks, the TD-LMMSE channel estimator emulates the sliding window effect by changing the coefficients of the estimator filter based on the time instant of the channel to be estimated within the OFDM symbol [2]. In order to reduce the channel estimation computational complexity, the sliding window method is used. In sliding window technique a subset of pilots instead of the complete set of pilots is used in estimating the channel state. The window size (filter length) is adjustable. There is a tradeoff between computational complexity and performance. The bigger/longer the filter length, the better estimation performance we get. At a certain filter length, increasing the length will not give significant improvement any more. A pilot should always be available on the edge of each field for the sliding window to slide [3]. Even in the case of an environment aware receiver, the channel autocorrelation is not known in advance as it is dependent on the mobile velocity and not on the location. Consequently, we also propose a joint estimation of rapidly varying channel and of Doppler Effect experienced by that channel.

2. Review of Literature

The paper [1] is a systematic review on the challenges, modeling, design, and analysis of high mobility communication systems. Due to the high mobility of the communication devices, there is fast channel variation in the physical layer, fast link variations in the link layer, and fast topology variation in the network layer. The fast time-varying operation environment imposes formidable challenges on system designs, and it also provides Doppler diversity that can be exploited to improve system performance. Considering the unique properties of high mobility communications, a list of key challenges and opportunities provided by the high mobility environment has been summarized in the paper.

HavalAbdulrahman thesis [2] uses sliding window technique within the Wiener filtering for the estimation. This window slides from the first pilot position to the next pilot position until it arrives at the edge of the OFDM frame. This sliding happens in the frequency direction and in the time direction. The filter coefficient is in the center within the frequency give the MMSE estimate, hence the best estimate. While the other coefficients in the edges gives larger errors, hence a larger MSE.

The paper [3] presents a new TD-LMMSE algorithm based on sliding window concept to track the communication channel variations in a high speed environment for single input single output SISO-OFDM system. To apply the sliding window concept a time domain LMMSE filter for SISO-OFDM systems was designed in the paper [3]. The TD-LMMSE filter emulates the sliding window effect and it has almost the same performance at all instants within the period of one OFDM symbol even on the edges. The numerical results reported in the paper also show that the proposed TD-LMMSE algorithm outperforms Basis Expansion Models based algorithm proposed in the literature in terms of MSE and BER at high speed. The paper also proposed a simple technique for the estimation of the channel autocorrelation essential for the design of the time domain LMMSE filter. By considering the channel statistics are perfectly known, the results obtained by the estimated autocorrelation represent a small degradation.

In the letter [4], a joint sliding window channel estimation and timing adjustment algorithm has been proposed for adaptive MLSE. Furthermore, a tuning scheme has been presented in order to improve the performance of equalizer. In the tuning method, the channel estimates are updated by using a single iteration of the LMS adaptation algorithm. Simulation results have shown that the proposed algorithms are effective for the channel estimation of the adaptive equalizer.

In paper [5], an adaptive sliding window MMSE ICI canceller technique has been proposed. It shows that in a frequency selective channel, different subcarriers suffer from different interference distortion conditions. Therefore, allowing the canceller to choose a different window size for every subcarrier proved to be advantageous for frequency selective time-varying channels. The results in the paper [5] shows remarkable advantages of the proposed algorithm compared to a conventional MMSE equalizer with a constant window size.

The paper [6] developed a pilot symbol assisted modulation Polynomial channel estimation technique and analyzed assuming rectangular 16-QAM over a flat Rayleigh fading channel. The performance of the Polynomial channel estimation technique is tested for different orders of polynomial, while increasing the Doppler frequency and frame length in order to find out the practical optimal performance of the proposed estimator.

3. System Design

A multicarrier system can be efficiently implemented in discrete time using an inverse FFT (IFFT) to act as a modulator and an FFT to act as a demodulator. The transmitted data are the “frequency” domain coefficients and the samples at the output of the IFFT stage are “time” domain samples of the transmitted waveform. Fig. 1 and 2 shows a typical MIMO-OFDM system with four transmitting and four receiving antennas. In general, MIMO-OFDM system has N_t number of transmitting antennas and N_r number of receiving antennas.

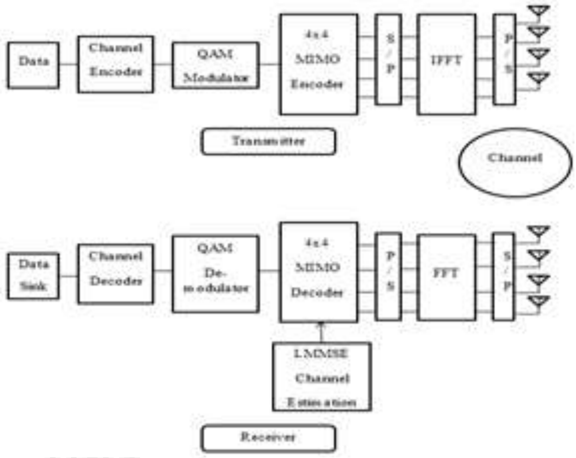

Figure 1: Block Diagram of MIMO-OFDM

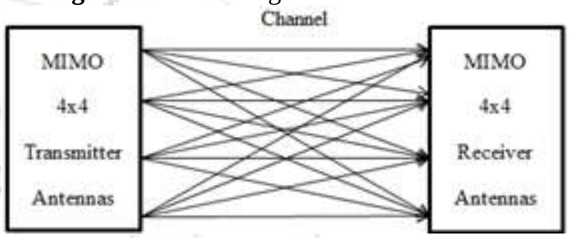

Figure 2: MIMO transmission

Let $X = \{X_0, X_1, \dots\dots, X_{N-1}\}$ denote length-N of data symbol block. The IFFT of data block X yields the time domain sequence, $x = \{x_0, x_1, \dots\dots, x_{N-1}\}$, i.e.,

$$x_n = IFFT_N\{X_N\}(n) \qquad (1)$$

The signal X is modulated by using IFFT and a cyclic prefix is added which acts as guard interval. Then, the modulated signal is transmitted and the antenna at the receiving side receives the incoming signal which will be the convolution of the channel and the transmitted signal. At the receiver, the cyclic prefix is removed first from the received signal. Then fast Fourier transform (FFT) is performed and the demodulated signal can be represented by the equation,

$$Y = HX + W \qquad (2)$$

Where Y is the received signal in frequency domain, H is the channel gain in frequency domain, X is the transmitted signal in frequency domain and W is the zero mean Additive White Gaussian Noise (AWGN) with variance σ_w^2.

It is assumed that the signal is transmitted over a multi path Rayleigh fading channel characterized by,

$$h(\tau) = \sum_{i=0}^{L-1} \alpha_i \delta(\tau - \tau_i) \qquad (3)$$

Where $\tau_i$the time delays of the different paths and L are is the number of multipath. At the receiver, the synchronization is perfect so that transmitted data can be extracted. So that we make an assumption that the cyclic prefix is longer than the channel maximum excess delay.

A. Sliding Window concept

In order to enhance the system performance, instead of block wise estimation we use sliding window technique for traditional OFDM symbol. In this technique, the CIR at any instant within the OFDM block is estimated using window of observations that may correspond to previous or upcoming OFDM symbol along with the current OFDM symbol. For large spacing between pilot carriers, we chose a sliding window that is positioned symmetrically with respect to the time instant under consideration. The time window's length can exceed the length of a single OFDM symbol [2]. Since the channel estimation is now based on a sliding window in time, it may contain observation from two consecutive OFDM symbols. In this case, the traditional frequency domain based channel estimation will not work, so we opt for time domain estimation techniques. Several types of time domain channel estimators can be used. In this paper, we are using cross-correlation based estimation as the channel is quasi-static within the sliding window.

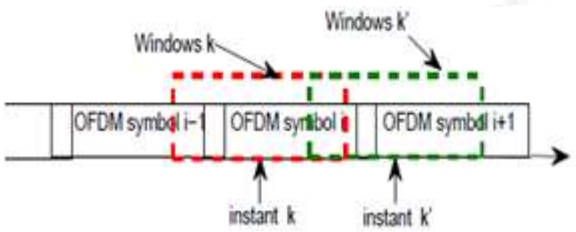

Figure 3: Channel Estimation using Sliding Window [3]

B. LMMSE Channel Estimation

For applying sliding window concept to MIMO-OFDM system we will be using Time Domain Linear Minimum Mean Square Estimation (TD-LMMSE) so the time domain representation of received signal instance k is given by,

$$y_k = h_k x_k + w_k \tag{4}$$

The TD-LMMSE channel estimator minimizes the mean square error between the actual and estimated channels i.e. finding the matrix w_k that minimizes the MSE criterion between h_k and the linear estimator $\hat{h}_k = y_k w_k$. The TD-LMMSE estimator is obtained by applying the Wiener–Hof equation as follows,

$$\hat{h}_{LMMSE,k} = C_{h_k,y_k} C_{y_k}^{-1} y_k \tag{5}$$

The cross-covariance matrix of $L\ x\ L_w$ is given by,

$$C_{h_k,y_k} = E[h_k y_k^H] = C_{h_k,h_k} x^H \tag{6}$$

The auto-covariance matrix of $L_w\ x\ L_w$ is given by

$$C_{y_k} = E[y_k y_k^H] = x C_{h_k,h_k} x^H + \sigma_w^2 I_N \tag{7}$$

The LMMSE estimator can be rewritten as follows by using the above relations,

$$\hat{h}_{LMMSE,k} = C_{h_k,h_k} x^H \left(x C_{h_k,h_k} x^H + \sigma_w^2 I_N \right)^{-1} y_k$$
$$= C_{h_k,h_k} [C_{h_k,h_k} + \sigma_w^2 (x x^H)^{-1}]^{-1} h_{LS} \tag{8}$$

Where h_{LS} is the Least Square (LS) estimate and is given by,

$$h_{LS} = \frac{y_k}{x_k} \tag{9}$$

Based on this TD-LMMSE channel estimation the results are obtained.

The mean square error is defined by,

$$MSE = \frac{1}{L} E[(\widehat{h_k} - h_k)^H (\widehat{h_k} - h_k)] \tag{10}$$

4. Results and Discussion

The simulation results for the TD-LMMSE using sliding window concept is observed for MIMO-OFDM system and the results are compared with SISO-OFDM for with and without sliding window technique. The results are compared on the basis of BER and MSE parameters.

Fig. 4 shows the BER vs SNR plot for SISO-OFDM and MIMO-OFDM with and without sliding window technique. From this plot we observe that the bit error rate for MIMO-OFDM with sliding window technique has less BER compared to other systems. The BER for SISO-OFDM without sliding window technique is high.

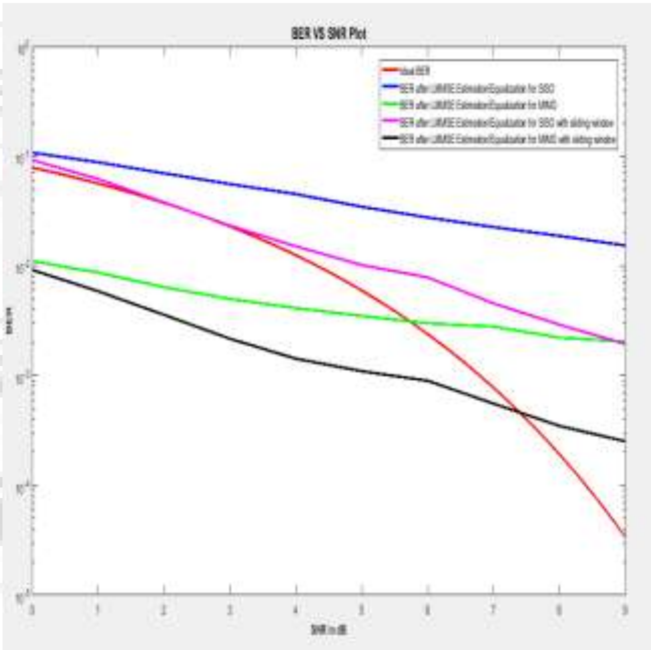

Figure 4: BER vs SNR plot

The Fig. 5 is the MSE vs SNR plot for TD-LMMSE for SISO-OFDM and MIMO-OFDM with and without sliding window. From the figure we can see that the MSE for the proposed system i.e. MIMO-OFDM with sliding window is showing improved results when compared with other systems.

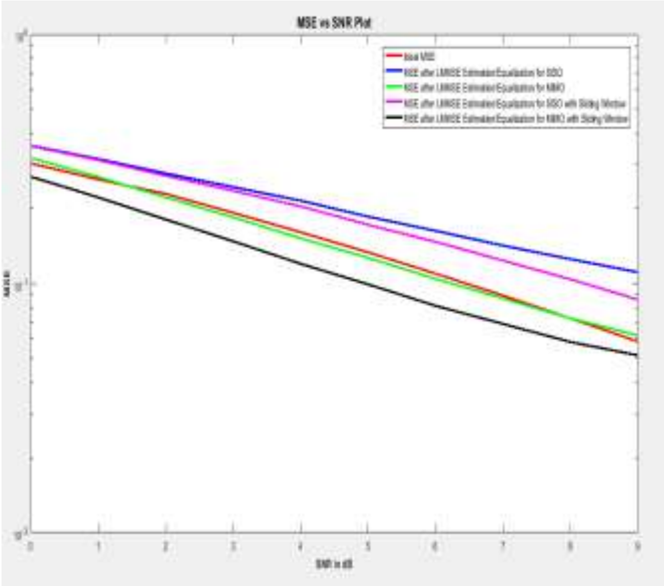

Figure 4: MSE vs SNR plot

From the above results we can conclude that the proposed system gives significant results in terms of BER and MSE. The MIMO-OFDM system with sliding window improves the overall performance of the system. Also, the received signal has less error and thus, reliable communication is achieved.

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