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Sparse channel estimation of MIMO OFDM systems using LS and MMSE method

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ABSTRACT

In wireless communication systems, Orthogonal Frequency Division Multiplexing (OFDM) is implemented widely due to its high rate transmission capability. The bandwidth efficiency and robust against multipath propagation makes OFDM as a suitable applicant for wireless communication. Channel State Information (CSI) is the vital parameter in deciding the capacity of the system. In this paper, the sparse MIMO channel is estimated using Least Square (LS) and Minimum Mean Square Error (MMSE) algorithms. The performance of these algorithms depends on the number of pilot symbols. The complexity of LS algorithm is very low but the mean square error is high. MMSE algorithm uses the second order channel statistics to reduce the mean square error. Simulation results shows that MMSE algorithm outperforms LS algorithms in terms of Mean square error and Bit Error Rate (BER).

Keywords: *MIMO, Channel estimation, Orthogonal Frequency Division Multiplexing (OFDM), Bit error rate (BER), Least Square (LS), Minimum Mean Square Error(MMSE).*

1. INTRODUCTION

In wireless communications, Multiple Input Multiple Output (MIMO) technology is one of the major attracting techniques because it offers increases in data throughput and coverage without additional bandwidth or transmitter power. It also provides high spectral efficiency. MIMO is an important part of modern wireless communication standards such as IEEE 802.11n (Wi-Fi), 4G, 3GPPLTE, WiMAX and HSPA+[4]. Orthogonal frequency division multiplexing (OFDM) is based on technology of multicarrier communication The main idea of multicarrier communications is to divide the total signal bandwidth into number of subcarrier, thus helping to eliminate Inter Symbol Interference (ISI). It also allows the bandwidth of subcarriers to overlap without Inter Carrier Interference (ICI). In [6] OFDM therefore is considered as an efficient modulation technique. Its increased complexity over the conventional system caused by employing N modulators and filters at the transmitter and N demodulators and filters at the receiver are the disadvantages. This complexity can be removed by the use of the FFT and IFFT at the receiver and transmitter, respectively. The MIMO OFDM system consists of N_t transmit and N_r receiving antenna along with pilot carriers in frequency domain. MIMO OFDM is a new broadband wireless technology used in channel estimation due to high data rate and because of its strength against multipath fading effects. The major problem faced in channel estimation is how to obtain the channel state information correctly.

In training symbol based channel estimation the two types of arrangements are used. One is the block type and the another is comb type [6]. The block type arrangement channel estimation is done under the assumption of slow fading where the channel transfer function not changes rapidly while in comb type, the interpolation is used for the estimation. The technique LS estimation are widely used for channel estimation. In the Least square OFDM channel estimation, channel frequency response at pilot positions is acquired and then use these observations to interpolate the rest of the subcarriers. This method is simple to use. Generally, accurate channel estimation requires more pilots than channel coefficients. When the channel has large delay spread and contains many multipath signals, the pilot number raises rapidly. For MIMO, the overhead of pilot symbols becomes considerable as number of transmitter antennas increases. A prior knowledge about the channel sparsity is a possible solution. Wireless channels are typically sparse in practice. Sparse channel refers to number of nonzero elements is less compared to channel coefficients. With some sparse recovery algorithms, the number of pilots can be considerably reduced. Matching pursuit (MP) and orthogonal matching pursuit (OMP) are commonly employed sparse recovery algorithm, which sequentially identifies a small subset of nonzero taps.

This Paper is organized as follows. Section 2 provides the MIMO-OFDM system description. For MIMO-OFDM system the channel estimation algorithms are discussed in section 3. Detailed results in terms of Mean square error and bit error rate are given in Section 4. Finally, the conclusion is discussed in section 5.

2. SYSTEM DESCRIPTION

Multiple Input Multiple Output system for wireless communication has gained attraction in the recent past. Multiple antennas are used to introduce multiplexing gain, a diversity gain, or an antenna gain, thus enhancing the bit rate, the error performance, or the signal-to-noise-plus-interference ratio of wireless systems, respectively. Wide band data transmission makes the channel frequency selective and introduces Inter Symbol interference (ISI). Orthogonal Frequency Division Multiplexing (OFDM) is the widely accepted multicarrier technique for wide band data transmission. OFDM technique converts the frequency selective channel into flat fading channels that avoids the use of equalizers. The combination of MIMO with OFDM is an attractive solution for bandwidth limited and frequency selective underwater channel conditions.

2.1 Orthogonal frequency division multiplexing

The fundamental idea of OFDM systems is the division of the available frequency spectrum into several subcarriers. To obtain a high spectral efficiency, the frequency responses of the subcarriers are kept to be overlapping and orthogonal. This orthogonality can be completely maintained with a small loss in SNR, even though the signal passes through a time dispersive fading channel, by introducing a cyclic prefix (CP). A block diagram of a baseband OFDM system is shown in Figure 1.[3]

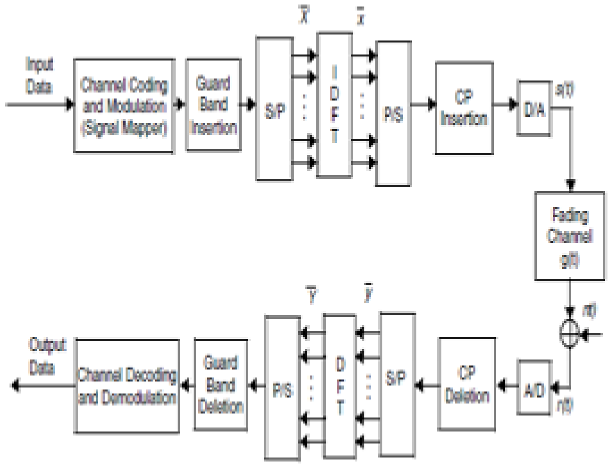

Figure 1. Block diagram of a baseband OFDM system

The binary information is grouped, coded, and mapped according to the modulation in a signal mapper. QAM Modulation is proposed in the work. After the guard band is inserted, an N-point inverse discrete-time Fourier transform (IDFT) block transforms the data sequence into time domain. Following the IDFT block, a cyclic prefix extension of time length TG, chosen to be larger than the expected delay spread, is inserted to remove inter symbol interferences and inter carrier interferences [5]. The D/A converter contains low-pass filters with bandwidth 1/TS, where TS is the sampling interval. The channel is modelled as an impulse response h(τ) followed by the complex additive white Gaussian noise (AWGN), where α_i is a complex values and $0 \leq \tau_m \, TS \leq TG$.

2.2 Mimo -ofdm system model

Multiple-Input Multiple-Output systems produce massive capacity increases when the rich scattering environment is properly exploited. When examining the performance of MIMO systems, the MIMO channel must be modeled properly. Figure 2 shows a block diagram of a MIMO system with N_t transmit antennas and N_r receive antennas. The channel for a MIMO system can be represented by H channel matrix.

$$H = \begin{bmatrix} h_{11} & \dots & h_{1Nt} \\ h_{21} & \dots & h_{2Nt} \\ . & \dots & . \\ . & \dots & . \\ h_{Nr1} & \dots & h_{NtNr} \end{bmatrix}$$

Where, h_{ij} is the complex channel gain between the j^{th} transmitter and i^{th} receiver. Each channel gain h_{ij} is assumed to be independently identically distributed zero mean complex Gaussian random variables with unit variance.

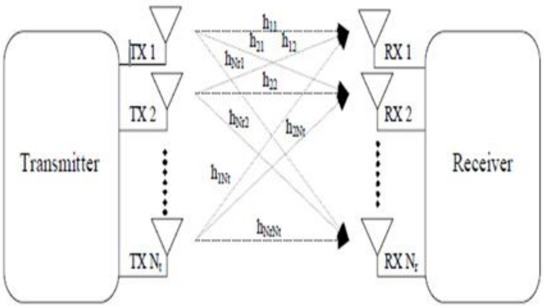

Figure 2. MIMO System

A simple MIMO system can be modelled as

$$Y = HX + N \quad (1)$$

Where X and Y are the transmitted vectors and received vectors, H is the channel matrix and N is the noise vectors respectively. It is assumed that the signal is transmitted over a multi path Rayleigh fading channel characterized by

$$h(t) = \sum_{m=1}^{M} \alpha_m \zeta(t - \tau_m T_S) \quad (2)$$

Where, τ_m is the time delays of the different paths and M is the number of multipath. At the receiver, the synchronization achieved is ideal so that transmitted data can be extracted perfectly. At the receiver, after passing through the analog-to-digital converter (ADC) and removing the CP, the DFT is used to transform the data back to frequency domain. Lastly, the binary information data is obtained back after the demodulation and channel decoding.

Let $X = [X_k]^T$ and $Y = [Y_k]^T$ where (k=0,1...N-1) denotes the input data of IDFT block at the transmitter side and the output data of DFT block at the receiver side, respectively. Let $H = [H_n]^T$ is the sampled channel impulse response and $N = [N_n]^T$ is the AWGN where (n=0,...,N-1). Defining the input matrix as diagonal matrix and the DFT-matrix is F [3],[5].

$$F = \begin{bmatrix} W_N^{00} & \cdots & \cdots & W_N^{0(N-1)} \\ \vdots & \cdots & \cdots & \vdots \\ \vdots & \cdots & \cdots & \vdots \\ W_N^{(N-1)0} & \cdots & \cdots & W_N^{(N-1)(N-1)} \end{bmatrix}$$

$$W_N^{i,k} = (1/\sqrt{N})^{-j2\Pi(ik/N)} \quad (3)$$

Under the assumption that the interference is completely eliminated [3]

$$\overline{Y} = DFT_N(IDFT_N(\overline{X}) \otimes \overline{H} + \overline{N})$$

$$\overline{Y} = \overline{XH} + \overline{N}$$

3. CHANNEL ESTIMATION

In an OFDM system, the transmitter modulates the message bit sequence into QAM symbols, performs IFFT on the symbols to convert them into time-domain signals, and sends them out through a wireless channel. The received signal is usually inaccurate by the channel characteristics. In order to recover the transmitted bits, the channel effect must be estimated and compensated in the receiver. The orthogonality allows each subcarrier component of the received signal to be expressed as the product of the transmitted signal and channel frequency response at the subcarrier. Thus, the transmitted signal can be recovered by estimating the channel response at each subcarrier. In general, the channel can be estimated by using pilot symbols known to both transmitter and receiver, to estimate the channel response of the subcarriers between the pilot. In general, data signal as well as training signal, or both, can be used for channel estimation.

3.1 Pilot based channel estimation

Training symbols can be used for channel estimation [4], usually providing a good performance. However, their transmission efficiencies are reduced due to the required overhead of training symbols such as preamble or pilot tones that are transmitted in addition to data symbols. Assume that all subcarriers are orthogonal then the training symbols for N subcarriers can be represented by the following diagonal matrix:

$$X = \begin{bmatrix} X[0] & 0 & \dots & 0 \\ 0 & X[1] & \dots & . \\ . & \dots & \dots & 0 \\ 0 & \dots & 0 & X[N-1] \end{bmatrix}$$

where X[k] denotes a pilot tone at the k^{th} subcarrier, with E{X[k]}=0 and Var{X[k]}=$\sigma^2 x$ where k= 0, 1,2,…,N-1. Let X is given by a diagonal matrix, since we assume that all subcarriers are orthogonal. Given that the channel gain is H[k] for each subcarrier k, the received training signal Y[k] can be represented as

$$Y = \begin{bmatrix} Y[0] \\ Y[1] \\ : \\ Y[N-1] \end{bmatrix}$$

$$= \begin{bmatrix} X[0] & 0 & \dots & 0 \\ 0 & X[1] & \dots & : \\ : & \dots & \dots & 0 \\ 0 & \dots & 0 & X[N-1] \end{bmatrix} \begin{bmatrix} H[0] \\ H[1] \\ : \\ H[N-1] \end{bmatrix} + \begin{bmatrix} N[0] \\ N[1] \\ : \\ N[N-1] \end{bmatrix}$$

where H is a channel vector given as H={H[0],H[1],.. .H[N-1]}^{T} and N is a noise vector given as N={N[0],N[1],…,N[N-1]^T with E{N[k]}= 0 and Var{N[k]}=$\sigma^2 z$ where k=0,1, 2, ….N-1. In the following discussion, let $\hat{H}$ denote the estimate of channel H.

3.2 Least square channel estimator

The Least square estimate of the channel can be expressed as $\hat{H}_{LS}$ where $X^H X\hat{H} = X^H Y$, [4] which gives the solution to the LS channel estimation as in [4]

$$\hat{H}_{LS} = (X^H X)^{-1} X^H Y = X^{-1} Y \qquad (4)$$

Let us denote each component of the LS channel estimate $\hat{H}_{LS}$ by $\hat{H}_{LS}$ [k] where k = [0,1,2,…, N-1].Since X is assumed to be diagonal due to the ICI-free condition, the LS channel estimate $\hat{H}_{LS}$ can be written for each subcarrier as

$$\hat{H}_{LS}[k] = \frac{Y[k]}{X[k]} \qquad (5)$$

where k=[0,1,2,…,N-1].The mean-square error (MSE) of this LS channel estimate is given as

$$MSE_{LS} = E\{(H - \hat{H}_{LS})^H (H - H_{LS})\} \quad (6)$$

3.3 Minimum mean square error channel estimator

The Minimum Mean Square estimate of the channel can be expressed as $\hat{H}_{MMSE}$ where it employs the second-order statistics of the channel conditions to reduce the mean-square error.

$$\hat{H}_{MMSE} = FR_{hy} R^{-1}{}_{yy} y \qquad (7)$$

Where F is Matrix of DFT and $R_{hy}$is cross correlation of H and Y

$$R_{hy} = E\{hy^H\} = R_{hy} F^H X^H \qquad (8)$$

4. RESULTS AND DISCUSSION

4.1 .System parameters

OFDM system parameters used in the simulation are indicated in the Table 1. The aim is to achieve better channel estimation performance. Simulations are carried out for different signal -to-noise (SNR) ratios. The simulation parameters to achieve those results are listed in the table 1.

Table -1: Simulation parameters

Parameters	Specification
FFT Size	256
No of Subcarriers	256
Number of Transmitter antenna	2
Number of Receiver antenna	4
Signal Constellation	QAM
No of Blocks	100
Channel Model	Rayleigh Fading
Channel Taps	6

The BER and MSE curves are obtained by varying the number of pilot carriers. MSE and BER values calculated using LS algorithm is shown in Figure 3(a) and 3(b) respectively. As the number of pilot symbols increases the estimation error decreases but the spectral efficiency decrease with the increasing number of pilot carriers.

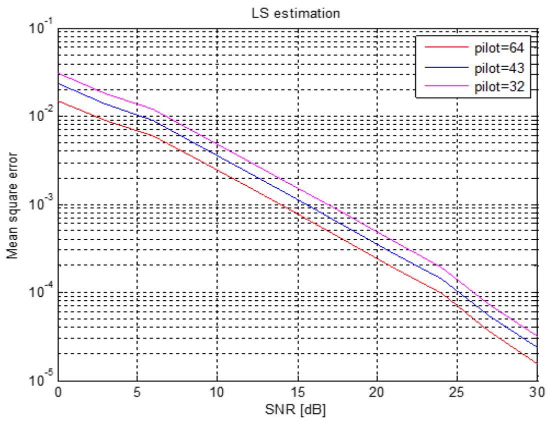

Figure 3(a) Mean square error of LS estimation

In the above result it is observed that the MSE is reduced as number of pilot carriers are increased. The spectral efficiency is achieved only when the usage of minimum number of pilot carriers.

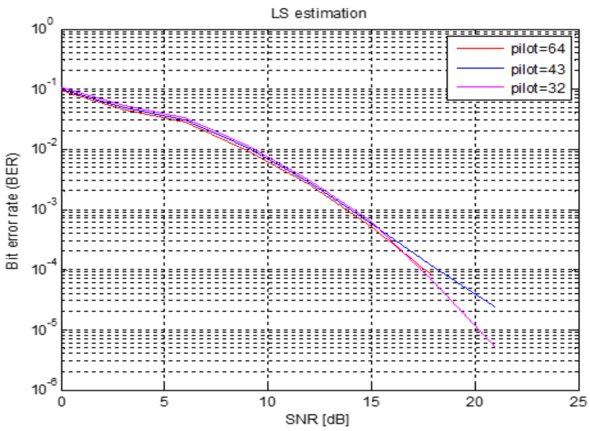

Figure 3(b) Bit Error Rate of LS estimation.

Figure 4(a) shows the MSE of MMSE estimation versus SNR which is averaged over 100 OFDM blocks at every signal to noise value. MMSE algorithm provides better performance but its computational complexity is high compared to LS. The obtained result in figure 4(a) is for the usage of 128 pilot carriers out of 256 sub carriers.

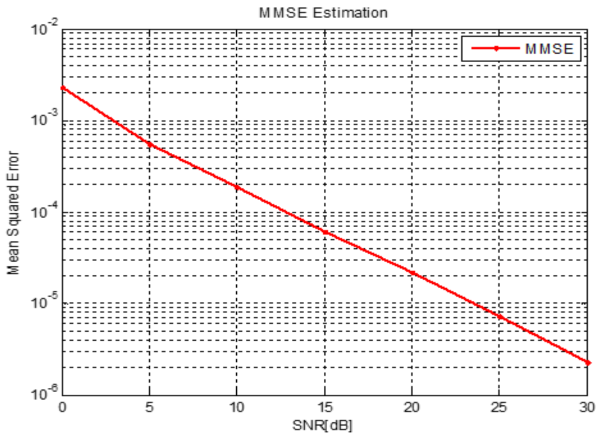

Figure 4(a) Mean square error of MMSE estimation

Figure 5 compares the performance of LS and MMSE algorithms in terms of the estimation error. Estimation error with MMSE algorithm is less than that of LS algorithm. The second order channel statistics are pre-requisite for the implementation of MMSE algorithm. The obtained result is considering all the subcarriers as pilot carriers.

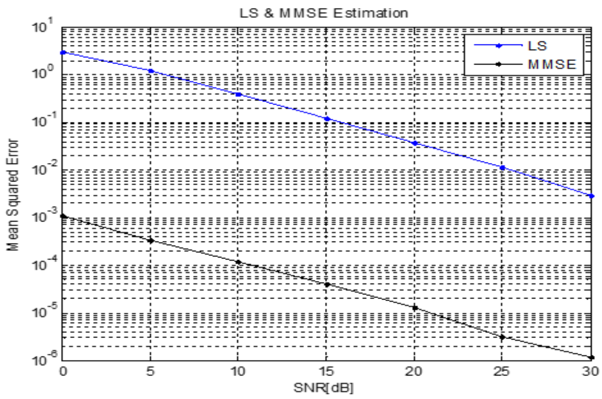

Figure 5. Mean Square error of LS and MMSE estimation

5. CONCLUSION

Channel state Information is one of the vital parameters in MIMO-OFDM system. Pilot based channel estimation algorithms are discussed in this paper. MMSE algorithm is compared with LS algorithm. MMSE algorithm needs the channel statistics for the estimation of the channel. The complexity of MMSE algorithm as per the simulation results, the performance of MMSE algorithm is better than LS algorithm in terms of MSE and BER.

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