Channel Estimation Analysis in MIMO-OFDM Wireless Systems

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Abstract-In modern wireless communication systems, a combination of multiple-input multiple-output (MIMO) system with the orthogonal frequency division multiplexing (OFDM) technique can be used to achieve high data rate and &better spectral efficiency. A Channel estimation technique using pilot carriers for multiple input multiple output(MIMO) systems for a Rayleigh fading channel is proposed in this paper. The channel estimation is carried out with conventional Least Square (LS) and Minimum Mean Square (MMSE) estimation algorithms. The performance of MIMO-OFDM system is evaluated on the basis of Bit Error Rate (BER) and Mean Square Error (MSE) level.

Keywords- MIMO-OFDM , Channel Estimation, Pilot carriers, Minimum Mean square error.

I. INTRODUCTION

Mobile communication systems transmit bits of information via changes in amplitude and phase of radio waves. In the receiving side of mobile system ,amplitude or phase can vary dramatically. This results in degradation of system quality since the performance of receiver is highly dependent on the accuracy of estimated instantaneous channel . So channel estimation technique is introduced to improve accuracy of the received signal. The radio channels in mobile communication systems are usually multi path fading channels, which are causing inter symbol interference(ISI) in the received signal. To remove ISI from the signal, many kind of detection algorithms are used at the receiver side. These detectors should have the knowledge on channel impulse response(CIR) which can be provided by separate channel estimator. The channel estimation is based on the known sequence of bits which is unique for certain transmitter and which is repeated in every transmission burst. Thus the channel estimator is able to estimate channel impulse response for each burst separately from the known transmitted bits and corresponding received samples.

OFDM(Orthogonal Frequency Division Multiplexing) is a multi-carrier modulation technique which is used to transmit high rate data stream through wireless medium. It divides the high-rate data stream into parallel lower rate data streams which are transmitted simultaneously over a number of separate subcarriers. This technique is also used to eliminate Inter Symbol Interference (ISI). It also allows the bandwidth of sub carriers to overlap without Inter Carrier Interference (ICI). Good spectral efficiency in OFDM can be achieved by using special set of orthogonal carrier frequencies.

MIMO-OFDM (multiple input multiple output- orthogonal frequency division multiplexing) is a new wireless broad band technology which has great capability of high rate transmission and its robustness against multi-path fading and other channel impairments. In MIMO system, multiple number of transmitters at one end and multiple number of receivers at the other end are effectively combined in such a way to improve the channel capacity This technology can improve the spectrum efficiency, reliability& coverage. Space time block coding is used to transmit & receive multiple number of a data stream across a number of antennas at the transmitter and receiver to improve reliability of data transfer. The one of the main challenge of MIMO-OFDM systems is how to obtain the channel state information accurately for coherent detection of information symbols. The channel state information can be obtained through different types of estimation algorithms such as training based, blind and semi blind channel Estimation.

The blind channel estimation is carried out by evaluating the statistical information of the channel and particular properties of the transmitted signals. This estimation has no overhead loss and it is only suitable for slowly time-varying channels. But in training based channel estimation, training symbols or pilot tones that are known to the receiver, are multiplexed along with the data stream for channel estimation. The Semi-blind channel estimation algorithm is a hybrid combination of blind channel estimation & and training based channel estimation which utilizes pilot carriers and other natural constraints to perform channel estimation.

The training-based channel estimation can be performed by either block type pilots or comb type pilots. In block type pilot estimation, pilot tones are inserted into all frequency bins within the periodic intervals of OFDM blocks.

This estimation is suitable for slow fading channels. But in comb type pilot estimation, pilot tones are inserted into each OFDM symbol with a specific period of frequency bins. This channel estimation is suitable where the changes even in one OFDM block. The comb-type pilot channel estimation consists of algorithms to estimate the channel at pilot frequencies and

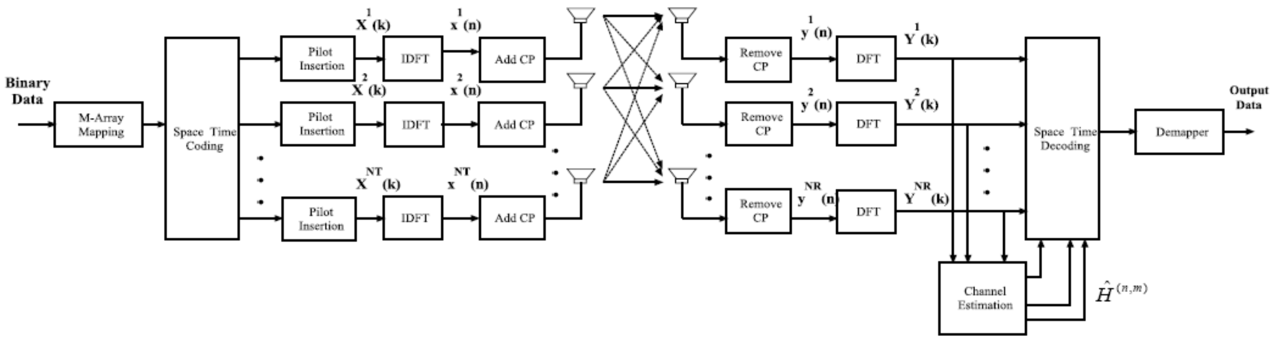

Figure 1. MIMO-OFDM System Modeling

interpolation is used to find the channel at signal frequencies. Optimal low rank MMSE (Minimum Mean Square Error) estimator is used for this analysis. This channel Estimation is compared with LS algorithm.

II. MIMO - OFDM SYSTEM

Figure.1 shows the block diagram of the MIMO-OFDM system. For easy analysis, MIMO–OFDM system with two transmitting antennas and two receiving antennas is considered. The total number of sub carriers is N. The MIMO-OFDM transmitter has *Nt* parallel transmission paths and each path performing serial-to-parallel conversion, pilot insertion, *N*-point IFFT and cyclic extension before the final TX signals are up-converted to RF signal and transmitted. The channel encoding and digital modulation can also be done per branch, where the modulated signals are space-time coded using the Alamouti algorithm before transmitting from multiple antennas . At the receiver, the CP is removed and *N*-point FFT is performed per receiver branch and then the operations like digital demodulation and decoding are done. Finally all the input binary data are recovered with certain BER.

As a MIMO signaling technique, *Nt* different signals are transmitted simultaneously over *Nt* X *Nr* transmission paths and each of those *Nr* received signals is a combination of all the *Nt* transmitted signals and the distorting noise. It brings in the diversity gain for enhanced system capacity . But channel estimation and symbol detection is more complex due to the more number of channel coefficients. The data stream from each antenna undergoes OFDM Modulation. The Space Time Block Coding(STBC) is used for encoding purpose and the encoding matrix is given as

$$X = \begin{bmatrix} X_1 & -X_2^* \\ X_2 & X_1^* \end{bmatrix} \tag{1}$$

Where

$$X1 = (\ X[0]\ \ -X^*[1]\ \ X[2]\ \ -X^*[3]\ \ \ldots\ldots\ -X^*[N\text{-}1]\ ) \tag{2}$$

$$X2 = (\ X[1]\ \ X^*[0]\ \ X[3]\ \ X^*[2]\ \ \ldots\ldots\ X^*[N\text{-}2]\ ) \tag{3}$$

The vectors $X1$ and $X2$ are modulated using the inverse fast Fourier transform (IFFT) and a cyclic prefix code is added which act as a guard time interval. Then two modulated signals $Xg1$ and $Xg2$ are transmitted by the transmitting antennas. Assuming that the guard time interval is more than the expected largest delay spread of a multi path channel. 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 (4)

$$\begin{bmatrix} Y_1 \\ \vdots \\ Y_{N_R} \end{bmatrix} = \begin{bmatrix} H_{1,1} & \cdots & H_{1,N_T} \\ \vdots & \ddots & \vdots \\ H_{N_R,1} & \cdots & H_{N_R,N_T} \end{bmatrix} \begin{bmatrix} X_1 \\ \vdots \\ X_{N_T} \end{bmatrix} + \begin{bmatrix} W_1 \\ \vdots \\ W_{N_T} \end{bmatrix} \tag{4}$$

In the above equation $[W_1, W_2 \ldots\ldots W_{NT}]$ denotes additive white Gaussian noise(AWGN) and $H_{m,n}$ is the (single-input single-output) channel gain between the m'th receiver and n'th transmitter. For simple analysis, two transmitting and two receiving antennas are considered. By Knowing the channel state information at the receiver, Maximum Likelihood (ML) detection technique is used for decoding the received information. It can be given by equation (5) & (6).

$$\tilde{S}[2k] = \sum_{i=1}^{N_R} H_{i,1}^*[2k]Y_i[2k] + H_{i,2}[2k]Y_i^*[2k+1] \tag{5}$$

$$\tilde{S}[2k+1] = \sum_{i=1}^{N_R} H_{i,2}^*[2k+1]Y_i[2k] - H_{i,1}[2k+1]Y_i^*[2k+1] \tag{6}$$

Where $k = 0,1,2\ldots\ldots(N/2)\text{-}1$

Assuming that the channel gains between two adjacent Sub channels are approximately equal. i.e.

$$H_{i,1}[2k] = H_{i,1}[2k+1] \tag{7}$$

$$H_{i,2}[2k] = H_{i,2}[2k+1] \tag{8}$$

III. MIMO-OFDM CHANNEL ESTIMATION

A simple signal model for MIMO-OFDM system is explained here. In training based channel estimation algorithms, training symbols or pilot tones that are known to the receiver, are multiplexed along with the data stream for channel estimation. The receiver should have the knowledge of pilot tones for the estimation of channel at the receiver side.

A block fading channel is a channel which is constant over a few OFDM symbols. In this channel, pilots are transmitted on all sub carriers in periodic intervals of OFDM blocks. This type of pilot arrangement is shown in Fig. 2(b), is called as block type arrangement.

A fast fading channel has channel impulse response changes rapidly within symbol duration and the channel changes between adjacent OFDM symbols. In this fast fading, the pilots are transmitted at all times but with an even spacing on the sub carriers, representing a comb type pilot placement which is shown in Fig. 2(a) .The channel estimates from the pilot sub carriers are interpolated to estimate the channel at the data subcarriers.

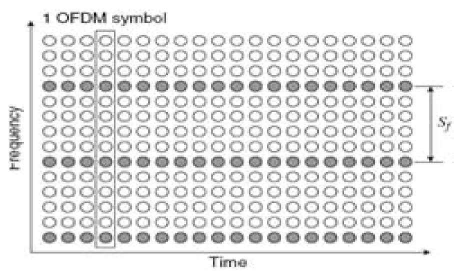

Figure .2(a) Comb Type Pilot

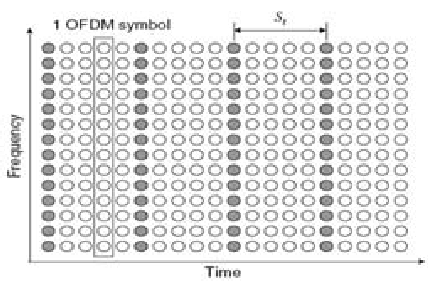

Figure .2(b) Block type Pilot

The Least square (LS) channel estimation for MIMO-OFDM System between n'th transmitter and m'th receiver antenna is given by the equation (9).

$$\widehat{H}_{LS}^{(n,m)} = \left(X^{(n)}\right)^{-1} Y^{(m)} \tag{9}$$
$$X = diag\{X(0), X(1), \ldots . X(N-1)\} \tag{10}$$

$$Y = [y(0), Y(1), \ldots . y(N-1)]^T \tag{11}$$

MMSE channel estimation for MIMO-OFDM System between n'th transmitter and m'th receiver antenna is

$$\widehat{H}_{MMSE}^{(n,m)} = F R_{hY} R_{YY}^{-1} Y^{(m)} \tag{12}$$

Where

$$R_{hY} = R_{hh}^{(m,n)} F^H (X^{(n)})^H \tag{13}$$

$$R_{YY} = X^{(n)} F R_{hh}^{(n,m)} F^H (X^{(n)})^H + \sigma^2 I_N \tag{14}$$

$$F = \begin{bmatrix} W_N^{00} & \ldots & W_N^{0(N-1)} \\ \vdots & \vdots & \vdots \\ W_N^{(N-1)0} & \ldots & W_N^{(N-1)(N-1)} \end{bmatrix} \tag{15}$$

$$H = [H(0), H(1), \ldots . . H(N-1)]^T \tag{16}$$

$$W = [W(0), W(1), \ldots . . W(N-1)]^T \tag{17}$$

n = 1, 2….N_T, m = 1, 2….N_R and N_T, N_R are the numbers of transmit and receive antennas, respectively, X(n) is an N X N diagonal matrix whose diagonal elements correspond to the pilots of the nth transmit antenna and Y(m) is N length received vector at receiver antenna m.

IV. SIMULATION

A. System Parameters

Different system parameters for a Rayleigh fading channel MIMO-OFDM system used in the simulation are shown below

FFT Size -128; No. of carriers -128 ; guard Interval -32; Modulation –QPSK; Pilot type –Block & Comb pilot.

Simulation is done under the assumption that proper synchronization is maintained between the transmitter & receiver. In order to avoid inter-symbol interference, the guard interval value is taken as high .

B. MIMO-OFDM system Modeling & Simulation

Multi path fading channel model for 2 X 2 MIMO-OFDM system with sampling interval N_s is given by the following equations.

$$h_{11}(n)=\delta(n)+ \delta(n-0.5N_s)+ \delta(n-3.5N_s) \tag{18}$$
$$h_{12}(n)=\delta(n)+ \delta(n-0.4N_s)+ \delta(n-1.1N_s) \tag{19}$$
$$h_{21}(n)=\delta(n)+ \delta(n-0.4N_s)+ \delta(n-0.9N_s) \tag{20}$$
$$h_{22}(n)=\delta(n)+ \delta(n-0.6N_s)+ \delta(n-2.2N_s) \tag{21}$$

The MIMO-OFDM system performance is evaluated by means of the plot of Mean Square Error (MSE) and Bit Error Rate(BER) which is shown in Figure.3 & Figure.4. Block-type and comb type pilot based channel estimation using LS and MMSE algorithms are used to model Rayleigh fading channel of MIMO-OFDM system.

The instantaneous Mean Square Error (MSE) is defined as the average error within an OFDM block and that can be expressed as

$$MSE = \frac{1}{N}\sum_{k=1}^{N}|H(k) - H_e(k)|^2 \qquad (22)$$

Where k is the index of the sub carrier and $H_e(k)$ is estimated by the value of channel attenuation.

Figure. 3 shows the Mean Square Error (MSE) for the LS and MMSE channel estimation algorithms of MIMO- OFDM systems. It is observed from figure that MMSE channel estimation has low Mean Square Error than LS channel estimation algorithm.

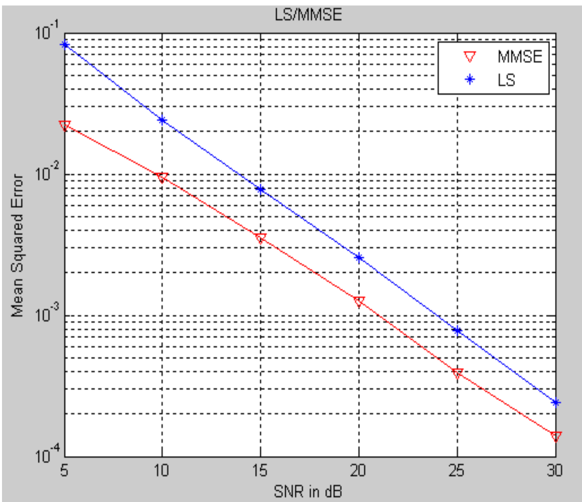

Figure 3. MSE for LS/MMSE estimators to MIMO- OFDM system

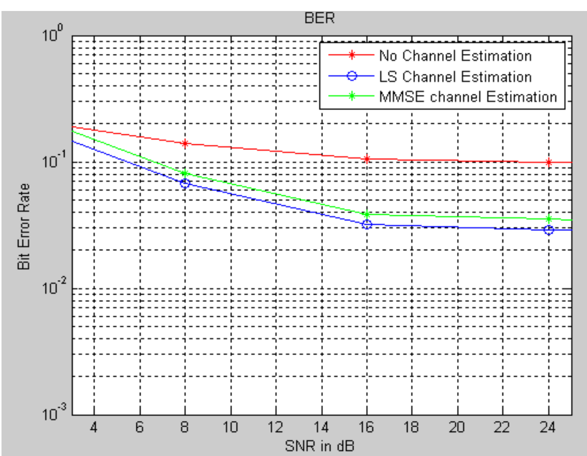

Figure 4. BER plot for MIMO -OFDM with LS/MMSE Estimators

Figure. 4 shows the BER plot of the MIMO-OFDM system with LS/MMSE Estimators . From the plot, it is observed that bit error rate (BER) is high without any channel estimation. By the introduction of channel estimation, the BER is reduced. It is shown from figure ,Minimum Mean Square Error(MMSE) Estimator has lower BER than LS Estimator.

Figure 5. shows the BER plot of MIMO-OFDM system With block and comb type pilot carriers. It is assumed that channel is known to the receiver. By comparing both block type and comb type carrier estimation, Comb type carrier estimation has lower bit error rate and better performance.

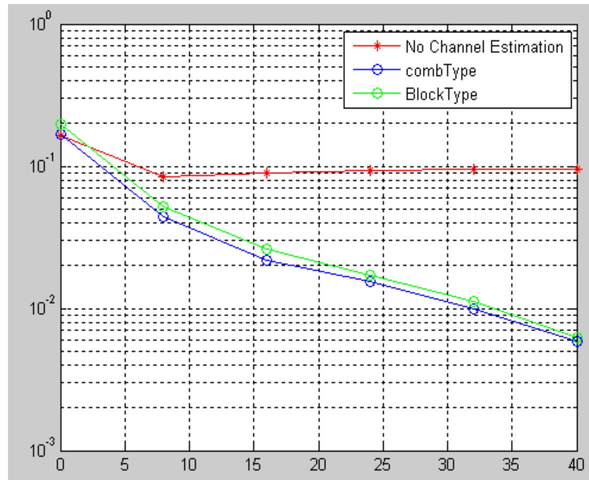

Figure 5. BER Plot for Comb type & block type Pilot

V. CONCLUSION

In this paper channel estimation on MIMO-OFDM system for a Rayleigh fading channel is analyzed. The two different algorithms such as LS channel estimation & MMSE channel estimation algorithms are applied and simulation is performed. The simulation results show that MMSE channel estimation of MIMO- OFDM system has less MSE & less BER than LS channel Estimation and also the simulation shows channel estimation using comb type pilot carrier has lower BER than block type pilot carrier. So MMSE channel Estimator has better performance than LS channel estimator.

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