Pilot-Assist Channel Estimation for Multi-input Multi-output (MIMO) 2x2 OFDM System

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Abstract: In this paper, we study the system performance in terms of symbol error rate (SER) in the estimation of channel impulse response by utilizing pilots when the channel is suffering Rayleigh fading and the user is traveling at 3 km/hr, 120 km/hr or 350 km/hr; these pilots are inserted at various locations of the resource block of Multi-input Multi-output 2x2 Orthogonal Frequency-Division Multiplexing (OFDM) system. The algorithms of Least Square (LS) and Minimum Mean-Squared Error (MMSE) are performed in the channel response estimation. From simulations it appears that the performance by using MMSE algorithm is better than that by using the LS criterion with an advantage of around 3 dB gains.

1 INTRODUCTION

In OFDM system the information data are encoded and modulated by using multicarrier modulation technique and then they are transmitted through a fading channel, e.g. the Rayleigh fading channel and at the receiver end it sometimes needs to estimate this channel impulse response before a correct determination of the transmitted data can be performed. It has many algorithms been developed in the literature such as Least Square (LS) [1-5], MMSE [6-10] and Regressive Least Square (MMSE) [11-15] to perform the channel estimation task.

In this paper the system performance in terms of symbol error rate (SER) of a Multiple-input Multi-output (MIMO) 2x2 Orthogonal Frequency-Division Multiplexing (OFDM) [16-20] system is investigated when the mobile user moves through the channel in the speed of 3 km/hr, 120 km/hr and 350 km/hr respectively and the channel is suffering a Rayleigh fading. This channel impulse response is estimated by inserting various pilots at some pre-determined locations of the OFDM resource block by utilizing LS and MMSE algorithms.

This paper is organized as follows. In Section II we will introduce the system architecture and its functional block diagrams for typical MIMO 2x2 OFDM systems, we then discuss the allocation of pilots in the resource block in the estimation of channel response and introduce the algorithms of LS and MMSE. In Section III we will implement the system simulation to evaluate the system performance when a mobile travels at speed of 3 km/hr, 120 km/hr and 350 km/hr respectively through a channel when the channel is suffering Rayleigh fading. A conclusion is drawn in Section IV.

2 SYSTEM MODEL

The system has the structure as shown in Fig. 1. The information is first encoded with Space-time Block Code (STBC) and then it is modulated and translated into the format as a Multiple-input Multiple-output 2x2 system. Pilot signals are then inserted at particular locations of the system resource block and they are combined with QPSK modulated data signals to pass through the Inverse Fast Transform (IFFT) block to convert a frequency domain signal into a time domain one. The resulting signal then passes through the Analog-to-digital converter (ADC), the antenna system and is transmitted through a Rayleigh fading channel. At the receiver side the received signal is passed through the same functional blocks as the transmitter side but in the reverse direction and finally the signal is recovered at the end of the system.

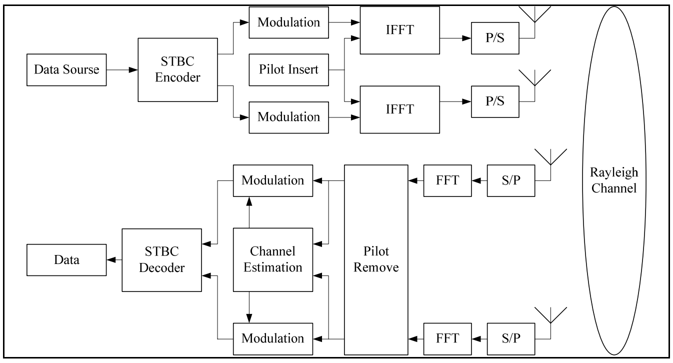

Figure 1 System Structure

2.1 Selecting Pilot Insertion and Removal

As shown in Fig. 2 is a two dimensional resource block for an OFDM system with symbol number represented in the x-coordinate while the subcarrier number is shown in the y-coordinate. In this OFDM system it uses pilots as the training signals to estimate the channel response, it needs to consider an optimal way to insert these pilots into the resource block to ascertain a good channel characteristics estimation; meanwhile it needs to consider to use a minimum number of pilot signals in the channel response estimation to save or reserve as much as possible resource locations in the resource block for data transmission. We will try to insert pilots into the shaded rectangular block of the resource block as shown in Fig. 2. It is illustrated in the figure as inserting pilots at two transmitter antennas of a 2x2 MIMO system. It has many possible ways for these pilots' insertions but the basic principle is to keep the pilots uncorrelated with each other as much as possible when they are inserted into the two transmitter antennas.

We consider four types of pilot insertion in the resource block in our simulation. For example in the insertion of Type 1 pilots, the pilots for antenna 1 are inserted at the (1,1) location for every shaded block in the figure, i.e. they are allocated at locations (1,1), (1,5), (9,1), (9,5), (17,1), and (17,5) while for the insertion of Type 1 pilots for antenna 2 they are allocated at (1,2), (1,6), (9,2), (9,6), (17,2), and (17,6), where the first index designates the symbol location and the second index is the subcarrier location. They are two locations, (2,1) and (2,2), in every shaded block are left unused they can be used when four antennas are considered in MIMO 4x4 antenna system. Similarly in considering Types 2, 3 and 4 pilots they are inserted at specific locations of every shaded block in the resource block. After we have inserted the pilots in their specific locations of the resource block we can then proceed to the channel estimation by using the algorithm of LS or MMSE.

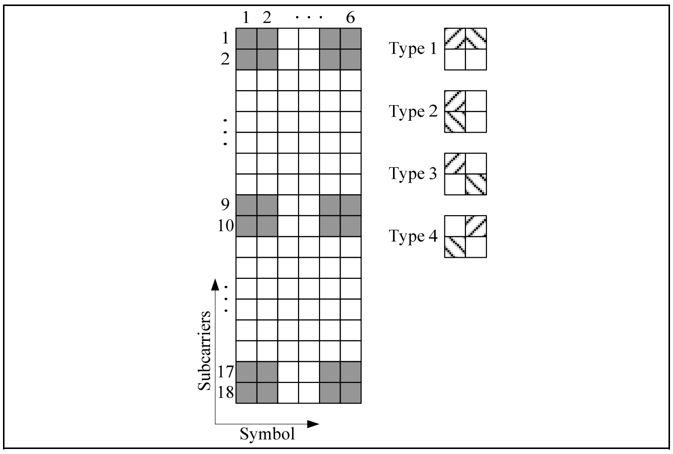

Figure 2 Pilots Allocation

2.2 Interpolation Method

At the receiver end, after the receiving signal passes through the Fast Fourier transform it uses the LS method to find the channel impulse response at the specified pilot locations of the resource block for transmitting antennas 1 and 2. It then uses linear interpolation technique to find the channel responses at other locations of the resource block.

For example in considering Type 1 pilots allocation as shown in Fig. 2 and assume the channel is an ideal channel, after we get the channel impulse responses at the pilot locations (1,1), (1,5), the channel responses at the non-pilot locations (1,2), (1,3), and (1,4) can be determined through interpolation and from the channel responses found at the pilot locations (1,1) and (1,5). Then from the channel responses at locations (1,1) and (9,1) from the pilots transmission the channel responses at non-pilot locations (2,1), (3,1), and (4,1) and up to (8,1) are similarly estimated through interpolation. After the channel responses at all locations that have pilots inserted either in the first (symbol) or the second (subcarrier) coordinate are determined then other locations that originally do not have any pilots inserted can be determined similarly by using linear interpolation from responses at locations that are already determined as described in the above. When the channel is noisy and suffering from fading effect the above interpolation algorithm for finding the channel responses at non-pilot locations need be modified. It first uses the LS method to find the channel responses at all locations of the resource block from the given responses at the pilot locations and then by implementing the MMSE criterion to modify and update the responses. In the following we will briefly discuss and describe the LS and MMSE interpolation techniques.

2.3 Channel Estimation

In the MMSE criterion, it assumes that the estimated channel impulse response $\hat{H}_{LMMSE}$ is linearly related with the received data Y as $k = R_{HY} R_{YY}^{-1}$ and the relation between $\hat{H}_{LMMSE}$ and Y can be expressed in the following [8]:

$$\hat{H}_{LMMSE} = R_{HY} R_{YY}^{-1} Y \tag{1}$$

where R_{HY} is the cross-correlation between the channel impulse response H and the received data Y,

$$R_{HY} = E(HY^K) = E(H(XH)^K) = R_{HH} X^K \tag{2}$$

where R_{YY} is the auto-correlation of the received data Y and K denotes the Hermitian matrix operation ·

$$\begin{aligned} R_{YY} &= E(YY^K) = E((XH+N)(XH+N)^K) \\ &= XX^K [R_{HH} + (XX^K)^{-1} \sigma_n^2] \end{aligned} \tag{3}$$

where R_{HH} is the auto-correlation matrix of the channel impulse response and σ_n^2 is the variance of the Gaussian noise. Then $\hat{H}_{LMMSE}$ can be rewritten as:

$$\begin{aligned} \hat{H}_{MMSE} &= R_{HY} R_{YY}^{-1} Y \\ &= R_{HH} X^K (XX^T)^{-1} [R_{HH} + (XX^K)^{-1} \sigma_n^2]^{-1} Y \\ &= R_{HH} [R_{HH} + (XX^K)^{-1} \sigma_n^2]^{-1} (X^{-1} Y) \end{aligned} \tag{4}$$

By using Eq. (4) we can derive the optimal channel impulse response and then calculate its associated least mean square error $l = R_{HY} R_{YY}^{-1}$ and then from this derived optimal channel impulse response it can generate the best estimation of the transmitted data.

Then we introduce the use of LS criterion in the channel response estimation. At the receiver end, the received data Y is obtained by multiplying the information data X with the Rayleigh channel impulse response H plus the white Gaussian noise N . It needs to first estimate the channel impulse response $\hat{H}$, the mean square error between Y and XH can then be expressed as [5]:

$$e^2 = (Y - XH)^K (Y - XH) \tag{5}$$

In order to generate the optimal channel impulse response $\hat{H}$, we need to minimize the resulting system mean square error, i.e. we need to make partial derivative of e^2 with respect to H , and the estimated channel impulse response H with LS criterion can be found as:

$$\hat{H} = X^{-1} Y \tag{6}$$

With the channel impulse response $\hat{H}$ derived in this way we can then demodulate the received data to get the transmitted data.

3 SIMULATION

With the four types of pilots as introduced in the above section we will study the system performance such in terms of symbol error rate (SER) when the pilots are inserted at different locations of the resource block and the mobile moves from low to high mobility respectively. The results are shown in Fig. 3-5. Also it shows from these simulations the results generated from MMSE are better than those from using the LS method, it has roughly 3 dB advantage, for mobile travels from low speed, 3 km/hr, and up to highest speed, 350 km/hr.

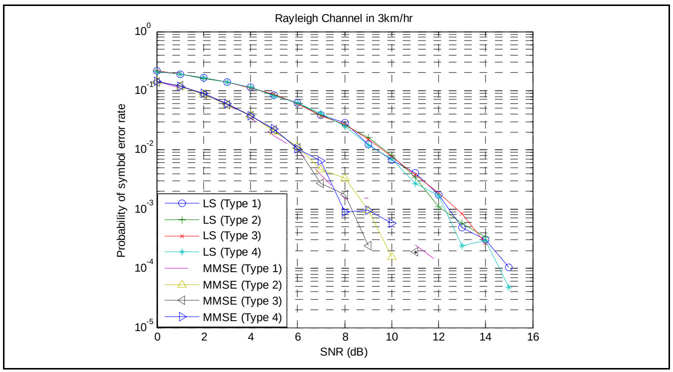

Figure 3 LS and MMSE Simulation Results when the Mobile moves at 3 km/hr

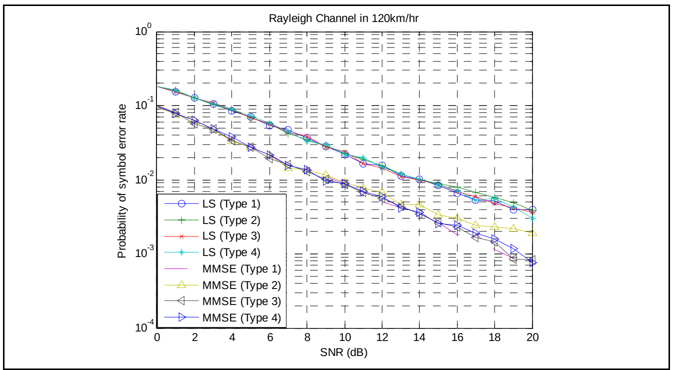

Figure 4 LS and MMSE Simulation Results when the Mobile moves at 120 km/hr

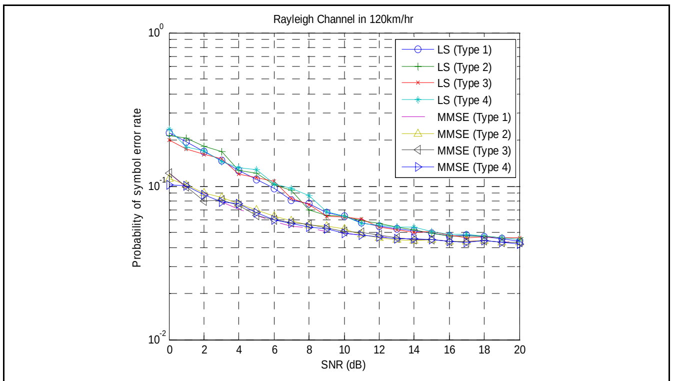

Figure 5 LS and MMSE Simulation Results when the Mobile moves at 350 km/hr

4 CONCLUSION

In this paper we used the algorithms of LS and MMSE to estimate the channel impulse response for a Rayleigh fading channel when a mobile moves from low speed to high speed in MIMO 2x2 OFDM system and the channel impulse response is estimated from the response at the pre-selected pilots locations in the resource block. From simulations it revealed that the performance by using MMSE algorithm is better than that by using the LS criterion it has an advantage of around 3 dB gains. In the consideration of simulating system performance in different fading environments and different pilot patterns it can be similarly performed and evaluated.

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