Optimal Training Signals Design for MIMO-OFDM Systems Channel Estimation based on MMSE Algorithm

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Summary
channel estimation based on training signals is a basic approach in achieving channel mode information in the receiver. Due to the importance of channel estimation quality, computational complexity, and convergence speed which directly influence the performance of telecommunication systems, this paper aims to study channel estimation method applying MMSE algorithm based on training signals. The performance of channel estimation algorithm is shown analytically and based on computer simulations of the fading channel. In order for optimal training signals to reach channel estimation with the minimum error, we analyzed and depicted channel estimation error.

Key words:
MIMO-OFDM, Fading Channel, Channel Estimation, MMSE Algorithm

1. Introduction

Increasing demand for high data rate telecommunication systems as well as efficient service quality provides a real challenge for designing such systems and creates a research ground in telecommunication. Since the increasing of bandwidth and/or sending power, to increase the data rate, is expensive and often impractical, employing such techniques as MIMO and OFDM efficiently employing the available bandwidth are more common. The combination of these two techniques provides the opportunity (due to the advantages of each technique) to access a wide coverage and a high rate data telecommunication network so much so that MIMO-OFDM were turned into the core technology in fourth generation telecommunication systems. In order to benefit from these systems, the channel mode information in the receiver is needed. This information is obtained by different algorithms in estimation theory. Two major approaches in calculating channel mode information in the receiver are signal-based channel estimation and blind channel estimation. Increasing the number of transmitter and receiver's antennas multiples the number of unknowns (channel coefficients between transmitter and receiver antennas pair). Therefore, channel estimation in multiple antenna systems is more difficult than channel estimation in one antenna systems [1].

An MIMO-OFDM system with N transmitter antenna, M receiver antenna, and K sub-carrier is shown in the following transmitter and receiver block diagram.

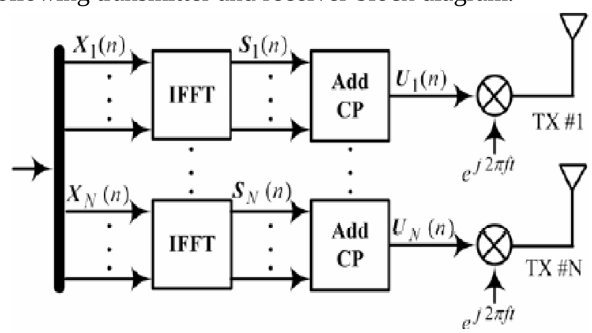

Fig. 1 Diagram block of MIMO-OFDM system's transmitter.

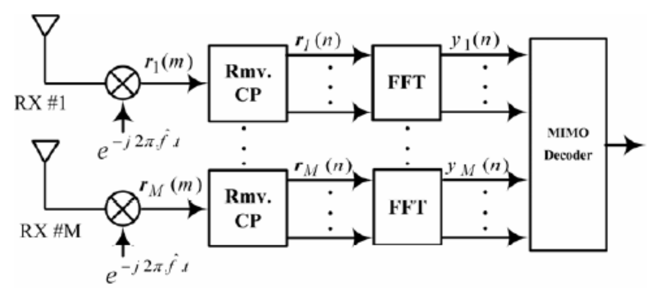

Fig. 2 Diagram block of MIMO-OFDM system's receiver.

2. Channel Estimation Algorithm Based on MMSE Criterion

This section examines MIMO-OFDM channel estimation algorithm based on Bayesian criterion. MMSE algorithm is the most popular estimation algorithm based on Bayesian

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criterion. MMSE estimator enhances channel estimation quality applying channel statistical information. Since different channels between each transmitter antenna and receiver antenna pair are independent and include the equal statistical distribution, MMSE estimation for each transmitter and receiver antenna pair is done equally [2]. According to [2], channel MMSE estimation related to each transmitter and receiver pair is achieved as follows:

$$\widehat{H}_{MMSE} = \boldsymbol{R}_{HH}(\boldsymbol{R}_{HH} + \boldsymbol{R}_{VV})^{-1}\widehat{H}_{LS} \quad (1)$$

Where RHH is channel frequency response covariance matrix and RVV is noise covariance matrix in the frequency domain. $\widehat{H}_{LS}$ is also channel frequency response estimation based on LS algorithm. It should be noted that we use the relationship (1) in case block pattern applies in training symbol. According to [2], we have:

$$R_{HH} = K\, W R_{hh} W^{H} \quad (2)$$

Where R_{hh} is channel impulse response $L \times L$ covariance matrix. There is also:

$$R_{VV} = K W R_{vv} W^{H} \quad (3)$$

Where R_{VV} is noise $L \times L$ covariance matrix in the time domain. By placing (1), (2), and (3) relationships we have [2]:

$$\widehat{H}_{MMSE} = W \hat{h}_{MMSE} \quad (4)$$

Where $\hat{h}_{MMSE}$ is channel impulse response MMSE estimation, as it follows:

$$\hat{h}_{MMSE} = \boldsymbol{R}_{hh}(\boldsymbol{R}_{hh} + \boldsymbol{R}_{vv})^{-1}\hat{h}_{LS} \quad (5)$$

Where LS estimation is channel impulse estimation. Since the dimensions of the above matrixes are considerably smaller than the relationship (1), in practice, we use the relationships (4) and (5) for channel MMSE estimation. In fact, we should only calculate channel impulse response LS estimation based on training sub-carriers and then by applying relationships (4) and (5), achieve the channel frequency response MMSE estimation in all sub-carriers. Moreover, R_{VV} of a diagonal matrix is calculated thus:

$$R_{vv} = \frac{\sigma_n^2}{K_p\, P_0} \mathrm{I}_L \quad (6)$$

Due to the channel impulse response WSSUS and Gaussian distribution, its covariance matrix is diagonal and is achieved by channel power delay profile. Thus, we need channel power delay profile in order to apply MMSE estimation algorithm.

3. MMSE Algorithm Based on Channel Covariance Matrix Estimation

Considering the fact that statistical information like channel power delay profile is not necessarily available in telecommunication receiver, MMSE algorithm, in practice, can be applied via channel power delay profile estimation. Because channel impulse response is independent in the time domain, the channel impulse response covariance matrix is a diagonal matrix. Different channels of each transmitter and receiver antenna pair have equal conditions as well as equal statistical distribution. Therefore, the delay in each channel route is equal too. Power delay profile estimation and channel impulse response covariance matrix is calculated thus [3-6]:

$$\left[\widehat{\boldsymbol{R}}_{hh}\right]_{ll} = \frac{1}{MN}\sum_{j=1}^{M}\sum_{i=1}^{N}\left|\hat{h}_{ji}[n,l]\right|^{2} \quad (7)$$

Where $\hat{h}_{ji}[n,l]$ is channel impulse response LS estimation.

4. Computer Simulation and its Results

This section analyses based on the conducted computer simulations, LS and MMSE estimator performance in estimating the channel coefficients. In figure 3 and 4, simulation for OFDM systems with 64 sub-carriers and a number of different transmitter and receiver antennas conducted in fading frequency selective channels. System's bandwidth is 1 MHz; its modulation QPSK. In the conducted simulation, sending information is discontinuous and in consecutive frames and L is the tap of channel.

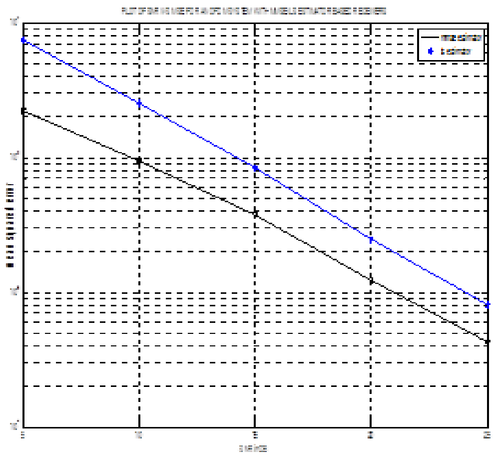

Fig. 3 Comparing LS and MMSE estimator performance with 64 sub-carriers for a SISO-OFDM system.

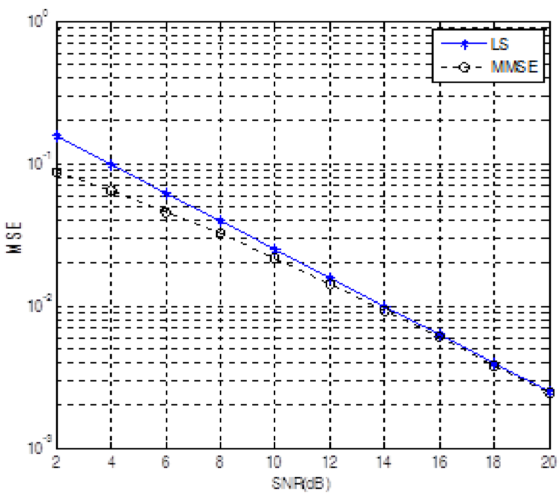

Fig. 4 Comparing LS and MMSE estimator performance with 64 sub-carriers for an MIMO-OFDM system having two transmitter and two receiver antennas.

Figure 5 depicts MMSE estimator performance based on block pattern in training symbol structure applying average SNR. The simulation is conducted for MIMO-OFDM system with 2 transmitter antennas and 2 receiver antennas. The overall channel bandwidth is $B = 10\ MHz$ which divided into $K = 1024$ sub-

channels. The number of multiple route channels is 6 and the channel delay spread equals $8\mu s$ Figure 4 depicts MMSE estimator along with impulse response covariance matrix estimation. This stimulation uses Li algorithm for channel LS estimation. As is clear in the following figure, MMSE estimation algorithm based on channel covariance matrix estimation, significantly boosts the performance of channel estimation in contrast to LS algorithm.

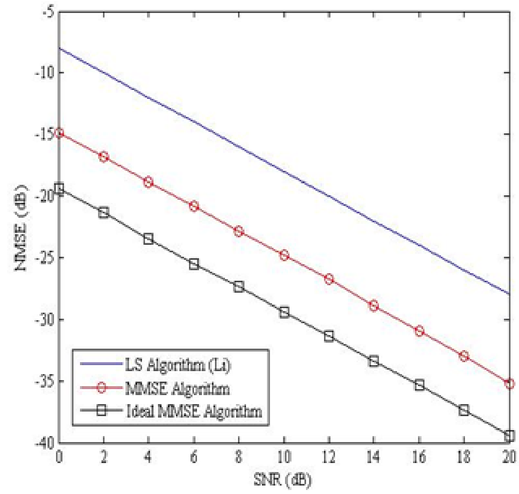

Fig.5 MMSE channel estimation algorithm based on SNR.

5. Conclusion

As it is depicted, in estimating channel coefficients, MMSE algorithm has a better performance than LS algorithm. This algorithm in comparison with LS estimator has more computational complexities and one needs to know about the channel condition, for example, channel autocorrelation matrix and noise variance.

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