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Channel Estimation based on Pilot Carriers in a OFDM based Communication System

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Abstract—The channel estimation can be performed by either inserting pilot tones into all subcarriers of OFDM symbols with a specific period or inserting pilot tones into each OFDM symbol. In this present paper, two major types of pilot arrangement such as block type and comb-type pilot have been focused employing Least Square Error (LSE) and Minimum Mean Square Error (MMSE) channel estimators. Simulation results are provided to verify the channel estimation techniques.

Keywords—Additive White Gaussian Noise, BER, MSE, BPSK, OFDM, MSE, MMSE.

I. INTRODUCTION

Orthogonal frequency division multiplexing (OFDM) provides an effective and low complexity means of eliminating inter symbol interference for transmission over frequency selective fading channels [1]. This technique has received a lot of interest in mobile communication research as the radio channel is usually frequency selective and time variant. In OFDM system, modulation may be coherent or differential. Channel state information (CSI) is required for the OFDM receiver to perform coherent detection or diversity combining, if multiple transmit and receive antennas are deployed [2]. In practice, CSI can be reliably estimated at the receiver by transmitting pilots along with data symbols. Pilot symbol assisted channel estimation is especially attractive for wireless links, where the channel is time-varying [3]. When using differential modulation there is no need for a channel estimate but its performance is inferior to coherent system [4].

II. INTRODUCTION TO OFDM

Orthogonal frequency division multiplexing (OFDM) is one promising multi-carrier technique adopted by many wireless communication standards. Thanks to fast Fourier transform (FFT) algorithm, OFDM becomes more popular due to its simple implementation. The basic idea of OFDM systems is to transmit symbols over multiple orthogonal subcarriers, so IFFT is performed with transmitted symbols at the transmitter, and FFT is performed with received symbols at the receiver. The basic principles and details of OFDM transmission was presented in [5]. Another advantage of OFDM is to convert a frequency-selective wideband channel into several frequency-flat narrow band channels [6].
Thus the complexity of receiver for OFDM systems is much simpler than that of receivers in single-carrier systems. However, OFDM systems will be sensitive to channel variation, which induce inter-carrier interference (ICI) by destroying the orthogonality between subcarriers [7]. Basic Principles of OFDM Defining s(k) as the symbol transmitted over the k^{th} subcarrier, and x(n) as the received symbol at the nth time index, the output of IFFT at the transmitter is given by

$$x(n) = \frac{1}{\sqrt{N_s}} \sum_{k=0}^{N_s-1} s(k) e^{j2\pi kn/N_s} \; for\; n = 0,1,\dots,N_s-1,$$

where the quantity n, k denote the time index in an OFDM symbol period and subcarrier index, respectively, and the number of subcarriers denotes Ns. Hence, we do not introduce the multi-path channel effects and noise [8]. Thus the received OFDM symbol at the nth time r(n) = x(n). In the receiver, the output of FFT at the kth subcarrier is given by

$$y(k) = \frac{1}{\sqrt{N_s}} \sum_{n=0}^{N_s-1} r(n) e^{j2\pi kn/N_s}$$

After rearrangement, the above equation becomes:

$$y(k) = \frac{1}{N_s} \sum_{n=0}^{N_s-1} \sum_{q=0}^{N_s-1} s(q) e^{\frac{j2\pi qn}{N_s}} e^{-\frac{j2\pi kn}{N_s}}$$

$$= \sum_{n=0}^{N_s-1} \sum_{q=0}^{N_s-1} s(q) e^{\frac{j2\pi n(q-k)}{N_s}}$$

$$= \frac{1}{N_s} s(k) N_s + \sum_{q=0, q\neq k}^{N_s-1} s(q) \sum_{n=0}^{N_s-1} e^{\frac{j2\pi(q-k)}{N_s}}$$

$$= s(k) for\ k = 0,1, \dots\ N_s$$

From the above equation, the received symbol y(k) = s(k) is not affected by the symbols from other subcarriers. To explain the orthogonality between subcarrier clearly, power spectrum of the output of FFT is plotted in Fig. 1.1, where TOFDM denotes the period of one OFDM symbol. This plot implies that the waveforms of different subcarriers are overlapped, but for one particular subcarrier frequency, the sidelobes from other subcarriers are equal to zero. In other words, the orthogonality between subcarriers is maintained [9].

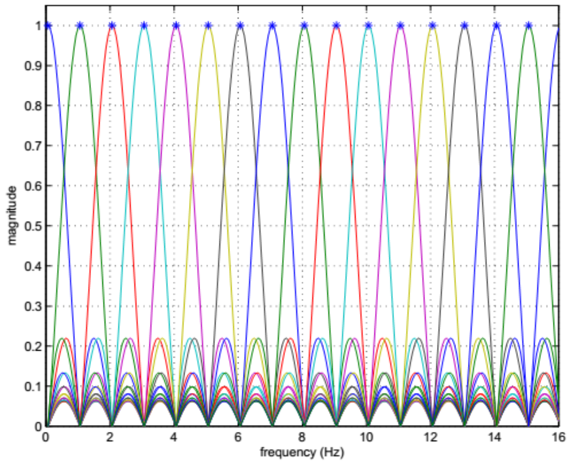

Fig 1.1: Power spectrum of baseband signals of the output of FFT at the receiver,

Pilot-Assisted Channel Estimation Techniques

Pilot-assisted channel estimation technique, which is also known as training-based channel estimation scheme, is a conventional way of obtaining channel estimate for communication Systems [10]. In this technique, training sequences of data known to the receiver are multiplexed with the transmitted information symbols at a pre-determined position before transmission. These training data are used at the receiver for estimating the channel state information corresponding to their positions [11]. The channel state information corresponding to the information data positions is then obtained by means of interpolating between different channel estimates earlier obtained from the training data sequence.In the context of MIMO Systems, different contributions have been published with regards to the pilot-assisted channel estimation techniques of which some of them could be found in [12].

In addition, different pilot patterns have been proposed for the implementation of the pilot assisted channel estimation techniques for both single antenna and multiple antenna Systems [13]. Optimal training for single antenna-aided OFDM with respect to the Mean Square Error (MSE) of the Least Square (LS) channel estimate as well as the MSE at the output of a zero-forcing receiver employing LS channel estimate is studied in [14]. However, in [15] optimal training for single input single output OFDM (SISO-OFDM) Systems with respect to the capacity based on Linear Minimum Mean Square Error (LMMSE) channel estimate is proposed. Channel estimation techniques based on pilot arrangement in OFDM system are studied in [16], while optimal training and pilot design for OFDM Systems operating over Rayleigh fading channel is investigated in [17].

Minimum Mean Square Error (MMSE) Estimation:

With knowledge of channel statistics channel estimation in MMSE [35] way can be written as

$$\hat{h} = R_{yh}^{H} R_{yy}^{-1}\ y$$

Where $R_{yy} = E[y\ y^H]$

$$R_{yh} = E[y\ h^H]$$

$$R_{hh} = E[h\ h^H]$$

The channel estimator is given by: $= h - \hat{h}$ which is Gaussian distributed with zero-mean [18]. The estimated channel frequency response on nth carrier can be obtained as:

$$\widehat{H}(k) = f_k^H \hat{h}$$

Least Square Error (LSE) Estimation:

If we define $(\varepsilon_p F_p D^H(X_p) D(X_p) F_P^H\ )^{-1}(\sqrt{\varepsilon_p} D\ (X_P) F_P^H)^H$then the least-square error (LSE) estimate of channel impulse response is given by[19]

$$\widehat{H} = Gy = h + n$$

Where n=Gw. The estimated channel frequency response on the kth subcarrier can be obtained as [20]

$$\widehat{H} = F_P^H \hat{h} = H(k) + v(k)$$

Where v(n) ~ CN (0, σ^2).

III. RESULTS AND DISCUSSION

Computer simulations using MATLAB have been employed to investigate the channel estimation error in an OFDM system. For computer simulation, the number of the subcarriers of the OFDM system, N, is 512. Number of FFT points are taken to be 64 and the length of cyclic prefix is 8. Both Rayleigh fading channel and Ricean fading channel are constructed for simulation, respectively. For the multipath Rayleigh fading channel, Jakes model [65] is applied to construct a Rayleigh fading channel for each path. For the multipath Ricean fading channel, modified version of Jakes model is employed.The simulations are carried out for two different modulation techniques i.e. Quadrature Amplitude Modulation (QAM) and Phase Shift Keying (PSK). Modulation order is varied taking values of M from 4 to 512 to study the effect of incerse in modulation order at MSE.

It is observed that the MSE for Rician channel is smaller when compared with Rayleigh channel for a specific modulation order. The reason behind this is the presence of line of sight path between transmitter and receiver in case of Rician channel which is abscent in Rayleigh channel.

We also have compared performance of LSE with MMSE estimator. MMSE estimation is better that LSE estimator in low SNRs where at high SNRs performance of LSE estimator approaches to MMSE estimator.

Figure 1.2 shows the result for a comparison between the performance of Rayleigh and Rician channel for time domain channel estimation. It can be easily observed that the MSE curves for Rician channel are lower than corresponding Rayleigh channel curves. Reason behind such behavior is the presence of line of sight component in case of Rician channel which lowers the MSE.

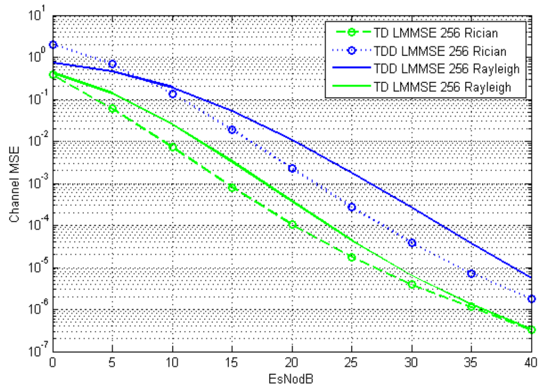

Fig 1.2: Comparison between 256 QAM Rayleigh and Rician TDD LMSSE and TD LMMSE

In figure 1.3, a comparison between Rayleigh and Rician channels for TD LMMSE algorithm for M=512 PSK is shown. Again it is observed that MSE for Rician channel is less for a given EsNodB value.

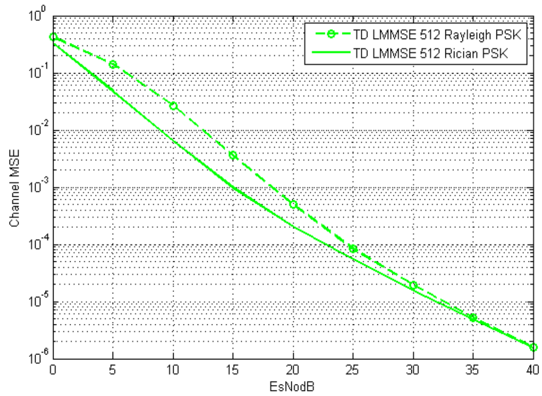

Fig 1.3: Comparison between 512 PSK Rayleigh and Rician TD LMSSE

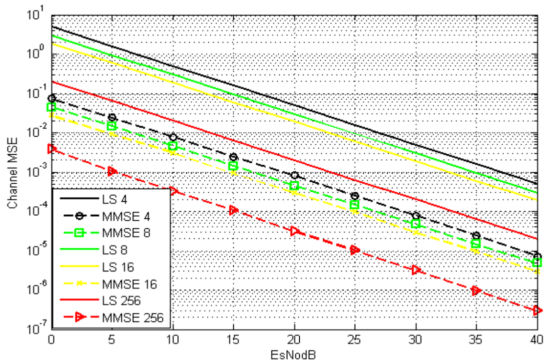

Fig 1.4: Comparison between M=4, 8, 16, 256 QAM Rayleigh LS and MMSE in frequency doamin

A comparison between M=4, 8, 16, 256 QAM in Rayleigh channel for LS and MMSE estimator algorithms in frequency domain is provided in figure 1.4. It is observed that LS and MMSE algorithms follow the same routine as the modulation order increases. LS algorithm provides more MSE when compared to MMSE algorithm in every case. As observed earlier, the MSE decrease as the modulation order increase.

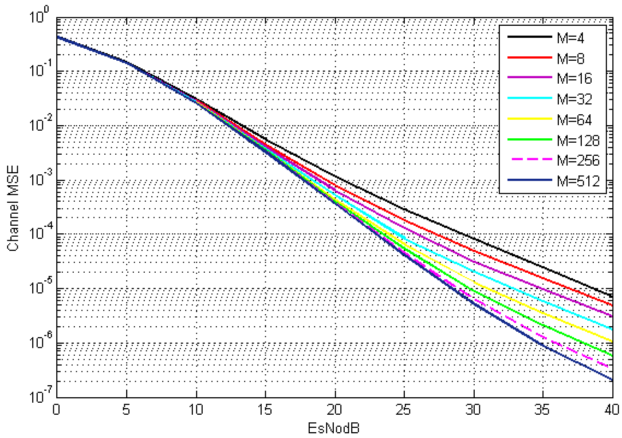

Fig 1.5: Comparison between different QAM Rayleigh TD LMSSE

TD MMSE algorithm is compared for M=4,8,16,32,64,128,256 and 512 QAM in Rayleigh fading channel in Fig 1.5.

IV. CONCLUSION

In this work, we have studied LSE and MMSE estimators in both frequency and time domain for Rayleigh and Rician fading environments. The estimators in this study can be used to efficiently estimate the channel in an OFDM system given a certain knowledge about channel statistics. The MMSE estimators assume a priori knowledge of noise variance and channel covariance. Moreover, its complexity is large compare to the LSE estimator. For high SNRs the LSE estimator is both simple and adequate. The MMSE estimator has good performance but high complexity. The LSE estimator has low complexity, but its performance is not as good as that MMSE estimator basically at low SNRs. In our simulations, we used QAM and PSK modulation schemes. The number of subcarriers of the OFDM system, N, is 512. Number of FFT points are taken to be 64 and the length of cyclic prefix is 8. We calculated MSE in channel estimation for different SNRs in simulation.

It is observed that the MSE for Rician channel is smaller when compared with Rayleigh channel for a specific modulation order. The reason behind this is the presence of line of sight path between transmitter and receiver in case of Rician channel which is abscent in Rayleigh channel.

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