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PILOT-AIDED CHANNEL ESTIMATION FOR WIRELESS OFDM SYSTEM IN FADING CHANNELS

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ABSTRACT

Orthogonal frequency division multiplexing (OFDM) is a special case of multi-carrier transmission and it can accommodate high data rate requirement of multimedia based wireless systems. Since channel estimation is an integral part of OFDM systems, it is critical to understand the basis of channel estimation techniques for OFDM systems so that the most appropriate method can be applied. In this article, an extensive overview of channel estimation techniques employed in OFDM systems are presented.

KEYWORDS: OFDM; LMS; MMSE; Weiner filter; Rayleigh channel; Rician Channel

1. INTRODUCTION

Future multimedia wireless services require high-bit-rate transmission over mobile radio channels. Orthogonal frequency-division multiplexing (OFDM) [1] is one such promising technique. Recent study has focused on OFDM systems for mobile environments, such as IEEE 802.16e and 802.20 etc. In mobile OFDM systems, fast fading channels cause ICI, thus resulting in serious performance degradation. Due to this, an accurate channel estimation method is required for ICI cancellation. Channel estimation enables OFDM systems toemploy the coherent modulation schemes such as QAM, and results in more improved capacity. OFDM divides the spectrum into a number of orthogonal and overlapping narrowband sub-channels to converts a frequency selective fading channel into a flat fading channel [2].

Moreover, the introduction of a so-called cyclic prefix at the transmitter reduces the complexity at receiver to FFT processing and one tap scalar equalizer at the receiver [3]. The simplified equalization at receiver, however, requires knowledge of the channel over which the signal is transmitted. To facilitate the estimation of the channel in an OFDM system (such as WiMax, WiBro, WiFi, and 3.9/4G), known signals or pilots could be inserted in the transmitted OFDM symbol. Different methods can then be applied to estimate the channel using these known pilots.

In wireless communication Systems, the time-varying nature of the channel as well as its frequency selectivity in a multipath scenario is considered as one of the major challenges. For accurate transmitted signal demodulation, equalization, decoding, and a host of other baseband processing applications, the provision of perfect and up to date channel knowledge is very vital.

The concept of using parallel data transmission by means of frequency division multiplexing (FDM) was published in mid 60's by Fazel & Fettwis [4], Some early developers can be traced back in the 50's a U.S. patent was filled and issued in January, 1970. The idea was to use parallel data streams and FDM with overlapping sub channels to avoid the use of high speed equalization, and to combat impulsive noise, and multipath distortion as well as to fully use the available bandwidth [5].A popular class of coherent demodulation for a wide class of digital modulation schemes has been proposed by Moher and Lodge [6], and is known as Pilot Symbol Assisted Modulation, PSAM. The main idea of PSAM channel estimation is to multiplex known data streams with unknown data.. Aghamohammadi [7] et al. and Cavers [8] were among the first analyzing and optimizing PSAM given different interpolation filters. The main disadvantage of this scheme is the slight increase of the bandwidth.

Channel estimation using superimposed pilot sequences is also a completely new area, idea for using superimposed pilot sequences has been proposed by various authors for different applications. In [9], superimposed pilot sequences are used for time and frequency synchronization. In [10], superimposed pilot sequences are introduced for the purpose of channel estimation, and main idea here is to linearly add a known pilot sequence to the transmitted data sequence and perform joint channel estimation and detection in the receiver [11].

In [12], performance of low complexity estimators based on DFT has been analyzed. In [13], block and comb type pilot arrangements have been analyzed. There are some other techniques, proposed for channel estimation and calculation of channel transfer function in OFDM systems. For example, the use of correlation based estimators working in the time domain and channel estimation using singular value decomposition [14].In [15], they proposed a channel estimation algorithm based polynomial approximations of the channel parameters both in time and frequency domains. This method exploits both the time and frequency correlations of the channel parameters. In [16], Julia proposed a very good approach for OFDM symbol synchronization in which synchronization (correction of frequency offsets) is achieved simply by using pilot carriers already inserted for channel estimation, so no extra burden is added in the system for the correction of frequency offsets.

2. SYSTEM DESCRIPTION

The OFDM system based on pilot channel estimation is given in Figure 1.

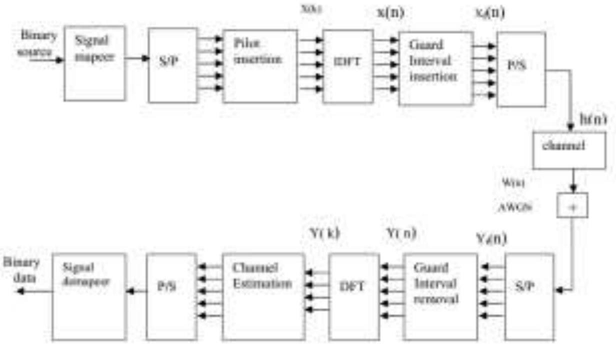

Fig 1: Baseband OFDM system

The binary information is first grouped and mapped ac-cording to the modulation in “signal mapeer”. After inserting pilots either to all sub-carriers with a specific period or uniformly between the information data sequence, IDFT block is used to transform the data sequence of length into time domain signal with the following equation [17]

x(n)=IDFT {X(k)} n=0,1,2,…,N-1

Where N is the DFT length. Following IDFT block, guard time, which is chosen to be larger than the expected delay spread, is inserted to prevent inter-symbol interference.
The received signal is given by:

$$y_f(n) = x_f(n) \bigotimes h(n) + w(n)$$

where w(n) is Additive White Gaussian Noise (AWGN) and h(n) is the channel impulseresponse. At the receiver, after passing to discrete domain through A/D and low pass filter, guard time is removed [18]. Following DFT block, the pilot signals are extracted and the estimated channel $\breve{H}(k)$ for the data sub-channels is obtained in channel estimation block. Then the transmitted data is estimated by:

$$\hat{X} = \frac{Y(k)}{\hat{H}(k)} \qquad k = 0,1, \dots N-1$$

Then the binary information data is obtained back in “signal demapeer” block [19].

3. CHANNEL ESTIMATION METHODS

A wideband radio channel is normally frequency selective and time variant. For an OFDMmobile communication system, the channel transfer function at different subcarriers appearsunequal in both frequency and time domains. Therefore, a dynamic estimation of the channel isnecessary. Different channel estimation methods are explained below.

Minimum Mean Square Error (MMSE) Estimation:

With knowledge of channel statistics channel estimation in MMSE [20] 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. The estimated channel frequency response on nth carrier can be obtained as:

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

Least Square Error (LSE) Estimation:

The least-square error (LSE) estimate of channel impulse response is given by

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

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

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

Where v(n) ~ CN (0, σ^2).

Channel Estimation Based On Interpolation Techniques:

Without going back to time domain channel frequency response for each subcarrier can be found by using interpolation techniques. In comb-type pilot based channel estimation, an efficient interpolation technique is necessary in order to estimate channel at data sub-carriers by using channel information at pilot sub-carriers [20].

Channel transfer function at pilot sub-carriers estimated in LSE sense. The estimated transfer function at pilot frequencies will be$\hat{H}_p(k) = \frac{Y(k)}{\sqrt{\varepsilon_p} X_p(k)}$

4. RESULTS

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 is applied to construct a Rayleigh fading channel for each path. For the multipath Ricean fading channel, modified version of Jakes model is employed.

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 absent 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.

Table 1: Channel MSE for different Es/No dB for 256 QAM in Rayleigh and Rician Channel

Estimation technique	Modulation scheme/Channel	EsNo (in dB)	Channel MSE
TDD LMSSE	256 QAM/Rayleigh	15	0.05266
		30	0.0002624

TDD LMSSE	256 QAM/Rician	15	0.0187
		30	3.816×10^{-5}
TD LMMSE	256 QAM/Rayleigh	15	0.003241
		30	6.375×10^{-6}
TD LMMSE	256 QAM/Rician	15	0.0007879
		30	3.899×10^{-6}

From the values of MSE given in table 1, it can be observed that channel MMSE for Rician channel is far less than compared with the MSE values of Rayleigh channel. It is also observed that the difference in MSE of Rayleigh and Rician channel for TDD LMMSE is higher for a given value of SNR when compared with TD LMMSE.

Following graphs show the graphs of channel mse v/s Es/No in dB for different modulation order of QAM in Rayleigh fading channel:

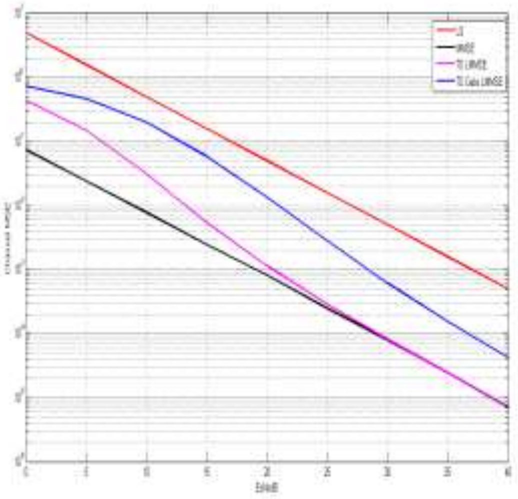

Fig 2: 4 QAM Rayleigh

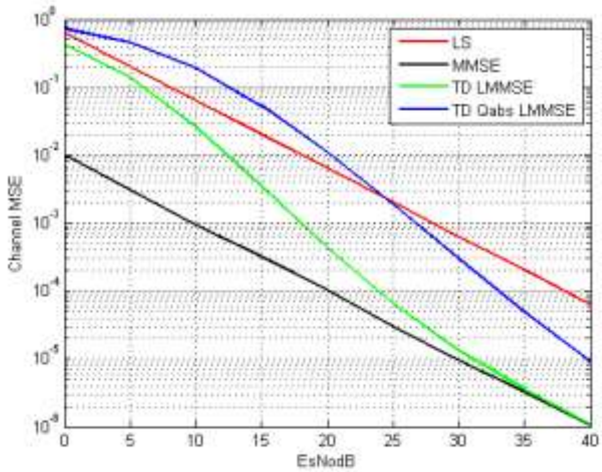

Fig 3: 64 QAM Rayleigh

It is evident from the graphs given above that the MSE decreases as we increase the modulation order from 4 QAM to 64 QAM. This can be observed by a drop in curves for a given value of EsNodB. Following graphs show the graphs of channel mse v/s Es/No in dB for different modulation order of QAM in Rician fading channel:

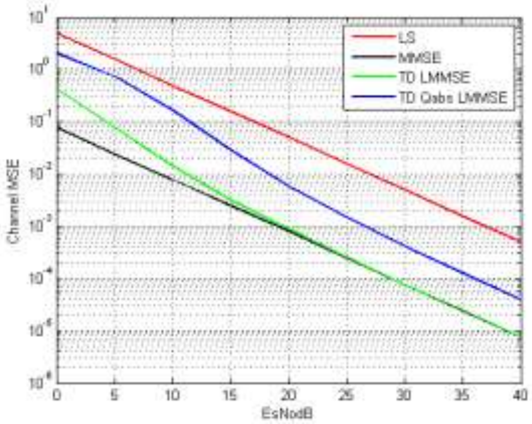

Fig 4: 4 QAM Rician

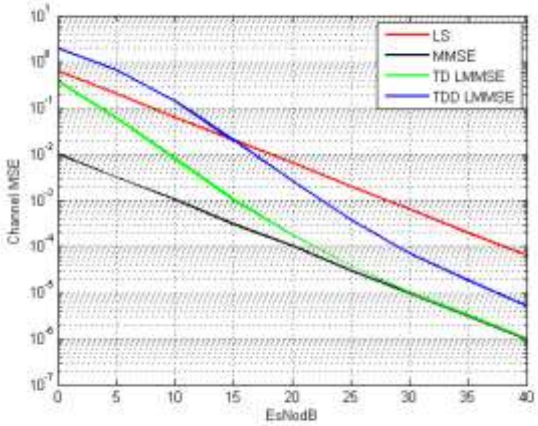

Fig 5: 64 QAM Rician

Following graphs show the graphs of channel mse v/s Es/No in dB for different modulation order of PSK in Rayleigh fading channel:

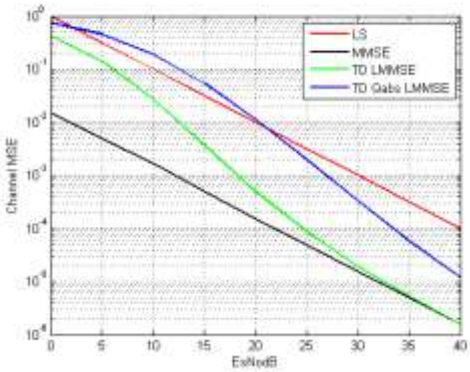

Fig 6: 4 PSK Rayleigh

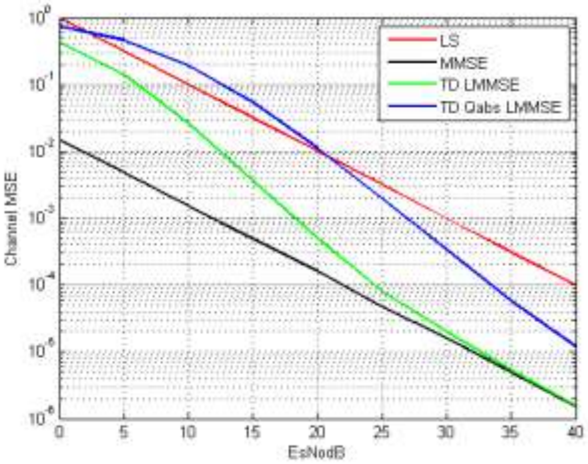

Fig 7: 128 PSK Rayleigh

Following graphs show the graphs of channel mse v/s Es/No in dB for different modulation order of PSK in Rician fading channel:

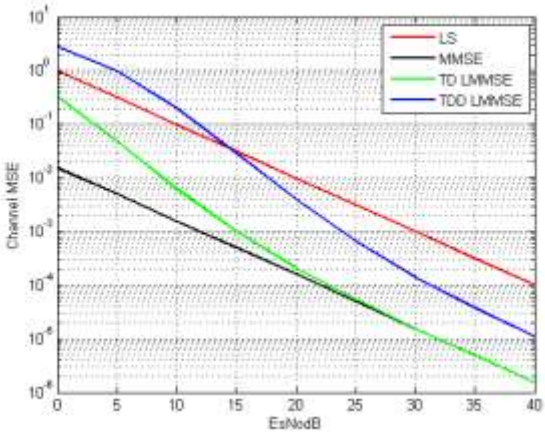

Fig 8: 4 PSK Rician

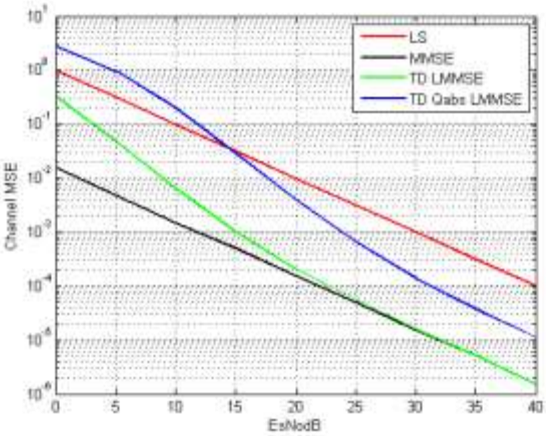

Fig 9: 128 PSK Rician

5. CONCLUSION

In this paper, we have 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. 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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