Comparison of Channel Estimators for OFDM Channel Estimation

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ABSTRACT
Channel estimation is a challenging problem for the wireless communication to recover original data. Various estimation approaches have been discussed in literature to get a better estimation. In this work pilot assisted channel estimation techniques are considered to obtain accurate channel state information (CSI) and compared least square (LS) and Linear Minimum Mean Square Estimator (LMMSE) estimation technique for Doppler shift. Simulation results shown that both estimation techniques, performed same at higher Doppler frequencies.

Keywords
CSI, MIMO, OFDM, WMAN, WLAN, MMSE

1. INTRODUCTION
The internet technology has changed people's lives and the way of their work. People use internet for shopping, working, and entertainment which drives the requirement for high data rate system. At the same time, people want to use the internet devices freely at any space and time, which requires the development of the wireless systems. To meet these requirements, novel techniques such as multiple-input and multiple-output (MIMO) and orthogonal frequency-division multiplexing (OFDM) have been developed to support the high data rate system. OFDM divides the available spectrum into a number of overlapping but orthogonal narrowband sub channels [1]. In this way, each sub channel is modulated with a conventional modulation scheme, like phase-shift keying or quadrature amplitude modulation. OFDM has the essential advantage to cope with severe channel impairments such as intersymbol interference (ISI) by using the cyclic prefix (CP). OFDM technology has been adopted to be used in many wireless standards such as WLAN and WMAN [2]. For wireless communication system, the radio channel is highly dynamic to make the design of the receiver to be a challenging task. Before it reaches the receiver, the signal may undergo scattering, reflecting in a multiple complicate path [3]. A large proportion of the wireless devices are mobiles and tablet. These devices with great mobility have a great impact on the performance of the wireless receiver. Though a differential modulation technique can be used to avoid the difficulty of the channel estimation, the signal-noise-ratio (SNR) need to be very low, around 3-4 dB and also results in a much lower data transmission rate, which is not desired for the current requirement [4].According to the study of He, Song and Zhu [5] channel estimation is of crucial significance to coherent demodulation performance in MIMO-OFDM (multi input multi output orthogonal frequency division multiplexing). It also helps to acquire CSI (channel state information) to assist scheduling and precoding.

In this paper, Pilot assisted channel estimation techniques are presented for accurate channel estimation and also to find the amount of pilot symbols to be transmitted from the transmitter and measuring at the receiver. OFDM channel estimation is simulated at various Doppler frequencies to investigate the LS and LMMSE estimation techniques using 4 bit data mapped pilot symbols into different constellation using 16 QAM modulation techniques.

2. PILOT ASSISTED CHANNEL ESTIMATION TECHNIQUES
The pilot-assisted channel estimation technology is also known as training-based method. In this method, the training data that are known to the receiver are multiplexed with the transmitted information at a pre-determinate position before transmission. Then the information of the receiving data can be obtained by interpolating between different channels with the previous training data. Following are the three requirements for pilot based channel estimation.

- Appropriate pilot pattern needs to be considered.
- Pilot-based channel estimation algorithm with low complexity should be identified.
- Accurate demodulation method toward successful channel estimation has to be developed.

Pilot pattern design is to determine where to insert the pilot and how closely between pilots. The appropriate way of inserting the pilot could be calculated according to the known communication environment and estimated speed from the terminal [6] and the minimum number of pilot symbols inserted is decided by Nyquist theorem as follows[7].

$$f_m.T.N_t \leq \frac{1}{2}, \qquad \tau_{max}.\Delta f.N_f \leq \frac{1}{2}$$

Where N_t is the interval in time domain and N_f in frequency domain. Here Δf is bandwidth of subcarrier and T is period of signal.

Block-type pilot and Comb-type pilot are the two basic channel estimations in OFDM systems Former channel estimation, is performed by inserting pilot symbols into all subcarriers with a specific period in time. The pilot symbols, because covering all frequencies, could be effective against the selective frequency fading, but more sensitive for the impact of fast fading channel. Therefore, the block-type pilot is developed under the assumption of slow fading channel. Comb-type pilot channel estimation is performed by inserting pilot tones into certain subcarriers of each OFDM symbol, where the interpolation is needed to estimate the conditions of date subcarriers.

3. BLOCK TYPE PILOT-BASED CHANNEL ESTIMATION

In this channel estimation pilots are transmitted periodically. If the channel is constant during the block, there will be no channel estimation error since the pilots are sent at all carriers. The estimation of the channel for this block-type pilot arrangement can be based on Least Square (LS) or Minimum Mean-Square (MMSE).Estimators based on LS and MMSE are as follows.

3.1 Least Square (LS) Estimator

The impulse response of multipath channel is as follows.

$$h(t,\tau) = \sum_{k=0}^{L-1} a_k(t)\delta(t-\tau_k)$$

Where $\tau_k$the delay of kth path is, $a_k(t)$ is the amplitude of kth path, and L is the number of sub-carriers, respectively. If the signal received without any ISI (inter symbol interference). The received signal is written as

$$Y = XF\hat{h} + W$$

Where Y is the vector of output signal, X is the diagonal matrix of pilots, $\hat{h}$ is the impulse response of the pilots of one OFDM symbol, W is the channel noise (always assumed to be AWGN), respectively. The cost function of LS algorithm[4] is written as,

$$J = \left|Y - XF\hat{h}\right|^2$$

The purpose of LS algorithm is to minimize the cost function J without noise. The advantage of Least Square algorithm is its simplicity, because noise and ICI is not considered. So, without using any knowledge of the statistics of the channels, the LS estimators are calculated with very low complexity, but obviously it suffers from a high MSE. It utilized to get initial channel estimates at the pilot subcarriers, which are then further improved via different methods.

3.2 Minimum Mean Square Error (MMSE) Estimator

The Minimum Mean Square Error estimator employs the second-order statistics of the channel conditions to minimize the MSE. Let e be the error of channel estimation and it is written as [20]

$$e = H - \hat{H}$$

Where H is actual channel estimation and $\hat{H}$ is raw channel estimation, respectively.And the MSE of channel estimation is $E\{|e|^2\}$=E$\left\{\left| H - \hat{H}\right|^2\right\}$, Where E {} is the expectation.

The performance of MMSE estimator is much better than LS estimator, especially under the lower Eb/No. Main drawback of the MMSE estimator is its high computational complexity.

3.3 Linear Minimum Mean Square Estimator

Linear MMSE estimators are chosen because they are simpler than optimal Bayesian estimators and retain the Minimum Mean Square Error criterion. Here the constraint on the estimator is assumed to be linear. A simplification of MMSE estimator is to replace the $(X^H X)^{-1}$ by its expectation $E\{(X^H X)^{-1}\}$, which means the average power of all subcarriers replace the instantaneous power of each subcarrier in order to reduce the computation [10].

The modified MMSE in LMMSE estimator is written as

$$\hat{H}_{LMMSE} = R_{HH}\left(R_{HH} + \frac{\beta}{SNR}I\right)^{-1}\hat{H}_{LS}$$

Here β is a constant depending only on the signal constellation.

$$SNR = \frac{E\{|X_K|^2\}}{\sigma_N^2}$$

R_{HH} denotes the auto-covariance matrixes of H and $\hat{H}$ is raw channel estimation. Mean Square Error of LMMSE is much lower than MMSE.

4. COMB TYPE PILOT-BASED CHANNEL ESTIMATION

The comb type pilot channel estimation has been introduced to fulfill the necessity of equalizing when the channel changes even from one OFDM block to the subsequent one. The estimation of the channel at the pilot frequencies for comb-type based channel estimation can be based on LS, MMSE or Least Mean-Square (LMS).

X(k) is the information transmitted over the OFDM consist of pilots and data, $x_p(m)$ is the value of m^{th} subcarrier pilot and N_f is the frequency interval of the inserted pilot symbols. It can be written as

$$X(k) = X(mN_f + 1)$$

$$X(k) = \begin{cases} x_{p(m)} & l=0 \\ Data & l = 1,2,\ldots\ldots, N_f - 1 \end{cases}$$

Here $N_f = \frac{N}{N_p}$

Since channel estimation is done only for a limited number of sub-carriers, interpolation must be used to estimate channel response over the whole channel bandwidth. Piecewise Constant Interpolation, Linear Interpolation, Second Order Interpolation and Cubic spline Interpolation are the different interpolation techniques used. Among all the interpolation technique cubic spline interpolation with higher order interpolation can be used for better interpolation accuracy.

5. RESULTS

OFDM channel estimation is simulated for LS and LMMSE estimators to analyse the performance under Doppler shift for symbol error rate. Motive of this study is to analyse how the estimator complexity of LMMSE estimator better for higher Doppler shift compare to LS estimator, so that higher channel accuracy obtained for good message rate.

Here pilot symbols are 4 bit data mapped into different constellation using 16 QAM modulation techniques. Summary of important parameter are as follows

Table 1. Simulation parameter

Number of subcarriers	128
Base-band modulation	16-QAM
Pilot interval	5
Channel model	Rayleign channel
Noise	AWGN
Cyclic prefix length	16
Equalization method	Zero forcing
Delay	[0 2e-6 4e-6 8e-6 12e-6]

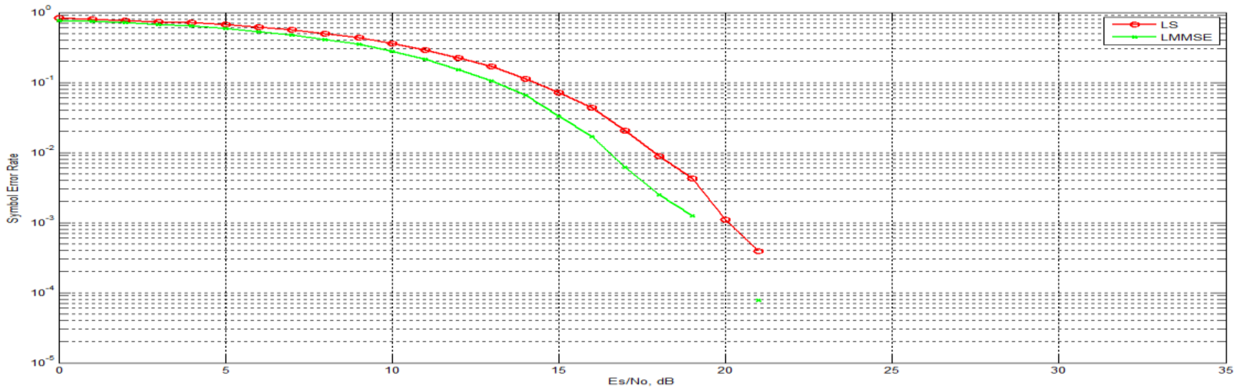

Fig.1: SER for LS and LMMSE estimation method at 10 dB Doppler Frequency

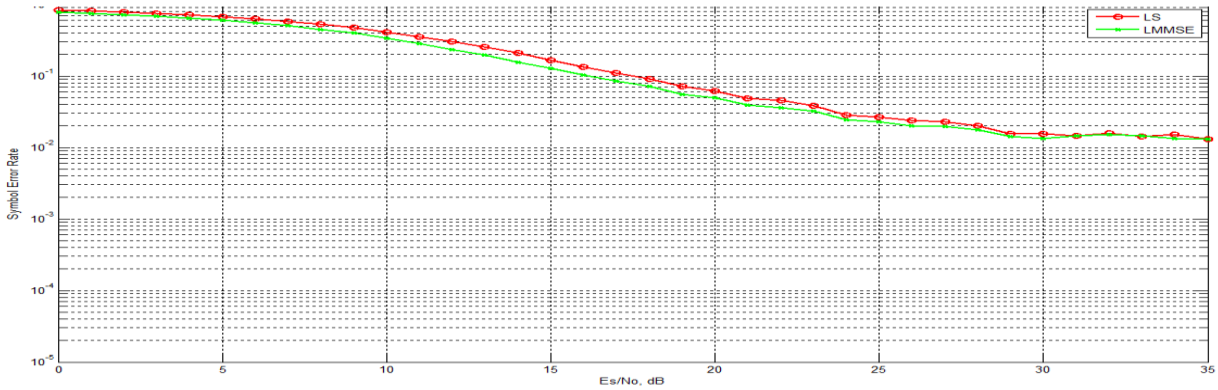

Fig. 2: SER for LS and LMMSE estimation method at 20dB Doppler Frequency

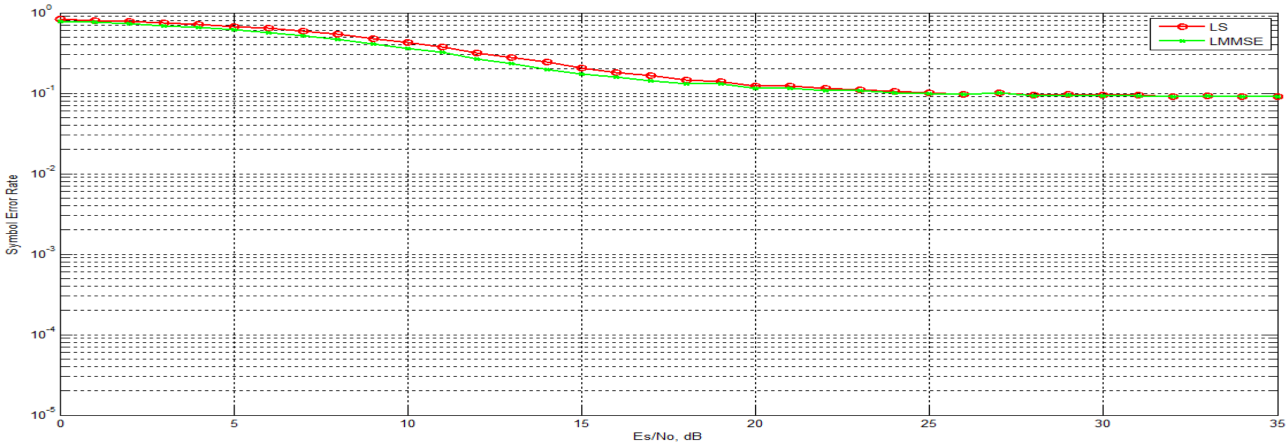

Fig. 3: SER for LS and LMMSE estimation method at 40dB Doppler Frequency

Results shown in figure-1 for OFDM channel estimation, LMMSE estimation has higher accuracy at Doppler frequency of 20dB and the performance of LMMSE estimation shown in figure-2 and figure-3 approaches with LS estimation as we tested it for higher Doppler frequencies (20 and 40dB). This shows that LMMSE reduces the computational complexity of MSE estimation but LS perform better for higher Doppler frequency with its simplicity.

6. CONCLUSION

In pilot assisted channel estimation pilot symbols are transmitted on each allocated subcarrier and the channel transfer factors are estimated by LSE, MMSE and LMMSE estimator applied on each subcarrier. This estimation approach provides a good estimation performance but prevents the transmission of data symbols within the pilot carrying symbol. Simulation results shows that LMMSE has higher accuracy for channel estimation at lower Doppler frequency and it estimation performance looks similar to LS for higher Doppler frequency. Thus a approach must be required whose performance parameters are independent from Doppler frequency shift. Mismatching of delay spread and the Doppler frequency shift may degrade the system performance in LMMSE at higher frequencies. Feedback Mechanism will be introduced in the existing channel estimation system to reduce the system complexity and improve its performance for higher data rate transmission.

7. REFERENCES

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