A Review of Channel Estimation Techniques for OFDM

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Abstract— During the past few years, the developments in digital communication are rapidly increasing to meet the ever increasing demand of higher data rates. Data rate is decreases due to multipath fading in multiuser environment. OFDM becomes promising technique for achieving higher data rate. Orthogonal Frequency Division Multiplexing (OFDM) has an edge over other frequency multiplexing techniques by using more densely packed carriers, thus achieving higher data rates using similar channels. The primary importance of channel estimation is that it allows the receiver to take into account the effect of channel on the transmitted signal, secondly channel estimation is essential for removing ISI, noise rejection techniques etc. In this report the channel estimation techniques for OFDM is examined and its implementation in MATLAB using pilot based block type channel estimation techniques. In the end, results of different simulations are compared to conclude that LS algorithm gives less complexity but MMSE algorithm provides comparatively better results. The focus of this paper is non-blind channel estimation technique & compare with blind techniques.

Keywords: OFDM; LS; MMSE; ISI

I. INTRODUCTION

A. Channel Estimation

Channel estimation is the process of characterizing or analyzing the effect of the physical medium on the input sequence (transmitted data). The basic channel block diagram of channel estimation procedure is shown in Figure. The primary importance of channel estimation is that it allows the receiver to take into account the effect of channel on the transmitted signal, secondly channel estimation is essential for removing ISI, noise rejection techniques etc. In wideband mobile communications systems, a dynamic estimation of the channel is essential before the deodulation of OFDM signals because the radio channel is time-varying and frequency selective. There are two main types of channel estimation methods, namely blind methods and training sequence methods. In blind methods, mathematical or statistical properties of transmitted data are used. This makes the method extremely computationally intensive and thus hard to implement on real time systems. In training sequence methods or non-blind methods, the transmitted data and training sequences known to the receiver are embedded into the frame and sent through the channel. Generally, the length of the training sequence is twice or thrice the order of the channel and it is computationally simple compared to blind methods. One of the popular methods is to make use of the training bits (pilot symbols) known to the receiver. The transmitter periodically, inserts the symbol from which the receiver derives its amplitude and phase reference. Although training sequence method is much less computationally intensive than the blind methods, the channel bandwidth is not put into effective use by the transmission of training sequences. Another channel estimation method is called semi-blind method. The semi-blind methods use information from both training sequence and statistical properties of the transmitted signal, which makes them more robust than the blind methods while they still require less training compared to the non-blind methods.

In OFDM system, data are modulated on frequency domain sub-channels and scaled by different sub-channel frequency response coefficients after passing through the multipath channel. For coherent detection, these sub-channel frequency responses must be estimated. This estimation is usually done using training symbols which are embedded in the symbol. In this thesis pilots are used for channel estimation. A possible way of performing channel estimation is illustrated in Fig.1.1 [6]

Fig. 1: Channel Estimation Procedure.[6]

In an OFDM receiver, channel estimation is performed in frequency-domain on the signal output from the FFT block. The received signal after passing through the channel can be described as,

\[ y(n) = H(k)x(n) + z(n) \]

Where k is the sub-channel (or sub-carrier) index, y(n) is the signal output from the FFT, H(k) is the channel frequency response corresponding to sub-carrier k, and z(n) is the noise. If the FFT input noise is white, the output noise is also white.

B. CHANNEL ESTIMATION OF OFDM SYSTEMS

For an OFDM mobile communication system, the channel transfer function at different subcarriers appears unequal in both frequency and time domains. Therefore, a dynamic estimation of the channel is always required. Pilot-based approaches are widely used to estimate the channel properties and correct the received signal. In this paper, two types of pilot arrangements, as shown in Figure are investigated.
The first kind of pilot arrangement, shown in Figure (2) is denoted as block-type pilot arrangement. This is sent periodically in time-domain and is particularly suitable for slow-fading radio channels. Because the training block contains all pilots, channel interpolation in frequency domain is not required. Therefore, this type of pilot arrangement is relatively insensitive to frequency selectivity. The second kind of pilot arrangement, shown in Figure 3, is denoted as comb-type pilot arrangement. In this case, the pilot arrangements are uniformly distributed within each OFDM block. Assuming that the payloads of pilot arrangements are the same, the comb-type pilot arrangement has a higher re-transmission rate. Thus, the comb-type pilot arrangement system provides better resistance to fast-fading channels. Since only some sub-carriers contain the pilot signal, the channel response of non-pilot sub-carriers will be estimated by interpolating neighbouring pilot sub-channels. Thus, the comb-type pilot arrangement is sensitive to frequency selectivity when comparing to the block-type pilot arrangement system.

1) Block, comb and scattered patterns of pilots with comparison

<table>
<thead>
<tr>
<th>Block Type</th>
<th>Comb Type</th>
<th>Scattered patterns</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time domain allocation, 1D estimator sufficient</td>
<td>Frequency domain allocation-1D estimator sufficient</td>
<td>Time and frequency domain allocation-2D estimators are required</td>
</tr>
<tr>
<td>Suitable over slow fading channel where estimation is performed once per block of data (when channel is constant over the whole block)</td>
<td>Suitability over medium or fast fading channel, Channel is assumed steady between two consecutive pilots</td>
<td>Suitability over medium and fast fading environment, mainly used for long frames, broadcast applications</td>
</tr>
<tr>
<td>Estimation may be based on LS, MMSE or modified MMSE</td>
<td>Estimation may be based on LS, ML estimator and PCMB</td>
<td>Estimation may be based on LS, Normalized LS, 2D filters-Wiener or Kalman</td>
</tr>
<tr>
<td>Does not affect the spectrum efficiency much but affect information transmission efficiency a lot.</td>
<td>Spectrum efficiency reduces due to additional pilot carriers and also the Bandwidth efficiency</td>
<td>Waste of spectrum and bandwidth efficiency. Better channel estimation is achieved compared to 1D scheme.</td>
</tr>
<tr>
<td>Interpolation is not required</td>
<td>Interpolation is required</td>
<td>Interpolation depends upon density of pilots</td>
</tr>
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</table>

II. REVIEW AND COMPARISON OF ERROR MINIMIZING ALGORITHMS

Channel estimators must be with less complexity and good channel tracking ability and high accuracy. The optimal channel estimator in terms of mean square error is based on 2D wiener filter interpolation but it is too complex for practical implementation. 1D channel estimation based on block or comb type structure is a tradeoff between complexity and accuracy. One can check the error between received sequence and known sequences in order to reduce it. In literature the various types of algorithms are as follows.

- **LS**: Least Square
- **MMSE**: Minimum Mean Square Error
- **LMS**: Least Mean Square
- **ML**: Maximum Likelihood
- **PCMB**: Parametric Channel Modeling Based

A. **LS**:

Without using any knowledge of the statistics of the channels, the LS estimators are calculated with very low complexity, but they suffer from a high mean square error. Suppose, X is pilot signal matrix, H is specified channel condition matrix (from previous OFDM block estimation) and Y is received signal matrix then for block type pilot structure, LS estimator minimizes the parameter (Y-XH)H(Y-XH). For block method, it is shown that the LS estimator of H is given by:

\[ H_{LS} = (X^H Y) / (N_p) \]

For comb type pilot based estimation for each transmitted symbol Np pilot signals are uniformly inserted into x(k), i.e. the total N subcarriers are divided into Np groups, each with L=N/Np adjacent subcarriers.

B. **MMSE**:

The MMSE estimator employs the second order statistics of the channel conditions to minimize the mean square error and yields much better performance than LS estimators, especially under the low SNR scenarios. A major draw back of the MMSE estimator is its high computational complexity, especially if matrix inversions are needed each time data in X changes. It can be derived that

\[ H_{MMSE} = \frac{R_{HH}}{R_{HH} + \sigma_n^2} \]

Where, HMMSE is the estimated channel by MMSE algorithm and HLS is the LS based estimate. RHH is the auto covariance matrix of H (channel conditions), \( \sigma_n^2 \) denotes noise variance.

C. **Modified MMSE**:

Modification is nothing but reduced complexity. Modifications:

1. Replace the term \( (X^H H + \sigma_n^2)^{-1} \) in Eq.(3.2) with its expectation \( E\{X^H X\}^{-1} \). Assuming the same signal constellation on all tones and equal probability on constellation points.
2. Low rank approximation (Optimal low rank MMSE=OLR-MMSE). We can only consider the initial taps with significant energy. So the effective size of the matrix is reduced dramatically after the low rank approximation is used.
3. The SVD also dramatically reduces the calculation complexity of matrices. MMSE methods are applicable.
for slowly time varying channel only. Also the knowledge of the channel transfer function for the previous OFDM data blocks is needed. While following method has eliminated both such problems. One proposed method in Reference employs low pass filtering in a transform domain so that ICI and AWGN components in the received pilot signals are significantly reduced. The cutoff frequency of the transform domain filter i.e. pass band of the filter is dynamically selected by tracking the received pilot signals. The channel transfer function for all the subcarriers is obtained by a high resolution interpolation realized by zero padding and DFT/IDFT. This proposed method is applicable for all linear modulation like MQAM based OFDM systems. The method can be applied in fast or slow-fading noisy radio channels. Comb type pilot arrangement is adopted. It is suggested to choose the number of pilot signals as a power of two so that the efficient radix-2 FFT/IFFT algorithms can be adopted, although other numbers can also be used. When the Doppler spread is large the proposed method in [1] works better than other methods but not as expected due to ICI caused by Doppler frequency shifts. An ICI self-cancellation approaches are proposed in many papers to combat ICI but the corresponding channel estimation methods are to be worked out.

### III. SIMULATION RESULT

![Fig. 3: Simulation results and comparison for SNR requirement for LS and MMSE schemes for BPSK modulation with 256 subcarriers](image)

A. Computational complexity analysis block

<table>
<thead>
<tr>
<th>Estimation scheme</th>
<th>Complexity</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>LS</td>
<td>Low</td>
<td>Simple vector division but performance depends on iterations</td>
</tr>
<tr>
<td>MMSE</td>
<td>High</td>
<td>Matrix inversion and other operations with size N, where N is the DFT size. (Typically 256, 512, 1024, or 2048).</td>
</tr>
</tbody>
</table>

Table 2: Computational complexity analysis

### IV. CONCLUSIONS

Training sequence based method is for coherent receivers, Blind method is for noncoherent receivers. Pilot based method is selected and blind methods are omitted. Firstly, the utilization of pilot signals for channel estimation techniques is especially attractive in fast time varying wireless channel and packet data transmission systems as they provide most accurate estimate of the channel with less processing complexity compared to blind. LS scheme is less complex than MMSE or LMS but at the same time less accurate. At the same time for fast changing channels more dynamism is also required and that is possible by less complex methods. it is clear that with less SNR requirement MMSE performs better but at the same time very less performance difference with LS. As a compromised solution it is decided to take multiple estimations in parallel or in loop to get the accuracy. Also limited number of iterations can also be considered for better results.

### V. FUTURE WORK

Instead of sending more pilots, enhance the estimation error exploiting the additional information provided by data observations. We introduced the semi-blind approach and presented two deferent ways to deal with the uncertainty concerning transmitted symbols.

### REFERENCES