

Research of Channel Estimation for OFDM Systems

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Abstract The future wireless mobile communication systems are aim to provide high-quality and high-rate mobile multimedia transmission. However, hostile multipath fading and time varying of radio conditions bring about complexity in channel character tracking. Orthogonal Frequency Division Multiplexing (OFDM), which is inherently resistant against inter-symbol interference (ISI), has therefore become the key technology of broadband high-speed wireless communication in future. Nevertheless, OFDM system is too vulnerable to channel estimation error. It is of great importance to estimate channel efficiently in OFDM system. And that is what this issue intended to do.

Keywords: Mobile communication ;OFDM; Channel estimation

1. INTRODUCTION

High-speed, reliable, high spectrum efficiency of wireless transmission technology is a hot area of research for future mobile communications, orthogonal frequency division multiplexing (OFDM) technology has been proven to be an effective means of resistance to multipath fading and increase system capacity, and is more kind of wireless communication standards adopted. It has a more effective against inter-symbol interference (ISI) caused by multipath propagation and high bandwidth efficiency, compared with the single carrier modulation has incomparable advantages in broadband wireless access.

Whether it is a single carrier system or a multicarrier system, the coherent demodulation at the receiving end to recover data information, more accurate CSI is required as an essential parameter data processing, therefore, the channel estimation is a key factor affecting the performance of the OFDM system. Channel estimation technique is to estimate the instantaneous characteristics of multipath fading channel, namely the estimated characteristics of the mobile channel from the received signal.

General channel estimation techniques are non-blind channel estimation techniques, blind channel estimation techniques and semi-blind channel estimation developed on the basis. Non-blind channel estimation techniques are required to send the pilot signal at the transmitter, therefore, also known as pilot-based channel estimation techniques..

In this paper, our aim is to compare the performance of channel estimation method based on the pilot, in different modulation methods, different channel fading, estimated under different channel estimation algorithms are analyzed and compared. In section II, the description of the OFDM system based on pilot channel estimation is given. In section III, estimations are discussed based on the pilot symbols channel, and a variety of algorithms is presented. In section IV, the simulation environment and results are described. Section V concludes the paper.

2. SYSTEM DESCRIPTION

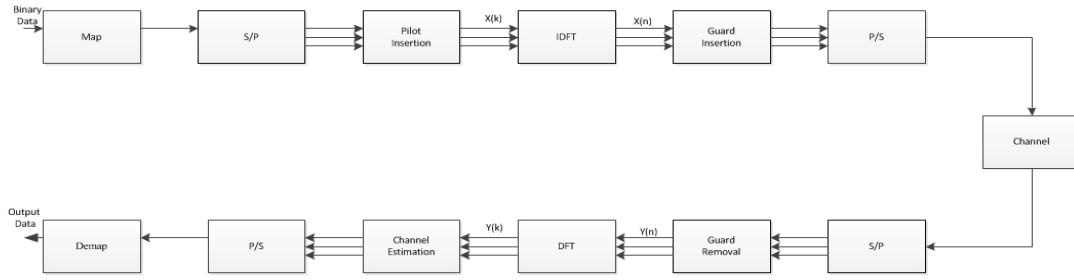


Fig. 1. OFDM System

A complete OFDM system based on DFT / FFT block diagram shown in Figure 1. The binary information is first grouped and mapped according to different signal modulation. After inserting pilots either to all sub-carriers with a specific period or uniformly between the information data sequence, IDFT block is to transform frequency domain samples into time domain samples.

Following IDFT block, guard time, which is chosen to be larger than the expected delay spread, is inserted to prevent inter-symbol interference. This guard time includes the cyclically extended part of OFDM symbol in order to eliminate inter-carrier interference (ICI).

The transmitted signal $x(n)$ will pass through the frequency selective time varying fading channel with additive noise. At the receiver, after passing to discrete domain through A/D and low pass filter, guard time is removed and $y(n)$ is sent to DFT block. Following DFT block, the pilot signals are extracted and the estimated channel $H(k)$ for the data sub-channels is obtained in channel estimation block. After the estimation of the transmitted data by:

$$x(k) = \frac{Y(k)}{H(k)} \quad k = 0, 1, \dots, N-1 \quad (1)$$

binary information data obtained from the de-mapping block.

3. THE WAY OF CHANNEL ESTIMATION

Estimation method based on auxiliary information is to insert into some known pilot symbols or training sequence in some fixed position of transmitter, at the receiving end by using the pilot symbol or training sequence estimate channel according to certain algorithm. Such estimation system occupied bandwidth, channel track is fast, easy to implement.

Estimation based on pilot is usually consider three key issues: First position of the pilot signal that the pilot arrangement pattern selection; the second is how to make an accurate estimate of the pilot channel from the received signal, and with low complexity channel estimation algorithm ; the third is How to use the appropriate interpolation algorithm by the estimated pilot channel information to get the channel estimation of data. The pilot pattern selection that is the choice of pilot insertion. When the pilot pattern design in OFDM system, both to make the pilot spacing as small as possible, in order to ensure time-varying and frequency-selective channel can be a good track, but also to make the system not because of too much pilot insertion cause a great spectrum of overhead. So in the design of the actual system, it should weigh all aspects of the requirements in order to achieve the most appropriate.

At present, the pilot insertion scheme can be divided into two categories: discrete pilot subcarriers and continuous pilot subcarriers. IEEE802.16e which recommended the use of two-dimensional discrete pilot subcarriers, and continuous pilot is divided into two cases: the block

pilot distribution and comb pilot distribution [7].

In the block pilot insertion mode, to divide OFDM symbols into m group, the first OFDM symbol is to transmit pilot signal in each group, and the other OFDM symbols transmit data information, such an estimate will use all sub-channels information. The pilot symbols in the time domain spacing uniform, continuous in frequency domain. Features of the program is pilot symbol covers all frequencies, so the pilot symbols can be effective against frequency selective fading, but more sensitive to the impact of the fast varying channels. Inability to accurately track the channel at all times, the block pilot more suitable for channel which relatively low Doppler shift and slowly fading.

Comb pilot insertion evenly uniformly divided N sub-channels into M group. In the first sub-channel fixed transmission pilot signal of each group, called the pilot sub-channel, while the other sub-carriers to transmit data information. The pilot symbols in the frequency domain spacing uniform, continuous in time domain. Contrary to block pilot distribution, comb pilot can be tracked channel at all times, so it is suitable for fast fading channel applications, but due to its insertion frequency discontinuities, comb pilot insertion is not conducive to confrontation frequency selective fading.

When practical application, due to the different characteristics of the channel should be used to select the appropriate pilot insertion method. So as to make more accurate and efficient channel estimation.

3.1 Channel estimation algorithm based on LS rule

Least-squares (LS) channel estimation is the sense of least squares obtained channel estimation algorithms[8]. Without considering the noise conditions, Make the minimum weighted error between model values and measurements [9]. And even if

$$\nabla = (Y - \hat{Y})^H (Y - \hat{Y}) \quad (2)$$

\hat{Y} Is the output signal obtained after the channel estimation, $\hat{Y} = X\hat{H} = XF\hat{h}_{LS}$, F Is the Fourier transform matrix.

$$\frac{\partial \nabla}{\partial \hat{h}_{LS}} = -2F^H X^H Y + 2F^H X^H X F \hat{h} = 0 \quad (3)$$

$$\text{Get } \hat{h}_{LS} = (F^H X^H X F)^{-1} F^H X^H Y = F^{-1} X^{-1} Y, \text{ so } \hat{H}_{LS} = X^{-1} Y = \left[\frac{Y(0)}{X(0)}, \frac{Y(1)}{X(1)}, \dots, \frac{Y(N-1)}{X(N-1)} \right]^T \quad (4)$$

$$\text{where } \hat{H}_{LS} = F \hat{h}_{LS} \quad (5)$$

LS algorithm is simple, but the results can be seen that it does not relate to the effect of noise, which bring some errors to estimation. To make estimation accuracy is improved, must find a more accurate algorithm, which also should be taken noise into account.

3.2 Channel estimation algorithm based on MMSE rule

For the minimum mean square error(MMSE) estimation based on pilot OFDM system, MMSE estimation better than the LS estimation [10].

If using the minimum mean square error channel estimation, mean square error expressed by ∇ :

$$\nabla = E\{|\varepsilon|^2\} = E\{|H - \hat{H}|^2\} \quad (6)$$

The minimum mean square error criterion is to estimate channel transfer function H to meet the minimum ∇ [10]. So:

$$\hat{H}_{MMSE} = R_{HY} (R_{YY})^{-1} Y \quad (7)$$

Where $R_{HY} = E\{HY^H\} = R_{HH}X^H$ is the channel transfer function and the received signal covariance matrix, $R_{YY} = E\{YY^H\} = XR_{HH}X^H + \sigma_n^2 I_N$ is a self-covariance matrix of the received signal, R_{HH} is self-covariance matrix of the channel transfer function, σ_n^2 is the noise variance.

So the frequency domain channel response MMSE estimate is:

$$\hat{H}_{MMSE} = R_{HH}(R_{HH} + \sigma_n^2(X^H X)^{-1})^{-1}\hat{H}_{LS} \quad (8)$$

References[10] showed that compared with the LS method, MMSE method with 10-15dB SNR gain. But it can be seen from (8), we must estimate the inverse of the channel estimation matrix $R_{HH} + \sigma_n^2(X^H X)^{-1}$, Since $(X^H X)^{-1}$ is different in different OFDM symbols, its inverse matrix to be updated in each OFDM symbol period, therefore a large amount of calculation.

3.3 Channel estimation algorithm based on LMMSE rule

There is a method to reduce the amount of calculation [11], namely LMMSE algorithm, is to use $E\{(X^H X)^{-1}\}$ instead of $(X^H X)^{-1}$, so $R_{HH} + \sigma_n^2(X^H X)^{-1}$ the inverse matrix do not need to recalculate, the same modulation scheme in all sub-channels (using the same symbols mapping mode), and the data symbols map in the points of the constellation with the same probability of occurrence, there are:

$$E\{(X^H X)^{-1}\} = E\{1/|X_K|^2\}I \quad (9)$$

Where, I is a unit matrix, define the average signal to noise $SNR = E\{|X_k|^2/\sigma_n^2\}$, represented by formula (8) can be derived as the following formula as:

$$\hat{H}_{MMSE} = R_{HH}(R_{HH} + \frac{\beta}{SNR}I)^{-1}\hat{H}_{LS} \quad (10)$$

Where, $\beta = E\{|X_i|^2\}E\{1/|X_i|^2\}$ is a constant determined by the modulation signal constellation when the baseband symbol mapping using 16QAM constellation, $\beta = 17/9$.

LMMSE channel estimation algorithm considering the effect of noise in solving optimization problem, so the smaller mean square error in channel estimation, but compare with LS is more complex, so the actual application should weigh the pros and cons of both.

3.4 Channel estimation algorithm based on SVD rule

Get in front of a full order MMSE estimation, but still large matrix computation, due to the frequency response of the channel spectral energy concentrated in the low-frequency part, that are mainly concentrated in the front rank P , the selection of P is slightly larger than the number of the maximum multipath channel of samples corresponding to the delay interval, Therefore, the singular value decomposition(SVD) algorithm is proposed [12].

SVD algorithm do approximate treatment on formula (11), thus further reducing the order to simplify calculation. Do singular value decomposition on the channel autocorrelation matrix:

$$R_{HH} = U \Lambda U^H \quad (11)$$

U is Unitary matrices, Λ is the eigenvalues diagonal matrix of R_{HH} , by MMSE algorithm can be further simplified as:

$$\hat{H}_{MMSE} = U \begin{bmatrix} \Delta_P & 0 \\ 0 & 0 \end{bmatrix} U^H \hat{H}_{LS} = U \Delta_P U^H \hat{H}_{LS} \quad (12)$$

After SVD transform, the signal energy will be concentrated on the P coefficients, so that in the low-range estimate, the complexity can be reduced. This low-end estimate is based on actual subspace projection subspace smaller, more concentrated energy, the estimation error is smaller.

4.THE ANALYSIS OF THE SIMULATION

This section will computer simulation analysis of the theory and algorithms mentioned before. And through a variety of comparison, find the advantages and disadvantages of different methods, which include a comparison of different channel estimation methods, comparison of channel estimation at different modulation modes, different pilot insertion comparison, and the comparison between the various algorithms.

4.1 Channel estimation simulation under different modulation modes

Simulation parameters: as defined by the IEEE802.16a standard, 256 subcarriers, each send 50 OFDM symbols, The pilot uses block inser, estimated using the LS algorithm. Channel model is JAKE.

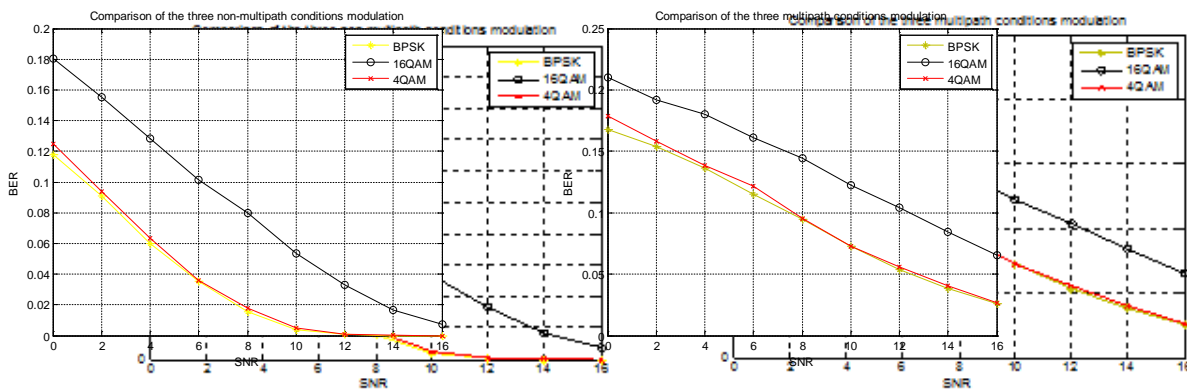


Fig.2.Comparison of the three modulation in multipath conditions and non-multipath conditions

From the above simulation figure shows , under normal circumstances modulation with larger code distance, error performance the better. The BER performance of 16QAM modulation is still less than the 4QAM modulation and BPSK modulation. However, the 16QAM modulation band utilization rate is the highest. Thus, in the band-limited system, it is also a promising modulation. 4QAM modulation performance somewhere between BPSK modulation and 16QAM modulation, band utilization rate is also the same. If the parameters are the same, the signal modulation using 4QAM effect is relatively good.

4.2 Comparison of block pilot insertion mode and comb pilot insertion mode

To compare the block pilot insertion and comb pilot insertion under what circumstances have better performance, simulation on slow fading channel and fast fading channel, make the following simulation, simulation parameters: as defined by the IEEE802.16a standard, using 16QAM modulation, 256 subcarriers, each send 100 OFDM symbols, The pilot intervals of comb pilot insertion and block pilot insertion pilot are all five, interpolation method uses linear interpolation method, estimated using the LS algorithm. Channel model is JAKE. Multipath time delay is 4 trails. Slow fading condition the maximum Doppler frequency is 0HZ, fast fading conditions the maximum Doppler frequency is 200Hz.

As can be seen from the simulation, in multipath conditions, slow fading channel, the performance of linear interpolation in block pilot insertion is better than the performance of linear interpolation in comb pilot insertion, which is due to the pilot block insertion covers all frequency that make it more conducive to resist multipath fading interference. While when the channel is fast fading channel, linear interpolation in comb pilot insertion mode due to can estimate at each time point, can adapt to this kind of rapid changing channel. In practical application, should be according

to different circumstances, compare multipath fading and time-varying channel changes, which is more serious and take the appropriate pilot insertion mode.

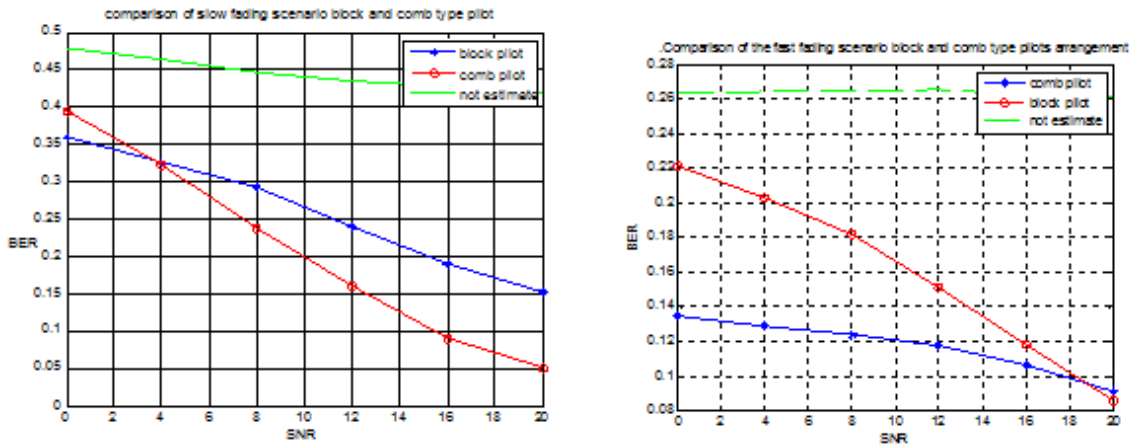


Fig.3.Comparison of the block and comb type pilots (LS algorithms).

4.3 Comparison of different channel estimation algorithm

To test the performance of different channel estimation algorithms, Here are time-varying and multipath channel models and simulation parameters: using 16QAM modulation, 256 sub-carriers, each send 50 OFDM symbols, block pilot insertion. The pilot interval is 5, the channel model is JAKE, 4 trails. The maximum Doppler frequency is 200Hz.

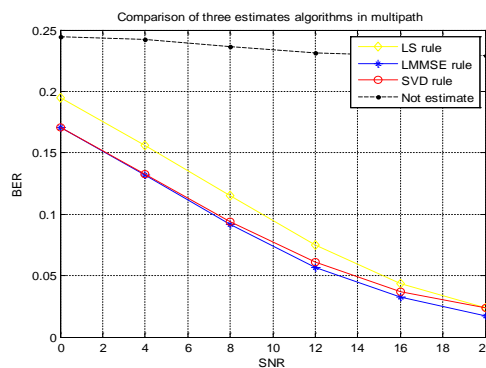


Fig.4.Comparison of three estimates algorithms in multipath

As can be seen from Fig.4, Although the error performance of LS algorithm is the worst, but in ensuring the performance of certain error conditions, it is very low implementation complexity, and therefore has a very high availability. LMMSE estimation algorithm takes into account the effect of noise, the error performance is better than LS estimation algorithm, able to make a more accurate estimate of the channel parameters. While the SVD decomposition algorithm and LMMSE algorithm with similar performance effect. In summary, LS algorithm complexity lowest, LMMSE algorithm complexity highest, the complexity of SVD decomposition algorithm between the two. Combined with the simulation results can be seen, SVD decomposition algorithm integrated better, can achieve good error performance in the case of lower complexity.

5.CONCLUSION

Through computer simulation to compare the performance of OFDM system on different estimation methods, different modulation, different pilot insertion methods and different algorithms. Firstly compare the effects of BPSK, 4QAM and 16QAM modulation on the estimation. Shows that

the greater code distance modulation, the better BER performance under normal circumstances. Then compare the two kinds of block and comb pilot insertion mode which is more suited to a particular channel environment, verify that the block pilot insertion mode is more suitable to deal with multipath fading channels, comb pilot insertion mode is more suitable to cope with the fast fading channel. Finally, through comparison and analysis performance on the LS, LMMSE, SVD decomposition of three estimating methods show that the estimation error performance of LMMSE algorithm is best, followed by SVD decomposition algorithm, LS algorithm is the lowest precision. The next work is mainly focus on the improvement and innovation of the OFDM channel estimation algorithm.

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