The Application of Interpolation Algorithms in OFDM Channel Estimation

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Abstract — **In this paper we propose algorithms for system channel estimation using Orthogonal Frequency Division Multiplexing, OFDM. Based on the latest high speed transmission technology, there are two ways to implement the techniques: using frequency domain or time domain channel estimation. In OFDM the known pilot signal is inserted to give a channel approximate estimate, and then the channel full response is obtained by interpolation algorithms. This paper proposes three interpolation algorithms and studies their characteristics qualities in channel estimation by simulation. We can use the conclusion to choose the correct interpolation algorithms in OFDM channel estimation.**

Keywords-OFDM; interpolation algorithms; channel estimation

I. INTRODUCTION

As we all know, multimedia and information technology plays an increasingly important role in human social life and development with the proposed personal communications concept. The need of personal high data rate wireless access is to promote wireless broadband multimedia communications development. The multipath delay caused inter-symbol interference which severely limits the data transfer rate on the radio channel, and then Orthogonal Frequency Division Multiplexing (OFDM) technology can effectively suppress inter-symbol interference, so it is widely used.

OFDM is an efficient technique used in high-speed digital transmission over multipath fading channels. An OFDM system requires an accurate estimate of the channel impulse responses for signal detection, and as a result, channel estimation becomes a key problem for OFDM systems. Its main idea is: The channel is divided into a number of orthogonal sub-channels. It changes high-speed data signals into parallel low speed sub-data streams modulated to each sub-channel. In the receiver we can separate the orthogonal signal and reduce interference between the sub-channels. Multiple antennas can be used in orthogonal frequency division multiplexing (OFDM) system to improve the communication capacity and quality of mobile wireless systems. Channel parameters are required for diversity combining, coherent detection, and decoding. In OFDM systems the multiple transmit antennas, such as permutation and space-time coding based transmit diversity, different signals are transmitted from different transmit antennas simultaneously. Consequently, the received signal is the superposition of these signals, which gives rise to challenges for channel estimation. In this paper, we investigate training-sequence design and parameter estimation simplification techniques for OFDM with multiple transmit antennas. for channel estimation.

A common conjecture is to use orthogonal sequences at different transmit antennas[1-3] . Training sequences are used in wireless communication systems to obtain initial estimation of channel parameters, timing, and frequency offset. For multiple transmit antenna systems, training sequences should be designed to decouple the inter-antenna interference for channel estimation.

Channel estimation based on pilot in OFDM system is investigated which is based on the channel modeling and parametric selection. In OFDM system because the entire system band is divided into a number of independent sub-channel bandwidth which has the same bandwidth, each sub-channel is to transmit their modulated signals. Channel estimation purpose is to get the channel state information through the pilot sequence. The common way is to directly estimate the channel frequency response[4-6]. There are three ways in OFDM channel estimation which are blind channel estimation, semi-blind channel estimation and training sequence channel estimation. The method based on training sequence channel estimation is most widely used and has a more stable performance[7-8].

II. THE OFDM SYSTEM MODEL

A. The OFDM system model

The OFDM system model is shown in Fig.1. OFDM is a block transmission system where data symbols are transmitted in parallel on a large number of sub-carriers. The complex data symbols are modulated on N subcarriers by an inverse discrete Fourier transform (IDFT). To form the OFDM symbol the last L samples are copied and put into a preamble station usually referred to as the cyclic prefix. The data vector is digital-to-analog converted and transmitted over a channel, whose impulse response we assume is shorter than the length of the cyclic prefix. One OFDM symbol thus has duration (N+L) Ts where Ts is the system's sampling period. In the receiver the signal is sampled, the cyclic prefix is removed, and the resulting data vector is demodulated by a discrete Fourier evaluate system performance.

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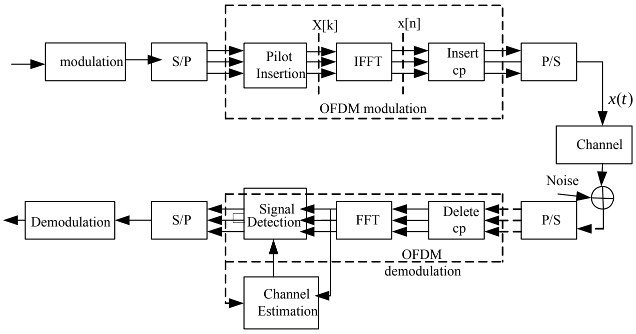

Fig. 1 OFDM system model.

The signal transmission is as follows: firstly the binary information data bits are mapped. Then X[k] is got according to the sub-carrier number N which is through the s/p transformation in accordance with the structure of the pilots and insert pilots. Finally we can use the Fourier inverse transform (IDFT or IFFT), which is expressed as

$$x(n) = \frac{1}{N}\sum_{k=0}^{N-1} X[k]e^{j\frac{2\pi kn}{N}}, n = 0,1,\cdots,N-1$$

(1)

Where n is the n time domain samples, k is the sub-carrier. In order to eliminate the inter-symbol interference to maintain orthogonality among sub-carriers, every two groups OFDM symbol insert cyclic guard interval (CP), which is the last symbols of each OFDM copied to the first part. Guard interval is greater than the length of the channel impulse response or is equal to the maximum delay. It is expressed as:

$$x(n) = \begin{cases} x(N+n), n = -N_g + 1, \cdots, -1 \\ x(n), n = 0,1,\cdots, N-1 \end{cases} \quad (2)$$

Complex base-band mobile wireless channel impulse response can be expressed as

$$h(t,\tau) = \sum_i \gamma_i(t)\delta(\tau - \tau_i)$$

(3)

Where τ_i is the i path's delay time, $\gamma_i(t)$ is the complex fading. Using the model of wide-sense stationary complex random process and supposing each track is independent, where the discrete forms is shown in formula (4).

$$h(n,\tau) = \sum_i \gamma_i(n)\delta(\tau - \tau_i)$$

(4)

The signal $x_g(n)$ affected by fading in receiver is expressed as

$$y_g(n) = x_g(n) * h(n,\tau) + w(n) \quad (5)$$

Where $w(n)$ is the AWGN.

B. *The summary of OFDM channel estimation*

The interpolation algorithms are very popular in OFDM channel estimation. Known the channel transmission characteristics of the pilot position, we can use the various internal algorithms to estimate the channel characteristics of data location. At present the common pilot plan are block pilot and comb pilot. The block pilot is periodically inserted pilot in time domain. The pilot is inserted in all the subcarriers [7]. Because this method that the pilot on the frequency domain is continuous, it is not sensitive to frequency selective fading; the Pilot on the time domain is not continuous, it usually requires the channel has a little change within a period of time or it even remains unchanged. So the block pilot suits to the constant reference channel and WLAN channel. The comb pilot is that the pilot is all inserted in some subcarrier according to the intervals. Because the pilot is continuously inserted in the time domain, it has a good effect to the fast fading. Thus the comb pilot suits to the flat fading channel.

In OFDM systems we generally use pilot symbol to estimate the channel. Today there are many estimation methods we have got. OFDM system channel estimation method is summarized in Fig.2.

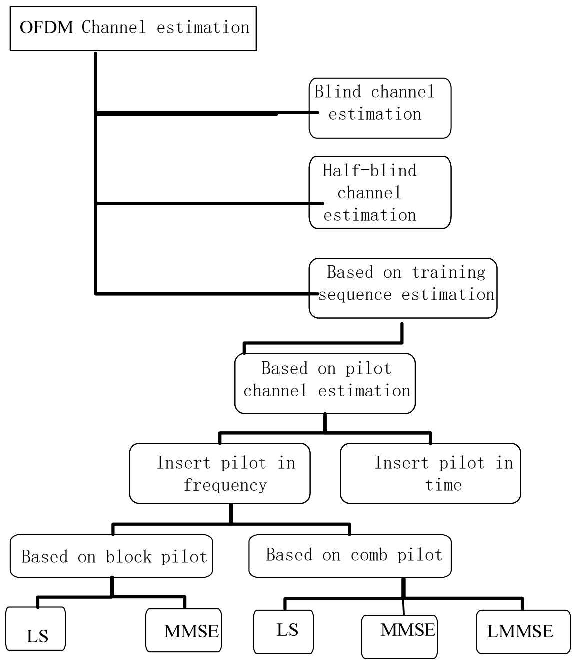

Fig. 2 The summary of OFDM channel estimation.

In OFDM systems we generally use pilot symbol to estimate the channel. Today there are many estimation methods we have used. Now the training sequence based on the channel estimation methods is wildly used.

The channel estimation model can be defined as follows. If $H(k)$ is the estimation of $H(k)$,we can get the $X(k)$ is the estimation of $X(k)$:

$$\hat{X}(k)=\frac{Y(k)+N(k)}{\hat{H}(k)}=X(k)\frac{H(k)}{\hat{H}(k)}+e(k),0\le k\le N-1 \quad (6)$$

The $e(k)$ is the error components caused by noise. It is can be proved that if $\hat{H}(k)$ is an unbiased estimation and $N(k)$ is the zero mean white noise process, $\hat{X}(k)$ will be the unbiased estimation. At the same noise conditions the estimated variance of $\hat{X}(k)$ is determined by the estimated variance of $\hat{H}(k)$, so how to get accurate channel estimation is very important.

III. THE STUDY OF INTERPOLATION IN OFDM CHANNEL ESTIMATION

This paper is mainly studied the channel estimation based on the pilot. The common interpolation methods are: linear interpolation, second-order interpolation method, cubic spline interpolation method, low-pass filter interpolation method and etc.

A. Linear interpolation

Linear interpolation method is to use before and after the adjacent two pilot sub-channel channel response to calculate the other data sub-channels channel response which is located between them. For the k-th channel, using a linear interpolation to obtain a channel frequency response is:

$$\begin{aligned}\hat{H}(K)&=\hat{H}(mL+l)\\&=\hat{H}(mL)+\frac{l}{L}(\hat{H}((m+1)L)-\hat{H}(mL))\\&=\hat{H}_p(m)+\frac{l}{L}(\hat{H}_P(m+1)-\hat{H}_P(m))\\k&=mL+l,\quad 0<l<L\end{aligned} \quad (7)$$

Where L<k<(m+1)L, L is the interval between the pilot sub-channel, m is the relative position of the pilot.

B. Second order nonlinear interpolation (Gauss interpolation)

Gauss interpolation is a kind of second order nonlinear interpolation. It uses the current and the three pilot symbols to estimate the performance which is better than the linear interpolation. The interpolation algorithm in frequency domain is described as follows:

$$\begin{aligned}\hat{H}(k)&=\hat{H}(mL+l)\\&=C_1\hat{H}_P(m-1)+C_0\hat{H}_P(m)+C_{-1}\hat{H}_P(m+1)\end{aligned} \quad (8)$$

$$C_1=\frac{\alpha(\alpha+1)}{2},C_0=-(\alpha+1)(\alpha-1)$$

$$C_{-1}=\frac{\alpha(\alpha-1)}{2},\alpha=\frac{l}{L}$$

In the same way, the interpolation algorithm can be obtained in time domain. For several locations of the start, the algorithm is degenerated into the linear interpolation.

C. Cubic spline interpolation

Each sub-carrier channel transfer function is approximately l/L to a cubic polynomial in this method. Where is expressed as

$$H_\varepsilon(k)=AH_\varepsilon(k_m)+BH_\varepsilon(k_{m+1})+CZ(k_m)+DZ(k_{m+1}) \quad (9)$$

Where A,B,C,D is determined by a d/D_f 's linear combination constant. $Z(k)=H_\varepsilon''(k)$ is the second order derivative of the subcarrier k on the channel frequency.

D. Low-pass filter interpolation

This method is added zeros to the sequence of the pilot sub-carrier channel response before using the low-pass interpolation. Then we can get all the sub-carrier channel frequency response.

IV. THE SIMULATION OF INTERPOLATION ALGORITHMS

In the paper we choose MATLAB software to simulate the interpolation algorithms in OFDM system. The simulation parameter is shown in the Table 1.

TABLE 1. THE SIMULATION PARAMETER

Parameter	Value
Modulation	QPSK
Doppler shift	200MHz
Number of multipath	6
Number of pilot	6
Pilot insertion interval	4
Channel	Rayleigh model
Number of sub-carrier	96
IFFT and FFT points	128

In this simulation we choose 6 pilots and use Rayleigh channel model. In this System, the Doppler frequency shift fm is 200MHz, multipath number is 6 diameters. The QPSK modulated technology is used in this simulation. The IFFT and FFT points are 128. To get the high quality of simulation, the different Doppler shits are used in this simulation.

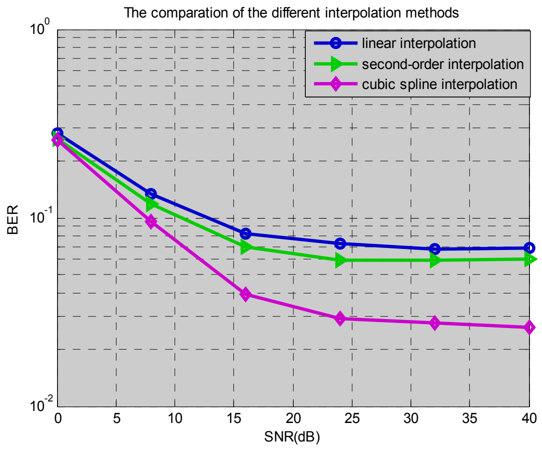

Fig.3 The Maximum Doppler shift is 200

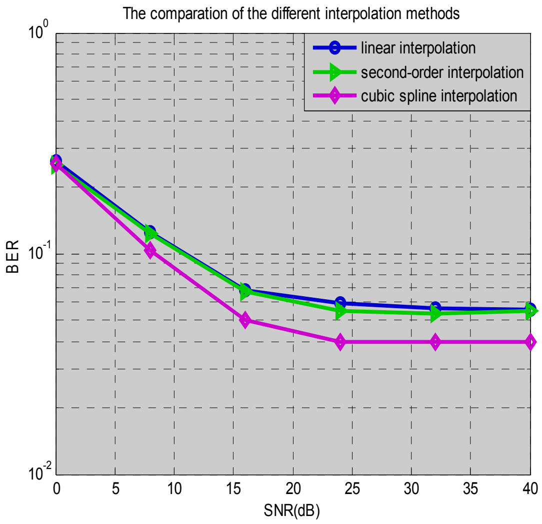

Fig.4 The Minimum Doppler shift is 30

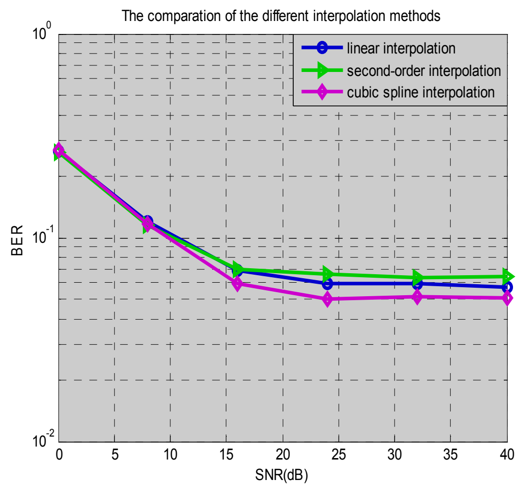

Fig.5 The Maximum Doppler shift is 1500

We can use the propagation model to simulate the characteristic of the different interpolation methods. Thus the results can be seen in the Fig.3, Fig.4, Fig.5. From the figures we can see that the cubic spline interpolation performance is the best in the three interpolation algorithms. The Doppler shift affects the communication quality. The performance of the interpolation is better when the maximum Doppler shift is low. With the increasing of the SNR, the better performance in OFDM channel estimation can be got using Low-pass interpolation method and cubic spline interpolation method.

Linear interpolation algorithm is simple, but the estimation error is large; Gauss interpolation algorithm has a slightly improved performance; spline Cubic interpolation is a kind of high order interpolation, high precision, but polynomial structure is more complex. In view of the threshold effect, we can use the method of low pass filtering after interpolation to eliminate the influence of noise and reduce the noise threshold.

The interpolation error caused by the linear interpolation accuracy is much larger than the noise. In Fig. (3) the Maximum Doppler shift is 200. The higher of the SNR, the better of the cubic spline interpolation BER. The computation of FFT has nothing to do with the interpolation multiple irrelevant because the FFT computation is only related to the number of FFT points. To the linear interpolation because the data volume will be the reciprocal relationship with the interpolation multiple, the amount of computing is a linear decline.

V. CONCLUSIONS

In this paper several interpolation algorithms based on the pilot channel estimation in OFDM system are compared and analyzed through the numerical simulation. The conclusion can be got through the simulation. The linear interpolation algorithm is not used for estimation in OFDM system. The interpolation accuracy is decreasing with increasing of the multipath effects and the deduction of the pilot number based on interpolation filter method. The FFT method calculation has nothing to do with the interpolation multiples, while the interpolation filter method is increasing along with the exponential growing.

For simplifying the simulation analysis, we made some necessary conclusion, which are given below:

The linear interpolation algorithm is effective only for a function with a rough slope, and can not be used for channel estimation of OFDM system discussed in this paper or similar system; Based on the interpolation filter the interpolation precision is gradually degraded with the increase of the multipath effect and the reduction of the number of pilot in the wireless channel; The interpolation precision of FFT method is only related to the computation precision under the condition of no noise, and the error power is equal to the noise power under the condition of noise system. FFT method must strictly ensure that the number of FFT points is the integer multiple relations with the pilot number and must be equal interval distribution. Based on the interpolation filtering method has not the limit

; Under certain signal to noise ratio condition, the error performance of the FFT method is equal to that of the interpolation filter. Even in low signal to noise ratio the FFT method is low to that of the interpolation.

To sum up in the high signal-to-noise ratio the FFT method is better than any other interpolation algorithm, but in some low signal-to-noise ratio conditions it is lower than the interpolation filtering method. The FFT method is not always optimal. We must decide to adopt what kind of interpolation method and reasonable pilot pattern design according to the system of signal environment.

In addition to the algorithm introduced in this paper, there are many other algorithms. For example, with the application of diversity technology research, diversity Channel estimation of OFDM system is also an important research direction, and the blind channel estimation is performed using pilot symbols. In short, the continuous development of OFDM channel estimation technology will provide a new generation mobile communication system based on OFDM.

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