The Novel Channel Estimation Algorithm Relying on ELM

Qingfeng DING[1, a]

[1]School of Electrical and Electronic Engineering, East China Jiaotong University, Nanchang, 330013,China

[a]email: brandy724@sina.com

Keywords: Channel Estimation; Extreme Learning Machine; Low-pass Filter; OFDM

Abstract. An Extreme Learning Machine (ELM)-based novel channel estimation algorithm is proposed for orthogonal frequency division multiplexing (OFDM) communication system with multi-path propagation characteristics. In addition, a low-pass filter is utilized to filter the noise components which are separated from the information component of the channel characteristics. The simulation results show that the proposed novel algorithm significantly outdo the traditional least squares (LS) algorithm, linear minimum mean square error (LMMSE) estimation algorithm sometime even better than the Maximum Likelihood (ML) algorithm.

Introduction

Broadband frequency-selective channel is divided into several narrowband flat fading channels by employing OFDM, which has a strong ability of anti-interference and anti-pulse from wireless multi-path fading channel in high-speed wireless data transmission. For the next generation wireless communication system, OFDM technology is one of the key technologies of the train control system based on wireless communication WLAN. In the future communication system LTE-R for a railway based on the long-term evolution (LTE), OFDMA (OFDM Access) is the downlink transmission technology [1].

In the OFDM wireless communication, the channel estimation is very critical aspect. The methods of channel estimation include the blind estimation, semi-blind estimation and non-blind estimation method [2-4]. The channel impulse response at the pilot of [5] is utilizing the least squares (LS) algorithm, which does not take the noise impact. The channel estimation algorithm utilizes the SVM algorithm, which has heightened computation complexity [6-7]. In addition, the optimal channel estimation for OFDM system is using MMSE criterion [8].While following the guidelines of the estimation algorithm, the biggest drawback is the heightened computation complexity, so the low rank estimation attracts much attention because it can obtain higher performance in the case of reduced computation complexity. Through the determination of the signal subspace dimension and then obtaining the compromise between the computational complexity and estimated performance, that in the case of the estimation performance unchanged, the computational complexity has effectively reducing by reducing the rank of the matrix. Literature [9] has proposed a rank value and adaptive tracking method.

The remainder of this paper is organized as follows. Section 2 gives the OFDM system model. Section 3 describes the novel channel estimation algorithm, whose LS operator is utilizing the ELM forecast strategies to increase the transmission efficiency of the system. Section 4 discusses the channel response transform domain characteristics obtained in section 3, and then through a low-pass filter the noise component is removed. Section 5 the performance between novel channel estimation algorithm in this paper and the classic channel estimation are compared by simulation. Section 6 the conclusion is given.

System Model

OFDM system model is shown in Figure 1. After the fast Fourier inverse transform (Inverse Fast Fourier Transform, IFFT), each OFDM input symbol is modulated to the mutually orthogonal on the N sub-carriers. The modulated signal is expressed as X_k, where k denotes the number of OFDM symbols transmitted. Each symbol contains N sub-carriers. In order to overcome the inter-symbol interference (ISI) due to multi-path effects of the channel, the OFDM symbols are required the guard interval in the front and rear inter-symbol, whose length is greater than the maximum channel delay. In order to ensure the orthogonality between sub-carriers, the cyclic prefix (CP) usually adds the guard interval in the OFDM system.

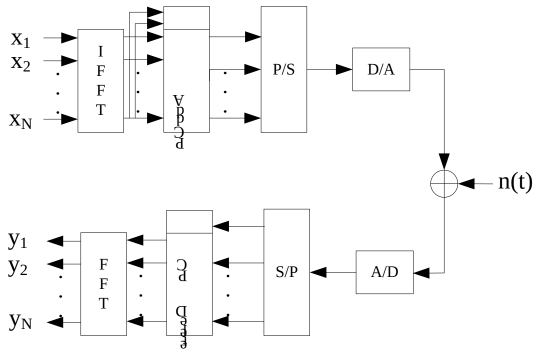


Fig.1. OFDM system model

The transmit devices and receive devices constitute a fading multi-path channel model composed by L paths, which can be expressed as:

$$g(t)=\sum_{l=0}^{L-1}\alpha_l\delta(t-\tau_l T_s) \tag{1}$$

In equation 1, L is the total number of multi-path. α_l is the gain value of the l^{th} and the path power delay spectrum is negative exponential distribution $\theta(\tau_l)=Ce^{-\tau_l/\tau_{rms}}$ in this paper, wherein τ_l is normalized delay of the l^{th} path, τ_{rms} is constant and T_s is the sampling period of the system. The entire system can be described by the following expression:

$$Y=XH+N \tag{2}$$

In equation 2, X and Y are the transmit signal and the receive signal vector. H is the channel fading factor vector $[h_1,h_2,\cdots h_{N-1}]^T$, $h_l=G(\frac{l}{NT_s})$, $G(\cdot)$ is the Fourier transform. N is independent identically distributed Gaussian white noise with zero mean and the variance σ^2. The noise N and the channel characteristics H are irrelevant.

The Novel Channel Estimation based on the ELM

A frame of signal is composed N_L OFDM symbols. Each OFDM symbol contains N sub-carriers, wherein N_p is the number of pilot sub-carriers. OFDM symbols employ the comb pilot pattern, and the pilot interval is I_f. A frame data expressed as:

$$X(m,n)=\begin{cases}X(m_1,n), m_1=1,...,N_p\times I_f\\ X(m_2,n), m_2=N_p\times I_f+1,...,N\end{cases} \tag{3}$$

In equation 3, $n=1,2,...,N_L$. Based on the general, the follow-up on the channel frequency characteristic are discussed with the n^{th} symbol in a frame as an example.

The ELM is a good learning algorithm with a single hidden layer of feed forward neural networks and rapidly learning [10]. The ELM prediction-based LS estimation algorithm is follow.

Step 1 m' is a pilot sub-carrier position, $m'=k\times I_f+1, k=0,...,N_p-1$. The pilot vector for the n^{th} sent symbol is $X_p=X(m',n)$, and the corresponding received pilot signal is $Y_p=Y(m',n)$. The frequency response of the pilot sub-carriers obtained by LS algorithm can be expressed:

$$\hat{H}_{LS}(m')=X_p{}^{-1}Y_p \tag{4}$$

Step 2 Interpolation function is utilized to obtain the frequency characteristic at first $N_p \times I_f$ sub-carriers $\hat{H}_{LS}(m_1) = f(\hat{H}_{LS}(m'))$, wherein $f(\cdot)$ is the interpolation function.

Step 3 Set the input layer weights ω_i and the bias b_i, $i = 1,..., \hat{N}$. $\hat{N}$ is the number of neurons in hidden layer.

Step 4 Calculate the hidden layer output matrix H and the weights of the output layer β .

Step 5 Predict the frequency characteristic of subsequent sub-carriers by

$$H_{ELM}(x) = \beta \cdot \hat{H}_{LS}(x) \tag{5}$$

Wherein x is the input and $\mathrm{H}_{\mathrm{ELM}}(x)$ is the prediction output.

Low-pass Filter-based Channel Estimation Algorithm

The white Gaussian noise in the noise subspace and the interference between the sub-carriers meet the zero-mean Gaussian distribution, therefore the noise component of the impulse response at pilot meets Gauss process with zero mean which is obtained by the channel estimation algorithm. The impulse response of channel component changes relatively slowly, while the changes in the noise component is very fast, therefore those two components can be separated by IFFT transform, which the noise component who rapid changes can be filtered off [11, 12].Based on subspace theory, a low-pass filter channel estimation algorithm is put forward. The algorithm is on the basis of known channel frequency characteristic, by analyzing the characteristics of the signal subspace and the noise subspace, and wherein the noise is filtered off, so that the information component of the channel will be retained. Based on ELM channel estimation algorithm, the performance of the L-ELM algorithm should has high improvement.

After IFFT transform, $H_{ELM}(i)$ can be expression at transform domain:

$$h_{ELM}(k) = \sum_{i=1}^{N} H_{ELM}(i) e^{-j\frac{2\pi}{N}ik} \tag{6}$$

Where k = 1, 2, ..., N.

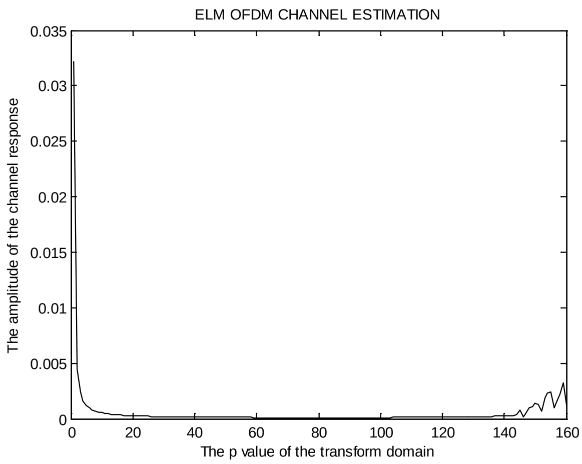


Fig.2. The Channel Characteristics of the Transform Domain

As can be seen from Figure 2, wherein the signal component is mainly concentrated near to the low frequency and the noise components are distributed in the entire frequency band, so after the signal passes through the low-pass filtering, the noise component can be filtered off, while the signal component is retained. The steps of the L-ELM algorithm are as follow:

Step 1 According to the equation 5, the frequency characteristic at n^{th} moment of the channel is calculated;

Step 2 According to equation 6, the channel characteristics at n^{th} moment in the transform domain is obtained, wherein the impulse response of channel component is mainly concentrated on the front of L sampled values and the other for the noise component;

Step 3 Through a low-pass filter, the noise component of the channel characteristics obtained at step 2 is filtered off;

$$\dot{h}_{L-ELM}(k)=\begin{cases} h_{ELM}(k), 1\le k\le K; \\ 0, \qquad\qquad Others \end{cases} \tag{7}$$

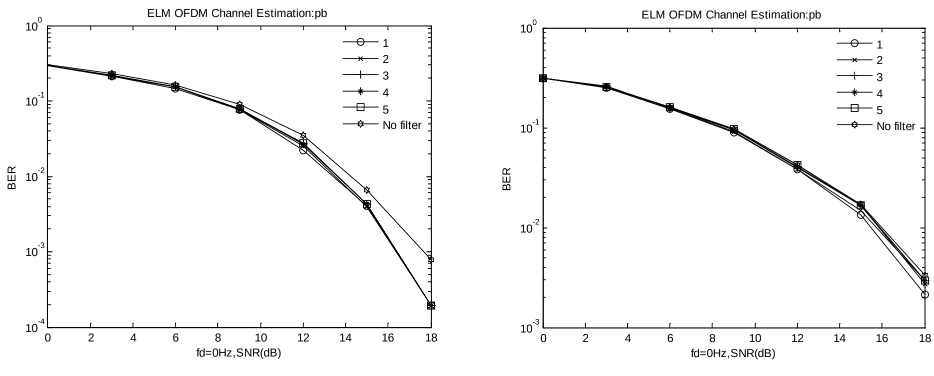
Wherein, K is the cutoff frequency of the low pass filter at the transform domain. By filtering the noise component is reduced to the K / N times original.

Step 4 The new channel characteristics in transform domain at n^{th} moment obtained at step 3 will be transformed by FFT, which replaces the original frequency response of the frequency response and the corresponding data estimated value is draw.

Simulation Results Analysis

In order to verify the effectiveness of the algorithm, the channel estimation algorithm based on the ELM and subspace theory is proposed in the paper for the simulation. Taking into account the subway operating in tunnel environment, OFDM system simulation conditions are as follows: the modulation uses 16QAM. The simulation frequency set 2.4 GHz, while the bandwidth is 1MHz. The sub-carrier spacing is 7.8125 kHz. The sum of sub-carriers is 128 while the length of cp is 16. One OFDM symbol length is 128μs, and then the CP length t_{cp} is 16μs. The channel includes 5 diameters [13], while the power delay spectrum is the negative exponential distribution $e^{-\tau_l/\tau_{rms}}$, wherein τ_l is the l^{th} path delay, $\tau_{rms}=\frac{1}{4}t_{cp}$.

Figure 4 shows the BER performance curve of a different cutoff frequency of the low-pass filter to take and L-ELM algorithms with the Ratio of Signal to Noise (SNR), wherein the horizontal and vertical coordinates respectively represent SNR and BER. The CP length is 16. It can be seen from Figure 2 that low-pass filter cutoff frequency should be less than the CP length. As can be seen from Figure 3, when the cutoff frequency set 1, the BER is the smallest by changing the Doppler frequency from 0 Hz to 178 Hz (correspond to the speed of 80 km / h of the train). For the same conclusion can be obtained when the Doppler frequency shifts among the range of 0-300 Hz, this conclusion is robust.



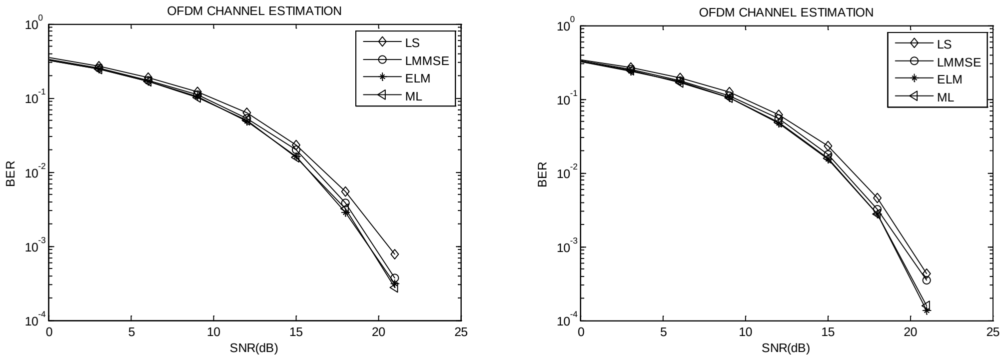
(a) The Doppler frequency f = 0Hz (b) The Doppler frequency f = 178Hz

Fig.3. Doppler shift L-ELM algorithm under the BER performance comparison curves

Figure 4 shows the BER performance of the LS algorithm, the LMMSE algorithm, the L-ELM algorithm and the ML algorithm. The curve changes with the SNR. Maximum of the Doppler shift is set to 178 Hz (correspond to the subway train speed of 80 km / h). The pilot spacing meets the sampling law as follow:

$$I_f \le \frac{1}{2}(\frac{1}{\Delta f\times\tau_{\max}})=\frac{1}{2}(\frac{10^3}{7.8125\times 16})=4 \tag{8}$$

The worst BER performance of the LS algorithm can be seen from Figure 4, while the BER performance of the LMMSE algorithm is followed. When the pilot interval is 4(in accordance with the sampling law), its BER performance of the L-ELM algorithm is little difference from the LMMSE algorithm, but when pilot interval is 8 (violation sampling law), its performance was significantly better than the previous two algorithms especially with the SNR increase.



(a) The pilot spacing is 4 (b) The pilot spacing is 8

Fig.4 BER performance curve of LS, LMMSE, ML and L-ELM algorithm

Conclusion

In order to improve the performance of channel estimation algorithm of OFDM system in tunnel environment, this paper presents novel channel estimation algorithm based on prediction theory: L-ELM channel estimation algorithm. Firstly, those algorithms obtain the channel frequency characteristic at preorder sub-carriers by using fewer pilots, and then use the ELM to predict the channel frequency characteristic at the subsequent sub-carriers. Then, after the characteristic of channel estimation value in transform domain has been obtained by FFT characteristic analysis, noise components are separated from the channel characteristic components by being passed through a low-pass filter, thereby the estimate properties has been effectively improved. The results based on those simulations are follow: under the conditions of in violation of the sampling theorem, the performance of channel estimation by using the prediction theory with fewer pilot signal is better than the typical interpolation algorithm, which improves the efficiency of the transmission system; Under the condition of delay in each path power spectrum conditions obeying negative exponential distribution, the BER performance is the minimum when the cut-off frequency of the low-pass filter sets 1, which the conclusions are robust by exam. The channel estimation and signal detection technique can also constitute a joint iterative receiver technology, so as to further improve the performance of wireless communication receiver.

Acknowledgement

This paper is supported by Key Laboratory of Specialty Fiber Optics and Optical Access Networks, Shanghai University of China, and a research grant from the National Natural Science Foundation (No.61132003, No. 61171086, No. 51267005) of China, Shanghai Leading Academic Discipline Project (No.S30108), Jiangxi Province Science Foundation for Youths (20142BAB217008) and Foundation of East China Jiaotong University (14DQ01).

References

[1] Karimi O B, Liu J, Wang C. Seamless Wireless Connectivity for Multimedia Services in High Speed Trains. IEEE Journal on Selected areas in communications.2012, 30 (4):729-739

[2] He L L, Wu Y C, Ma S D, et al. Superimposed Training-Based Channel Estimation and Data Detection for OFDM Amplify-and-Forward Cooperative Systems under High Mobility. IEEE Transactions on Signal Processing, 2012, 60 (1): 274-284.

[3] Li H, Jan W M B, Frans M J W. Low-Complexity LMMSE-Based MIMO-OFDM Channel Estimation Via Angle-Domain Processing. IEEE Transactions on Signal Processing, 2007, 55 (12) :5668-5680.

[4] Hung K C, Lin D W. Pilot-Based LMMSE Channel Estimation for OFDM Systems With Power-Delay Profile Approximation. IEEE Transactions on Vehicular Technology, 2010, 59 (1):150-159.

[5] Sun J C, Zheng C X, Zhou Y T, et al. Channel Estimation Algorithm of OFDM System Based on RLS-SVM. Journal of System Simulation, 2009, 21 (13):4009-4013.

[6] WU D X, FAN W P. A New Channel Estimation Method based on Pilot-aided and Local Adaptive Least Squares Support Vector Regression in Software Radio OFDM System. In: International Joint Conference on Artificial Intelligence. Los Alamitos: IEEE Computer Society, 2009. 349-352.

[7] Liu H Y, Sun J C, Gong Z W. Based on wavelet kernel recursive least square support vector machine OFDM channel estimation algorithm. Systems Engineering and Electronics, 2007,29 (9), 1249-1253.

[8] Muralidhar K, Li K H. A Low-Complexity Kalman Approach for Channel Estimation in Doubly-Selective OFDM Systems. IEEE Signal Processing Letters, 2009, 16 (7) :632-635.

[9] Cheng L B. An Improved LMMSE Channel Estimation Method and Its Performance Analysis. ACTA ELECTRONICA SINICA, 2008,36 (9) :1782-1785.

[10] Huang G B, Zhu Q Y, Siew C K. Extreme learning machine: Theory and application. Neuro computing, 2006,70(1/2/3) :489-501.

[11] Wang J K, Wang X, Xu P. High-Accuracy OFDM Channel Estimation Algorithm of OFDM Systems. Journal of Northeastern University: Natural Science, 2011, 32 (1):32-35.

[12] Li S P, Li X. OFDM channel estimation based on DFT decision threshold method. Journal of Computer Applications, 2011, 31 (12):3230-323.

[13] Jia M H. The subway tunnel environment millimeter wave propagation characteristics: [PhD thesis]. Shanghai: Shanghai University, College of Communication and Information Engineering, 2010.81-88