Multipath Delay Estimation by Jammed Pilot in OFDM System

XIA LEI[1], *MAOZHU JIN*[2,*], *SHIQING LIN*[1] *and PEIYU REN*[2]

[1] National Key Laboratory of Communications, University of Electronic Science and Technology of China, Chengdu, 610054, P.R. China
[2] Business School of Sichuan University Chengdu, 610065, P.R. China

Received: Jul 26, 2011; Revised Oct. 15, 2011; Accepted Jan. 22, 2012

Abstract: This paper studies orthogonal frequency-division multiplexing (OFDM) system channel estimation problem in the interference environment and the channel delay estimation algorithm is proposed. The algorithm consists of the narrowband interference detection and suppression and channel time delay estimation. First of all, this paper studied the statistical characteristics of channel frequency domain response value at pilot tones, use double threshold consecutive mean excision (CME) algorithm, to detect the interference of pilot subcarriers and interference suppression. Then, the authors analyze the channel frequency response mathematical model and alternating notch periodogram (ANP) spectral estimation method is used to obtain the channel time delay estimation value. The simulation results show that the use of this improved channel estimation algorithm very close to the performance of the Expectation Maximization (EM) channel estimation algorithm with ideal channel delay for channel estimation algorithm performance and BER performance and the delay is known.

Keywords: OFDM, Channel estimation, Alternating notch periodogram, Multipath delay estimation.

1. Introduction

Orthogonal frequency division multiplexing (OFDM) has recently been widely used in wireless communication [1]. Only in the presence of thermal noise, channel estimation methods can be roughly divided into blind (or semi-blind) [2,3] and pilot based channel estimation algorithm [4–7]. For the blind (or semi-blind) transmits data utilizing the inherent information to get the channel estimation value. This algorithm does not need extra bandwidth, high utilization of the spectrum, but its computational complexity is high, and the flexibility is not high, it was limited in using.

Based on pilot channel estimation algorithm uses the information of the sender and receiver are known pilot, the pilot sub-carriers at the channel frequency-domain estimates.

The estimated values of time-frequency two-dimensional interpolation, and get all the sub-carrier at the channel frequency domain estimates. Such method has good estimation performance and computational complexity than blind (or semi-blind) estimation method low.

However, these algorithms in the pilot subcarriers subject to interference, especially interference signal power, the channel estimation value and the true channel frequency response between the estimation error cannot be ignored, the estimation error along with when the frequency of two dimensional spread to the interpolated data subcarrier channel estimation value, and ultimately lead to the deterioration of the OFDM system performance [8].

The OFDM system channel estimation techniques under interference environment including joint interference detection and channel estimation method [8–10] and based on the Expectation Maximization (EM) channel estimation [11–17].

Joint interference detection and channel estimation often require some with the interference position in two adjacent OFDM symbols to maintain constant and continu-

---

[*] Corresponding author: e-mail: jinmaozhu@scu.edu.cn.

ous interfere with sub-carrier occupied bandwidth should be less than the coherence bandwidth of the channel, thus limiting its application.

Based on the EM channel estimation method is applied more widely, but its requirement for the channel time delay is known, the interference in the environment will also be a challenge.

Aiming at this problem, this paper proposes the use of alternating notch periodogram (ANP) spectral estimation method and the interference suppression technology of interference environment, the channel time delay estimation based on EM channel estimation method, which has a more widespread application.

2. Typical OFDM system channel estimation technologies under the environment of interference

Only considering the thermal noise, basic methods of the channel estimation generally can be divided into the blind (or semi-blind) channel estimation algorithm [2,3] and the channel estimation algorithm based on pilot [4–7].

For the blind (or semi-blind) channel estimation algorithm, it uses the internal information of transmission data to obtain the estimated value of the channel. Such an algorithm does not require additional system bandwidth, and the spectrum has a high efficiency. But its high computational complexity and low flexibility lead to having limitation in application.

The channel estimation algorithm based on pilot uses the information of the sender and receiver having known the pilot information to the channel frequency-domain estimation of the pilot sub-carriers. Use the estimated values to make two-dimensional interpolation of time-frequency, and get the channel frequency-domain estimation of all the sub-carrier. Such method has a good estimation performance and computational complexity is lower than blind (or semi-blind) estimation method.

About the channel estimation algorithm based on pilot, when the pilot sub-carrier is subjected to interference, the channel estimation value of the pilot sub-carrier obtained from the pilot signals contains the true channel frequency response and the interference signal; when the power of the interference signal is larger, there is a no ignorable estimation error between the channel estimation value and the true channel frequency response. The estimation errors with two-dimensional interpolation of the time-frequency spread to the channel estimation value of data sub-carrier, and finally lead to the performance of the OFDM system deteriorating.

In this paper, the channel estimation method is based on pilot channel estimation method. For the convenience of description, the definition of the total number of sub-carriers of the OFDM system is N, adjacent to the pilot sub-carrier interval is m, the total number of pilot subcarriers in an OFDM symbol is K.

At the sending end, the pilot signal and data signal with the mapping to the sub-carrier for the fast Fourier transform (Inverse Fast Fourier Transform IFFT), add the cyclic prefix, the CP sent by the sender. Assume that the CP length $L_{CP} \geq L$, L is the order of the discrete multipath channel.

In the slowly varying channel, time domain channel impulse response vector $\mathbf{h} = [h(0), h(1), ..., h(L-1)]^T$ remain unchanged within several OFDM symbol duration, so the $H(p)$ can be expressed as follows

$$H(p) = \sum_{l=0}^{L-1} h(l) \exp\left(\frac{-j2\pi\tau_l mp}{NT_s}\right), 0 \leq p \leq K-1 \qquad (1)$$

where τ_l is multipath delay and T_s is sampling time.

Write (1) as matrices:

$$\mathbf{H} = \mathbf{Q}\mathbf{h} \qquad (2)$$

where $\mathbf{Q}$ is a $K \times L$ matrix, whose (p, l) entry is

$$(\mathbf{Q})_{p,l} = \exp\left(-j2\pi\tau_l\left(mp + \mathit{\Delta}\right)/\left(NT_s\right)\right), 0 \leq l \leq L-1 \quad (3)$$

At the receiving end, the received the n OFDM symbols to CP after Fast Fourier Transform (FFT), get each sub carrier frequency signal, wherein a pilot subcarrier signal with $Y(p, n)$, then $Y(p, n)$ can be expressed as,

$$Y(p, n) = H(p)A(p, n) + I(p, n) + W(p, n) \qquad (4)$$

$$p = 0, 1, ...K - 1$$

The $H(p)$ expressed in the p pilot subcarriers position of channel frequency domain response, $A(p)$ said the pilot symbols itself. $I(p, n)$ is part of band interference in the n OFDM symbol of the number k sub-carrier of the frequency domain representation, and hypotheses in interference in$I(p, n)$ subcarriers, with a mean of zero, σ_I^2 variance for the Gauss distribution, without disturbing the subcarriers, $I(p, n) = 0$. $W(p, n)$ said additive white noise, with a mean of zero, σ_I^2 variance for the Gauss distribution. The Eq.(4) both sides at the same time divided by $H(p)$, the subcarrier channel frequency response estimate for $H(p)$:

$$\hat{H}(p) = H(p) + \frac{I(p, n) + W(p, n)}{(p)} \qquad (5)$$

Eq. (4) and Eq. (5) are written in matrix form

$$\mathbf{Y}(n) = \mathbf{A}\mathbf{H} + \mathbf{I}(n) + \mathbf{W}(n) \qquad (6)$$

$$\hat{\mathbf{H}} = \mathbf{H} + \mathbf{A}^{-1}\left(\mathbf{I}(n) + \mathbf{W}(n)\right) \qquad (7)$$

which is a diagonal matrix, its diagonal elements by a local guide frequency of the signal vector $[A(0), ..., A(K-1)]^T$.

2.1. *Joint interference detection and channel estimation method*[9]

In the slow varying channel it can be considered to remain the same channel in two adjacent OFDM symbols duration. That is $H(p, n) \approx H(p, n+1)$. The main steps of these algorithms are divided into three parts [9].

- Use the pilot frequency information of two adjacent OFDM symbols, and get the information related to interference; use detection algorithm to obtain the position of interference sub-carrier.
- The channel frequency domain response at the interference sub-carrier should be compensated. The compensation method can be make the channel information at the adjacent pilot sub-carrier directly as the channel estimated value at the interference sub-carrier, or use the channel information of the adjacent guide frequency sub-carrier and the interpolation algorithm to get the channel frequency response at the interference sub-carrier.
- Use the interpolation algorithm and let the channel frequency response at the processed pilot sub-carriers through time-frequency two-dimensional interpolation to get the channel frequency domain response at all sub-carriers. And the interpolation algorithms can be but the linear interpolation, cubic interpolation, DFT interpolation and so on. In the case of interference-free environment, the difference of the channel frequency response between the two adjacent OFDM symbol pilot sub-carrier is [9]:

$$\begin{aligned} \varDelta\hat{H}(p) &= \hat{H}(p,n) - \hat{H}(p,n+1) \\ &= \frac{W(p,n)}{A(p,n)} - \frac{W(p,n+1)}{A(p,n+1)} \end{aligned} \tag{8}$$

As reference [9], $\varDelta\hat{H}(p)$ obeys the complex Gaussian distribution ,that is, mean is 0 and variance is $2\sigma_w^2/|A(p)|^2$. Meanwhile the estimated value of Gaussian white noise variance is:

$$\hat{\sigma}_w^2 = \frac{1}{\hat{\lambda}} = \widehat{E}\{D(p)\} = \frac{1}{K}\sum_{p=0}^{K-1} D(p) \tag{9}$$

And where,

$$D(p) = |A(p)|^2 \left|\varDelta\hat{H}(p)\right|^2/2 \tag{10}$$

While in the case of interference, there is a large deviation in the Gaussian noise variance estimation getting from above formulas. At this point, it can use the order statistics of $D(p)$ to solve. Rank the sequence $\{D(p)\,|0 \le p \le K-1\}$ in ascending order, and obtain the new sequence $\left\{D_{(p)}\,|0 \le p \le K-1\right\}$. Take the front r_d, $0 \le r_d \le K-1$ order statistics and its joint probability density as follows:

$$\begin{aligned} &\phi(d_{(1)}, d_{(2)}, ..., d_{(r_d)}) \\ &= \frac{(K)!}{(K-r_d)!}[1 - F(d_{(r_d)})]^{(K-r_d)} \prod_{i=1}^{r_d} f(d_{(r_i)}) \end{aligned} \tag{11}$$

Take the logarithm for both sides of the equation (11) and by Derivation. Thus obtain the maximum likelihood estimates of $\hat{\sigma}_w^2$:

$$\hat{\sigma}_w^2 = \frac{1}{\hat{\lambda}} = \frac{(K-r_d)}{r_d} D_{(r_d)} + \frac{1}{r_d}\sum_{i=1}^{r_d} D_{(i)} \tag{12}$$

The reference [9] shows that the false alarm probability of statistics $D(p)$ is:

$$p_{FA} = \left(1 + \frac{\gamma}{r_d}\right)^{-r_d} \tag{13}$$

where $\gamma$is for a threshold factor. Give the fixed false alarm probability (p_{FA}), and obtain value of the corresponding $\gamma$by it. Take the threshold as flow:

$$T = \gamma\hat{\sigma}_w^2 \tag{14}$$

According to the threshold value $D(p) \ge T$, the pilot sub-carrier is considered to be subject to interference, or not.

For channel estimates of part with interference's pilot sub-carrier do the following to restore:

$$\tilde{H}(p) = median(\hat{H}(n), n = p-t, ..., p+t) \tag{15}$$

where $median\,(.)$ is for median, and $C = 2t + 1$ is for the filter window of the conditioned median.

The computational complexity of the method proposed in [9] is low, and under certain assumptions, it can effectively eliminate the impact of the part with interference to the channel estimation:

- The part with interference position remains unchanged in the two adjacent OFDM symbols;
- The share of bandwidth of the sub-carrier with continuous interference should be less than the coherence bandwidth of the channel;
- The ratio of the channel multi-path delay τ_l and the system sampling time T_s is an integer. And the adjacent pilot sub-carrier interval between the sub-carriers m, the number of sub-carrier, and the OFDM symbols of the total number of pilot sub-carrier are to satisfy the following relationship: $N = mK$;

If the equation (1) is not satisfied, it will lead to the detected pilot sub-carrier with interference more than the actual number and a false alarm will come out; If the equation (1) is not satisfied, the channel frequency response at the pilot sub-carrier with interference can not be an effective recovery, which will directly affect the subsequent DFT interpolation performance; If the equation (3) is not satisfied, make the point of K inverse transform of discrete Fourier for the sequence $\left\{\tilde{H}(p)\,|0-1\right\}$, and thus, the time domain impulse response $h(l)$ of the effective diameter has been broadening. The noise path also contains a part of the energy of the $h(l)$, which brings difficulty to multi-path decision, resulting in the degradation of the DFT interpolation performance.

2.2. *EM Algorithm*[13]

EM Channel estimation method uses the previous channel impulse response (CIR) estimated value and receives the pilot information, to get an estimated value of the interference signal and noise variance. Use the estimated value, according to LS or minimum mean square error MMSE criterion, and obtain the current iterative channel estimation. Do iteratively until the system performance to convergence or to the number of iterations.

Convenient for the description, definition [13]:

$$\sigma^2(p) = \begin{cases} \sigma_w^2 + \sigma_I^2, & jammed\ \ pilot \\ \sigma_w^2, & others \end{cases} \qquad (16)$$

Given the unknown parameters $\left(\mathbf{h}, \sigma^2\right)$, from Eq. (6) shows that, $\{\mathbf{Y}(n)\}$ normal distribution with mean for $\mathbf{AH}$, the covariance matrix $\mathbf{C} = diag\left\{\sigma^2(p), 0 \le p \le K-1\right\}$ Gaussian distribution, the joint distribution density function is:

$$p\left(\mathbf{Y}\left|\mathbf{h}, \sigma^2\right.\right) \qquad (17)$$

$$= \prod_{p=0}^{K-1} \frac{1}{(\pi\sigma^2(p))^M} \exp\left(-\frac{1}{\sigma^2(p)} \sum_{n=1}^{M} Z_n(p, \mathbf{h})\right)$$

where M is the number of selected OFDM symbol, and assume that the M symbol duration, $\mathbf{h}$ remain unchanged, $Z_n(p, \mathbf{h})$ is

$$Z_n(p, \mathbf{h}) = Y(p, n) - A(p)H(p) \qquad (18)$$

[13] assume that $\sigma^2(p)$ is a random variable, and obey The inverse-gamma distribution, its probability density function is:

$$p\left(\sigma^2\right) = \frac{\lambda}{\sigma^2} \exp\left(-\frac{\lambda}{\sigma^2}\right), \sigma^2 > 0 \qquad (19)$$

Using Eq. (17) and Eq.(19), [13] simplifies the edge likelihood function

$$\Phi(\mathbf{h}) = -\sum_{p=0}^{K-1} \ln\left(\lambda + \sum_{n=1}^{M} |Z_n(p, \mathbf{h})|^2\right) \qquad (20)$$

You can use the EM algorithm for solving of h, the maximum likelihood solution [13].

$$\hat{\mathbf{h}}_{MLE} = \arg\max_{\mathbf{h}} \{\Phi(\mathbf{h})\} \qquad (21)$$

It is worth noting, the algorithm presented in the paper [13] also assumes that the channel multi-path delay is known. However, the channel multi-path delay is unknown or the errors of the true value exist, the algorithm performance will deteriorate. So the channel multi-path delay estimation in robust interference environment is worthy of further study.

3. Narrowband interference detection technology

3.1. Single-threshold CME algorithm

The main idea of the CME (Consecutive mean excision) algorithm [18] is that according to the received signal statistical characteristics, set a reasonable threshold parameter γ. After get the FFT frequency magnitude mean of the received signal, regard the product of the two as the threshold value of the algorithm.

For this Single-threshold detection method, it is often difficult to strike a balance between the detection probability and the false alarm probability. When the threshold is higher, it can be avoided false alarms caused by background noise, but the missed detection event occurred at the same time, when the threshold is lower, false alarm is inevitable.

3.2. Dual-threshold CME algorithm

On account of Single threshold shortcomings, the paper [15] presents dual-threshold algorithm based on the CME. The main steps of the algorithm is as follows:

Initialize: order $m = 1$, take the first M from the sequence $\Phi_m = \{\phi(k)\,|0 \le k \le N-1\}$, and get the lower threshold

$$T_{low}(m) = \gamma_1 \sum_{k=0}^{M-1} \phi(k) \qquad (22)$$

where, the sequence Φ_m get from the sequence $\{|Y(k)|\,|0 \le k \le N-1\}$ in ascending order.

Step 1: Order $m = m + 1$.

Step 2: update the sequence Φ_m as follows

$$\Phi_m = \{|Y(k)|\,||Y(k)| \le T_{low}(m), 0 \le k \le N-1\} \qquad (23)$$

Step 3: Update $T_{low}(m)$

$$T_{low}(m) = \gamma_1 \sum_{|Y(k)| \in \Phi_m} |Y(k)| \qquad (24)$$

Step 4: When the number elements in Φ_m are no longer increasing, go to step 5. Otherwise repeat steps 1-3.

Step 5: Depend on the following formula to get a higher threshold:

$$T_{high} = \gamma_2 \sum_{|Y(k)| \in \Phi_m} |Y(k)| \qquad (25)$$

Compare those the amplitude sequence $\Phi_m = \{|Y(k)|\,||Y(k)| > T_{low}(m), 0 \le k \le N-1\}$, which is greater than the lower threshold, with T_{high}. When the result is greater than T_{high}, the sub-carrier is in interference. Otherwise the sub-carrier is not.

3.3. Detection algorithm based on the minimum threshold selection strategies

Above detection algorithms based on CME all require iterative process, making this kind of algorithm present delays in the process and the iterative process also increases the computational complexity of the system. In order to avoid the false alarms caused by the randomness of the background noise, the paper [16] considers that compute the average of the multiple OFDM symbol, making this mean more reliable. Because of the algorithm needs to assume that the interference suffered by the OFDM symbols of L is not unchanged, when this assumption is not satisfied, the performance of the algorithm will decrease.

4. Channel Multipathdelay Estimation

EM channel estimation method need to predict the channel multipath delay position13. this article will focus on the interference environment, the channel multipath delay estimation.

Without interference, re-writing Eq.(7):

$$\begin{aligned}\hat{\mathbf{H}} &= \sum_{l=0}^{L-1} \Theta(\tau_l) \exp\left(-j\frac{2\pi}{NT_s}\tau_l \Delta\right) h(l) + \mathbf{A}^{-1}\mathbf{W} \\ &= \mathbf{\Theta h}_\theta + \mathbf{W}'\end{aligned} \tag{26}$$

which the vector

$$\mathbf{h}_\theta = \left[h(0)e^{-j2\pi\tau_0\Delta/(NT_s)}, ..., h(L-1)e^{-j2\pi\tau_{L-1}\Delta/(NT_s)}\right]^T \tag{27}$$

Vector

$$\Theta(\tau_l) = [1, ..., \exp(-j2\pi\tau_l q(K-1)/(NT_s))]^T \tag{28}$$

Matrix

$$\mathbf{\Theta} = [\Theta(\tau_0), ..., \Theta(\tau_{L-1})] \tag{29}$$

is KL Order Vandermonde matrix.

It is noteworthy that similar mathematical expression model, Eq. (26) exactly and ANP [17] spectrum estimation. This means that the estimated value of the channel multipath delay $\tau_l (0 \le l \le L-1)$ can ANP spectrum estimation.

Directly according to the ANP, when interference power is strong channel multipath delay estimation will bring great error. Therefore, during the multi-path delay estimates before the deal with $\hat{H}(p)$ contains large interference suppression. Eq. (26) Section p element in $\hat{H}(p)$ can be written as

$$\hat{H}(p) = \sum_{l=0}^{L-1} h(l) \exp\left(-j\frac{2\pi}{NT_s}\tau_l(qp)\right) + \frac{W(p)}{(p)} \tag{30}$$

Without loss of generality, we assume the channel time-domain response of $h(l)$, $0 \le l \le L-1$ obey zero mean, the variance of $\sigma_h^2(l)$complex Gaussian announced, and between $h(l)$ and $h(k)$ independent of each other which the $l \ne k$.Because $W(p)$ distribution with mean 0 and variance of σ_w^2 complex Gaussian distribution, and $W(p)$ and $h(l)$ are independent of each other. $\hat{H}(p)$ also obey complex Gaussian announced its zero mean, variance:

$$\sigma_{\hat{H}}^2(p) = \sum_{l=0}^{L-1} \sigma_h^2(l) + \frac{\sigma_w^2}{|A(p)|^2} \tag{31}$$

Assume that each pilot's modulus values of the symbols is the same everywhere, and everywhere the same, the variance of $\hat{H}(p)$ for any $p, 0 \le p \le K-1$ variable, $\hat{H}(p)$ obey the same distribution. In order to increase the accuracy of the estimates of $\sigma_{\hat{H}}^2(p)$, by averaging all the pilot subcarriers at the $\sigma_{\hat{H}}^2(p)$, $\sigma_{\hat{H}}^2(p)$ is an estimate:

$$\hat{\sigma}_{\hat{H}}^2 = \frac{1}{K}\sum_{p=0}^{K-1} \sigma_{\hat{H}}^2(p) = \frac{1}{K}\sum_{p=0}^{K-1} \left|\hat{H}(p)\right|^2 \tag{32}$$

Use of the CME (Consecutive mean excision) algorithm and improved dual threshold the CME [18], the pilot subcarriers at the channel frequency-domain estimates for the following judgment:

1) Initialization:

Ascending order, the sequence

$$\left\{\left|\hat{H}(p)\right| | 0 \le p \le K-1\right\} \tag{33}$$

get the sequence

$$\{r(p) | 0 \le p \le K-1\} \tag{34}$$

before the sequence is removed, the M value is expressed as

$$\Pi_m = \{r(p) | 0 \le p \le M-1\} \tag{35}$$

where $m = 0$, M is a given constant. Can get a lower threshold, as follows

$$T_{low}(m) = \gamma_1 \sum_{0}^{M-1} r(p) \tag{36}$$

2) Step 1 let $m = m+1$

3) Step 2 Through the following ways to update the sequence Π_m

$$\Pi_m = \{r(p) | r(p) \le T_{low}(m), 0 \le p \le K-1\} \tag{37}$$

4) Step 3 Update $T_{low}(m)$:

$$T_{low}(m) = \gamma_1 \sum_{r(p)\in\Pi_m} r(p) \tag{38}$$

5) Step 4 When no further increase in the number of elements in the Π_m, go to step 5, otherwise repeat steps 1-3;

6) Step 5 Higher threshold according to the following formula:

$$T_{high}(m) = \gamma_2 \sum_{r(p)\in\Pi_m} r(p) \tag{39}$$

Those greater than the lower threshold sequence

$$\Pi_m = \{r(p) | r(p) > T_{low}(m), 0 \le p \le K-1\} \tag{40}$$

T_{high} comparison, that the sub-carrier to be disturbed is greater than T_{high}, or that the sub-carrier interference. Subcarriers, the channel frequency response value is set to a constant guide for these interference. Repeated the above process, you can get an estimate of the channel multipath delay $\hat{\tau}_l$, $0 \le l \le L-1$. Then we can get $\hat{\mathbf{Q}}$ in the Eq. (2) and $\hat{\mathbf{h}}$ by EM algorithm. So

$$\hat{\mathbf{H}}_{all} = \mathbf{F}\hat{\mathbf{h}} \tag{41}$$

where

$$(\mathbf{F})_{k,l} = \exp\left(-j2\pi\tau_l k / (NT_s)\right) \tag{42}$$
$$0 \le k \le N-1, 0 \le l \le L-1$$

5. Simulation Results And Analysis

5.1. Comparing different channel estimation technologies under the environment of interference

OFDM system parameters as is shown in table 1. The channel parameters as is shown in table 2 and $T_s = 2.5 \times 10^{-5} s$. Pilot pattern as is shown in table 3.

Parameters for joint noise variance and channel estimation algorithm [9] as is shown in table 4. And $\lambda = 0.1$, $M = 1$ in EM algorithm.

Table 1 OFDM system parameters

Parameter name	Parameter values
The number of subcarriers N	1024
Modulation mode	QPSK

Table 2 OFDM Channel parameters

Multipath Numbers	Multipath delay(s)	Multipath fading(dB)
1	0	0
2	1×10^{-3}	0

Table 3 OFDM Pilot pattern

Δ	4
Pilot interval m	6
Total Pilot number K	170

Denote Normalized Mean Square Error (NMSE) as

$$NMSE(\mathbf{H}) = \frac{1}{NS}\sum_{s=1}^{S}\sum_{k=1}^{N}\frac{\left|H(k,s) - \hat{H}(k,s)\right|^2}{|H(k,s)|^2} \tag{43}$$

Table 4 OFDM Parameters for joint noise variance and channel estimation algorithm

Parameter name	Parameter values
Detection probability P_d	0.999
False-alarm probability p_{FA}	4.5×10^{-5}
$r_{d,0}$	$K/2$
C	$2\alpha + 1$

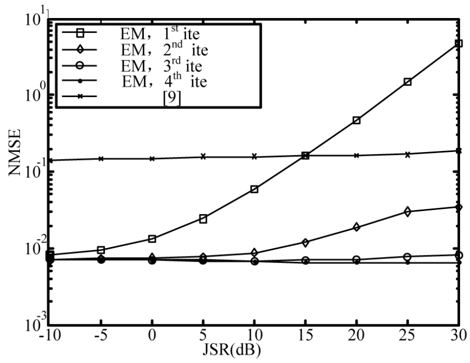

Figure 1 NMSE performance of two algorithms with different JSR.

where $H(q,k)$ is channel frequency responsibility on the kth subcarrier of the sth OFDM symbol. N is the number of total subcarriers and S is the number of total OFDM symbols.

Fig1 compares NMSE performance of EM algorithm and joint noise variance and channel estimation algorithm with different JSR. Where $SNR = 15$dB and the interference is the same between two OFDM symbols. The number of jammed pilot subcarriers is 5. Fig 3 shows the performance of the joint noise variance and channel estimation algorithm [9] is worse than EM algorithm [13] due to $N \neq mK$.

Fig2. compare NMSE performance of two algorithms with different number of jammed pilot subcarriers. Where $SNR = 15$dB and $JSR = 10$dB. Because $r_d = 50$ with joint noise variance and channel estimation algorithm, when the number of jammed pilot subcarriers is more than 120, the performance will significantly decreased.

5.2. Comparing different Narrowband interference detection technology

OFDM system parameters as is shown in table 1. For OFDM systems, the receiving end of received frequency signal because do not meet the above all kinds of part with disturbed detection algorithm of hypothesis conditions, each detection algorithm on the threshold of the parameter selection can only rely on experience value. But these algorithm

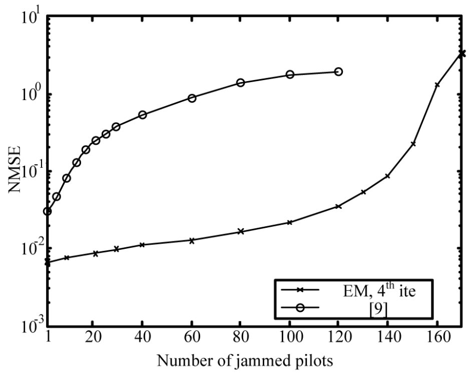

Figure 2 NMSE performance of two algorithms with different number of jammed pilot subcarriers.

testing ideas still stand. In emulation, threshold parameters in Single threshold CME $\gamma = 2.3$, lower threshold of threshold parameters in double threshold CNE $\gamma_1 = 1.95$, higher threshold of threshold parameters $\gamma_2 = 2.4$, based on the minimum threshold selection strategy detection algorithm $L = 32$, threshold parameters$\gamma = 2.8$. Define interference factors is The ratio of interference bandwidth and system bandwidth, $\rho = 0.1$, and assume that the interference bandwidth for continuous bandwidth.

Define detection probability is equal to detect and actual interference sub-carrier position matching the ratio of the number of sub-carriers of the Interfere and the number of sub-carriers of the actual interference, Define false-alarm probability is equal to the ratio of Be mistaken for disturbed sub-carrier number and not subject to interference sub-carriers.

Fig 3 shows the performance graph of the probability of detection of a variety of partial band interference detection technology with JSR change. Which SNR = 2 dB, disturbed sub-carrier position in the communication process remains unchanged. Figure 4 shows the probability of false alarm performance chart. As can be seen from the graph, A single threshold CME and double threshold CME performance quite, detection algorithm based on the minimum threshold selection strategies because seeking an average of multiple OFDM symbols, avoiding false alarms due to random noise, Improving the interference detection. However, because of this method for more than one symbol for average , making this method of tracking ability of interference change significantly decreased.

As an extreme case, The hypothesis in each OFDM symbol, Interference of sub-carrier at first position are not all the same, Fig. 5 and Fig. 6 shows the diagram of this case, The Performance figure of Various detection algorithm with JSR change. Which SNR = 2 dB. May be evident from the figure, Rapid deterioration of selection strategies based on the minimum threshold detection algorithm performance, This is due to the algorithm is an average of more than one OFDM symbol that decline the ability of the algorithm on interference tracking. There is almost no change in the performance of other algorithms.

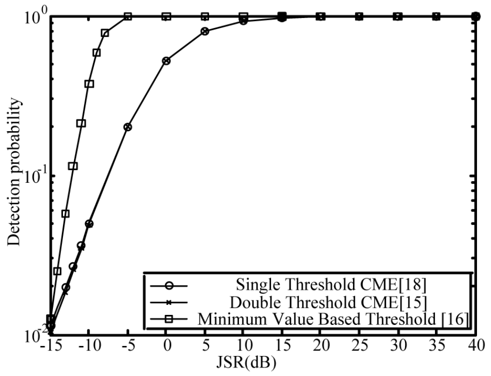

Figure 3 Kinds of interference detection algorithm detect probability performance in different JSR: interference with the same location.

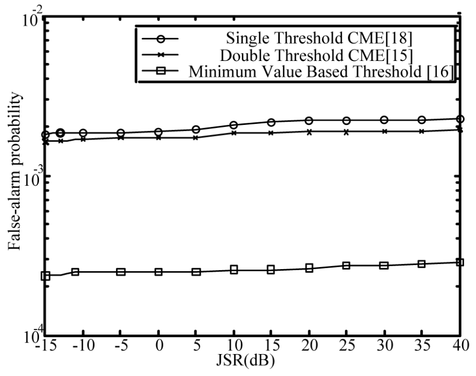

Figure 4 Kinds of interference detection algorithm detect False-alarm probability performance in different JSR: interference with the same location.

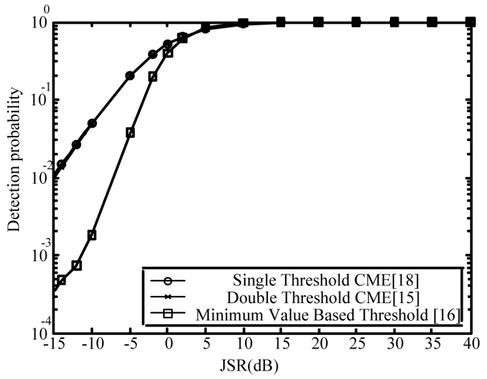

Figure 5 Kinds of interference detection algorithm detect probability performance in different JSR: Interference position random changes.

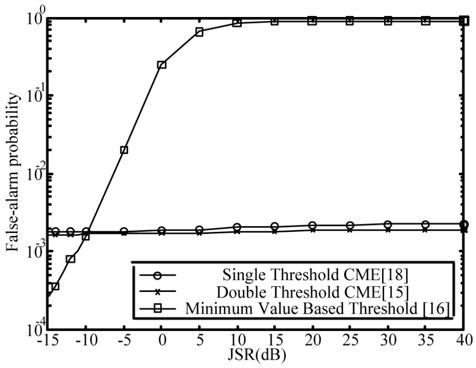

Figure 6 Kinds of interference detection algorithm detect False-alarm probability performance in different JSR: Interference position random changes.

5.3. *The performance comparison of the multipath delay estimation algorithm*

Baseband OFDM system parameters shown in Table 1. Channel parameters such as shown in Table 2, the pilot pattern using the comb pilot, as shown in Table 3.

The lower threshold (17) (20) of the parameter $\gamma_1 = 2.42$, the higher threshold parameter $\gamma_2 = 3$.

Fig. 7, Fig. 8 gives the diagram of the NMSE performance of the improved EM channel estimation algorithm with the JSR and SNR change, in which the interference pilot subcarriers and subcarriers to five continuous conduction, the ideal reference channel normalized delay known case of Fig. 7, SNR = 15dB, Fig. 2, JSR = 15dB.

It can be seen from the figure, the methods and channels normalized delay known under the EM estimation method performance is closer.

From Fig. 8, the method in the case of high SNR performance platform, this is due to the normalized time delay estimation there is a performance platform in the channel under the interference environment.

Fig. 9 shows the interference environment, the use of improved EM channel estimation algorithm for channel estimation in OFDM system BER performance chart, known maximum likelihood channel estimation system BER performance and delay due to the interference-free environment using the EM channel estimation algorithm of the system BER performance is almost the same, so the diagram will omit. From the figure, the improved EM channel estimation algorithm of the system BER performance very close to the BER performance and interference.

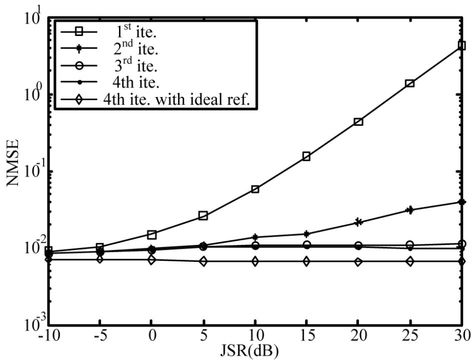

Figure 7 Improved EM channel estimation NMSE performance changes with the JSR.

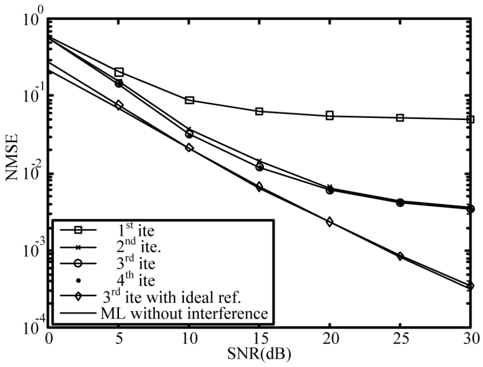

Figure 8 Improved EM channel estimation NMSE performance with SNR change.

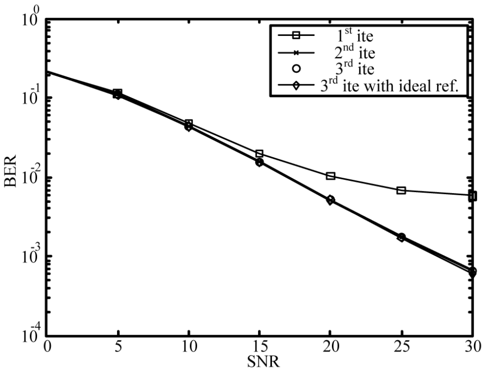

Figure 9 BER performance of OFDM system using improved EM channel estimation method.

6. Conclusion

This paper presents an interference environment, the channel time delay estimation algorithm. Analysis research pilot at the channel frequency response value of statistical properties, we use dual threshold CME algorithm to be strong interference suppression. Using Alternating Notch Periodogram (ANP) algorithm, we can get path delays of channel. Simulation results show that the channel this article to obtain a more accurate delay estimation, and can get very close to the ideal delay performance.

Acknowledgement

This work was supported by the National Science Foundation of China under Grant number 61032002, 71001075, 71020107027 and 60902026, Chinese Important National Science Technology Specific Projects under Grant 2011ZX 03001-007-01, Program for New Century Excellent Talents in University, NCET-11-0058.

References

[1] Y. H. Kim, I. Song, H. G. Kim, T. Chang and H. M. Kim, Performance analysis of a coded OFDM system in time-varying multipath Rayleigh fading channels, IEEE Trans. VT, 48(5)(1999)1610 -1615.

[2] N. Chen and G.T. Zhou, What is the price paid for superimposed training in OFDM, IEEE International Conference on Acoustics, Speech, and Signal Processing, (2004), May 17-21; Quebec, Canada 421-424.

[3] John E. Kleider, G. Maalouli and S. Gifford, et al. Preamble and embedded synchronization for RF carrier frequency-hopped OFDM, IEEE JSAC, 23(5)(2005) 920-931.

[4] S. Coleri, M. Ergen, A. Pury, etc., A study of channel estimation in OFDM systems, IEEE VTC2002-fall, (2002)October 7-10 ; Vancouver, Canada, 894-898.

[5] M. Garcia, J. P. Borrallo and S. Zazo., DFT based channel estimation in 2D-pilot-symbol-aided OFDM wireless systems, IEEE VTS2001, (2001) May 6-9; Rhodes, Greece, 810-814.

[6] L. J. Cimini. Analysis and simulation of a digital mobile channel using orthogonal frequency division multiplexing, IEEE Trans. on Communications, 33(7)(1985)665-675.

[7] B. Yang, B. L. Khaled and R. Cheng, et al. Channel estimation for OFDM transmission in multipath fading channels based on parametric channel modeling, IEEE Trans. on Communications, 49(3)(2001)467-479.

[8] M. Han, T. Yu and J. Kim, et al., OFDM channel estimation with jammed pilot detector under narrow-band jamming, IEEE Trans. on Veh. Technol., 3(57)(2008)1934-1939.

[9] D. Wang, L.D. Jiang and C. He, Robust noise variance and channel estimation for SC-FDE UWB systems under narrowband interference, IEEE Trans. on Wireless Comm., 8(6)(2009)3249-3259.

[10] T.T lin, F.H. Huang, Robust channel estimation with strong interference detector for OFDM systems, The 13th IEEE International Symposium on Consumer Electronics (ISCE2009), (2009) May 25-28; San Diego, US, 641-644.

[11] V. K. Jones, J. leary and J. M. Gardner, OFDM channel estimation in the present of interference, U.S. Patent 6487253, NOV 26 (2002).

[12] M. Ghosh and V. Gaddam, Joint channel and noise variance estimation in a wideband OFDM system, U.S. Patent 7352730, APR 1 (2008).

[13] M. Morelly and M. Moretti, Channel estimation in OFDM systems with unknown interference, IEEE Trans. on Wireless Comm., 8(10)(2009) 5338-5347.

[14] M. Morelly and M. Moretti, Channel estimation in OFDM systems with unknown interference, IEEE Trans. on Wireless Comm., 8(10)(2009) 5338-5347.

[15] C.J. Xia, J.P. An, Y.Z. Guo, etc., Improved suppression algorithm of digital narrowband interference in FFT domain, IEEE International Conf. on Wireless Commun., Networking and Mobile Computing, Sept. 2007, (2007)1036-1039.

[16] S. Wang, J. P. An, A. Hua, etc., A Minimum Value Based Threshold Setting Strategy for Frequency Domain Interference Excision, IEEE Signal Processing Letters, May, 17(5)(2002) 501-504.

[17] J. K. Hwang, Y. C. Chen, Super resolution Frequency Estimation by Alternating Notch Periodogram, IEEE Trans. SP, 41(2)(1993) 727-741.

[18] P. Henttu and S. Aromaa, Consecutive mean excision algorithm, IEEE 7th Int. Symp. On Spread-Spectrum Tech. Appl., (2002) Sept 2-5; Prague, Czech, 2-5.

Xia Lei received her Ph.D. in the Department of Communication and Information Engineering from University of Electronic Science and Technology of China in 2005. Her major research interests are mobile communication, multicarrier techniques, cooperative wireless communications, etc. She has published about more than 40 journal and conference articles in referred journals and conferences. She has often worked as a technical reviewer for journals and conferences. She is an IEEE Member since 2004.

Maozhu Jin received his M.S. degree in the Department of Electronics Science and Technology and Ph.D. in the Department of Business from University of Huazhong Science and Technology, Wuhan, China, in 2005 and 2008, respectively. In April 2009, he joined Business School of Sichuan University, Chengdu, China. His research interests include multi-objective optimization, game theory, service science and supply chain management.