A Modified LS Channel Estimation Algorithm for OFDM System in Mountain Wireless Environment

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Abstract

Orthogonal frequency division multiplexing (OFDM) is a transmission technique that is based on many orthogonal carriers that are transmitted simultaneously. OFDM effectively mitigates inter symbol interference (ISI) and has high-efficient frequency utilization. OFDM channel estimation is one of the key technologies in the OFDM system. In this paper, channel estimation techniques for OFDM systems, based on pilot-aided channel estimation algorithm, over mountain wireless environment are investigated. It is well known that least square (LS) and linear minimum mean square error (LMMSE) algorithms are effectual channel estimation methods for OFDM. We propose a novel modified LS channel estimation method, which is based on noise reduction procedure to improve the channel estimation accuracy. The simulation results demonstrate that comparing to LS channel estimation algorithm, LMMSE algorithm and the proposed modified LS algorithm provide better performances.

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Keywords: mountain wireless environment; OFDM; channel estimation algorithm; modified LS algorithm

1. Introduction

In mountain wireless environment, the signal transmission loss and signal fading are bigger than general wireless communication environment. To reduce the radio wave propagation loss and ensure the quality of wireless communication, very high frequency (VHF) is usually been used in mountain wireless frequency environment. Due to the limited spectrum resources, ultra-high frequency (UHF) is also been used. Mountain wireless communications have been the focus of communication workers all the time. Orthogonal frequency-division multiplexing (OFDM) is an efficient, high data-rate transmission technique for mobile and wireless communication. OFDM presents advantages of high-bandwidth

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efficiency, simple and efficient implementation by the application of the fast Fourier transform (FFT) and the inverse fast Fourier transform (IFFT), reduction of inter symbol interference (ISI) by inserting cyclic prefix (CP), and robustness to multi-path fading and delay [1–3].

Channel estimation technique is one of the key techniques in OFDM system. Until now there are three feasible methods in OFDM channel estimation, which are blind channel estimation, semi-blind channel estimation and pilot-aided channel estimation. Among them, the method based on pilot-aided channel estimation is widely used and has a more steady performance. Because the whole system band is divided into a number of independent subcarrier bandwidth which has the same bandwidth, each subcarrier is to transmit its modulated signals [4–5]. Conventional LS and LMMSE algorithms have been discussed in [6]. A simplified LMMSE channel estimation algorithm using Fourier Transform technique and an appropriate training-sequences-aided has been proposed in [7]. Pilot-aided channel estimation for single carrier systems with fading channels has been analyzed in [8]. The purpose of pilot-aided channel estimation is to get the channel state information (CSI) through the pilot sequence.

2. System Model

2.1. The basic structure of OFDM

A typical pilot-aided OFDM system is shown in Figure 1. At the transmitter, data symbols are grouped and mapped into multi-amplitude and multi-phase signals, which are depending on the modulation types. The complex signals are modulated on \( N \) subcarriers by an IFFT. In order to eliminate the effect of ISI, the last \( P \) samples of the OFDM symbol are copied and put into a preamble as the CP. In this research our multicarrier system employs 1024 subcarriers. One OFDM symbol has duration \((N+P)T_s\) where \( T_s \) is the system’s sampling period. Then these symbols are transmitted over a mountain wireless environment, whose impulse response is shorter than the length of the CP.

At the receiver, the CP is removed from the received time-domain samples. And the resulting data are sent to a FFT block to de-multiplex the multicarrier signals.

In the frequency domain, OFDM technology divides the entire transmission channel into several subcarriers so that each subcarrier with a flat fading characteristic, which also effectively overcome the mountain wireless channel frequency selective fading and efficiently reduce ISI on the system performance. To achieve maximum spectral efficiency and increase the spectrum utilization, each subcarrier in OFDM system uses a subcarrier modulation and each one is orthogonal to the other. Meanwhile, OFDM modulation and demodulation (IFFT and FFT) greatly simplify the system implementation complexity.

Each subcarrier of one OFDM symbol can adopt phase-shift keying (PSK) or quadrature-amplitude modulation (QAM). The OFDM symbol can be expressed as

\[
s(t) = \text{Re} \left\{ \sum_{i=0}^{N-1} d_i \text{rect}(t - t_i - T/2) \exp[j2\pi f_i (t - t_i)] \right\}, \quad t_i \leq t \leq t_i + T, \quad s(t) = 0, t < t_i \quad \text{or} \quad t > T + t_i
\]

where \( N \) and \( T \) denote the number of subcarriers and the OFDM symbol length. \( d_i (i=0, 1, \cdots , N-1) \) is the
data symbol which assigns to each subcarrier, and \( f_i \) is the carrier frequency of the \( i \)-th subcarrier, rect \((t) = 1, \ |t| \leq T/2, \ t_i \) is the starting time.

### 2.2. Mountain wireless channel

The wireless channel would constraint the performance of the wireless communication system. In factual wireless channel, the propagation path between the transmitter and receiver is very complex, which includes simple line of sight (LOS) communication, complex terrain objects communication. Unlike the cable channel, which can be fixed and predictable, the wireless channel is a propagation environment which would change with time, environment and other external factors. In mountain environment, where the mountain forests are dense and terrain is complex, the radio wave propagation environment is adverse. The propagation wave might be direct wave, and also might produce a large number of reflection, refraction, scattering and diffraction waves. Therefore, the mountain wireless channel is a relatively poor channel, we need to consider the characteristics of mountain environment, set aside a considerable decline of the margin when design the mountain wireless link.

In this paper we adopt the proposed mountain classic COST-207 channel measured model. The channel model is divided into 6 paths, where the relative delay are 0, 0.1, 0.3, 0.5, 15, 17 (unit: us) and the power attenuation are 0,-1.5,-4.5,-7.5,-8.0,-17.7(unit: dB). The first 4 paths’ Doppler spectrum types are Jakes and the latter 2 paths’ are Gauss II.

### 3. Pilot-aided channel estimation

Channel estimation is using some certain algorithms and methods through all known information to quantitative judge the current CSI. The result of channel estimation can be time-domain channel impulse response (CIR), and can also be the channel frequency response (CFR).

#### 3.1. Least-square (LS) algorithm

Least-squares algorithm in mathematical statistics from the curve fitting. For the OFDM system channel estimation, when only considering the pilot signal, the LS estimation can be expressed as

\[
Y_p(k) = X_p(k)H_p(k) + W_p(k)
\]

(2)

where \( k = m_0, m_1, \ldots, m_{K_p-1} \), \( K_p \) is the number of pilot signal, \( 0 \leq m_i \leq K - 1 \) \( i = 0,1,\ldots, K_p - 1 \). \( X_p \) and \( Y_p \) are transmitted pilot signal and received pilot signal. \( W_p \) is noise signal and \( H_p \) is the channel frequency domain response, where the subscript \( p \) is the pilot.

We can get the following conclusion

\[
H_{p,\text{LS}}(k) = \hat{H}_p(k) = Y_p(k) / X_p(k)
\]

(3)

#### 3.2. Linear-minimum-mean-square-error (LMMSE) algorithm

The LMMSE algorithm is based on statistical significance, so this algorithm needs to use the channel statistics information. Based on the LMMSE algorithm, the estimation results can be written as

\[
H_{p,\text{LMMSE}} = R_{pp}^{-1} \left( R_{pp} + \sigma_n^2 (X^H_p X_p)^{-1} \right)^{-1} H_{p,\text{LS}}
\]

(4)
where $R_{pp}$ is the channel autocorrelation matrix at pilot location, and $R_{pp} = \mathbb{E}\{H_p H_p^H\}$. $\sigma_n^2$ is the noise power.

### 3.3. Modified LS algorithm

The anti-noise performance of LS algorithm is not very well, so based on some channel priori knowledge, we can improve its anti-noise performance, and this is the foundation of the modified LS algorithm. The frequency domain channel parameters and the time domain channel pulse response of LS algorithm have the following IDFT relationship as

$$\hat{h}_{LS}[n] = \text{IDFT}[\hat{H}_{LS}[n]]$$

where $\hat{h}_{LS}[n] = (\hat{h}_{LS}[n,0], \hat{h}_{LS}[n,1], \ldots, \hat{h}_{LS}[n,N-1])^T$.

Under normal circumstances, the channel length $L$ to be significantly less than the OFDM symbol length $N$. That is in $\hat{h}_{LS}[n,k] \forall k \neq 0$, only for $k = 0,1,\ldots,L-1$, it contains useful channel information and the rest only contains noise. Append zeros at the end of $\hat{h}_{LS}[n,k] \geq L$ to obtain a $N \times 1$ vector as

$$\tilde{h}_{LS}[n] = (\hat{h}_{LS}[n,0], \hat{h}_{LS}[n,1], \ldots, \hat{h}_{LS}[n,L-1], 0, \ldots, 0)^T$$

Conventional length of channel length $L$ is equal to the CP length. In practical OFDM system, the CP length is often longer than the channel maximum multipath delay, so the noise reduction procedure of equation (7) is not complete. In this paper, we propose a precise calculation of channel length $L$, and $L$ can be expressed as

$$\tilde{L} = f_s \times \tau_{\text{max}}$$

where $f_s$ is system sampling rate and $\tau_{\text{max}}$ is the channel maximum multipath delays. Modify $\tilde{h}_{LS}[n]$ into $\tilde{h}_{LS}[n]$, we can rewrite $\tilde{h}_{LS}[n]$ as

$$\tilde{h}_{LS}[n] = (\hat{h}_{LS}[n,0], \hat{h}_{LS}[n,1], \ldots, \hat{h}_{LS}[n,\tilde{L}-1], 0, \ldots, 0)^T$$

The estimation results of modified LS algorithm can be expressed as

$$\tilde{H}_{\text{modified LS}}[n] = \text{DFT}[\tilde{h}_{LS}[n]]$$

### 4. Performance evaluation

In this section, we demonstrate the performance of the pilot-aided channel estimation for an OFDM system. In the simulation we choose COST207 channel mode. In this system, subcarrier number is 1024, the maximum Doppler frequency shift is 30Hz, sampling rate is 10Mbit/s. CP is 256 and the channel length is 172.

In this paper we use MATLAB to simulate the frequency characteristics of the above-mentioned LS, modified LS and LMMSE algorithms, then compare their characteristics. To gain insights into the average behavior of the channel estimation, we have averaged the performance over 5000 OFDM blocks.

Figure 2 shows the effects of different references on MSE of OFDM system with COST-207 channel. From this figure, it is clearly observed that the LMMSE algorithm has much smaller MSE than that of LS and Modified LS algorithms. Compared with LS algorithm, the MSE has significantly reduced based on
modified LS algorithm. When the MSE of modified LS and LS algorithms reach $10^{-3}$, the performance of modified LS algorithm can improve 6~8dB.

BER performances of the three algorithms under COST-207 channel are shown in Figure 3. Compared BER curves of the three estimation algorithms, the received signal reach the same BER, such as $10^{-3}$, the performance of LMMSE algorithm can improve 3dB and 1dB for LS algorithm and modified LS algorithm respectively. Because of the noise reduction procedure, up to 3dB gain can be obtained for certain SNRs by using the modified LS algorithm instead of the LS algorithm.

5. Conclusions

This paper presents pilot-aided channel estimation techniques for OFDM systems over mountain wireless environment. The LMMSE algorithm utilizes channel priori knowledge of noise variance and covariance of channel, this algorithm can obtain a relative better MSE and BER performance than LS and modified LS algorithms. In the modified LS algorithm, a noise reduction procedure is adopted and the channel length parameter $L$ has been newly revised. The modified LS algorithm can outperform up to 3dB gain over ordinary LS algorithm.

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6. References