Research on Channel Estimation for OFDM Systems with Receiver Diversity

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Abstract Receiver diversity for Orthogonal Frequency Division Multiplexing system in high-speed wireless data transmission is investigated. An improved channel estimate method that calculates the correlation of the channel impulse response and a reference signal to extract the channel information from its noisy version is proposed. It is demonstrated by theoretical analysis and computer simulation that for QPSK modulated OFDM systems with one transmitter antenna and four receiver antennas, the performance of the improved channel estimator outperforms Least Square and Discrete Fourier Transform-based channel estimator greatly.

Key words OFDM system; channel estimation; receiver diversity; multipath fading channel

接收分集OFDM系统的信道估计研究

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【摘要】研究了天线分集OFDM系统的高速无线数据传输特点，通过计算信道冲击响应与参考信号的相关函数，提出了一种增强型的信道估计方法。理论分析与计算机仿真表明，该方法能够有效地降低加性噪声对信道估计的影响，提高信道估计精度。在采用QPSK调制的一发四收的接收分集OFDM系统中，该增强型的信道估计方法的性能明显好于最小二乘信道估计和基于DFT的信道估计。

关 键 词 OFDM系统; 信道估计; 接收分集; 多径衰落信道
中图分类号 TN929.533 **文献标识码** A

For OFDM systems without co-channel interference, channel parameters estimation has been investigated to improve system performance by allowing for coherent demodulation. It is also well known that antenna diversity is an effective technique to combat fading in mobile wireless communication.

The structure of OFDM signaling allows a channel estimator to use both time and frequency correlation. In Refs.[1] and [2], the channel estimation for OFDM systems have been proposed based on frequency-domain filtering and time-domain filtering. A singular-value-decomposition-based channel estimation has been proposed in Refs.[3] and [4].

In this paper, we derive an improved channel estimate method that, by correlating between the channel impulse response and a reference signal, identifies the channel parameters of receiver diversity OFDM systems accurately.

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1 Receiver Diversity for OFDM System with Multipath Fading

The WSSUS multipath Rayleigh fading channel model can be characterized by [5]

$$h(t,t) = \sum_{p=1}^{P} a_p(t)d(t - t_p T) \tag{1}$$

where P is the path number, $\{a_P(t)\}$ is the complex amplitude of channel, and $\{t_pT\}$ is the path delay. Modeled by a discrete-time FIR filter, Eq.(1) is often rewritten as [6]

$$h(l) = \sum_{p=1}^{P} a_p g(l - t_p) \qquad l = 0,1,\cdots,L-1 \tag{2}$$

where $L=\lfloor t_p \rfloor+1$ denotes the channel length and $g(l)$ is a raised-cosine pulse with an excess bandwidth of 20% and a pulse duration of 10 sample periods.

For an M-receiver OFDM system, the received signal from the mth antenna at the kth tone and the nth block is denoted as

$$R_m[n,k] = S_m[n,k]H_m[n,k] + W_m[n,k] \quad n = 0,1,\cdots \quad 0 \le k < N \quad m = 1,2,\cdots,M \tag{3}$$

where $S_m[n, k]$ is the signal modulating the kth tone during the nth block, $H_m[n,k]$, the frequency response at the kth tone and the nth block, is assumed to be independent for different m' s, but with the same statistics. $W_m[n,k]$ is additive white Gaussian noise at the kth tone and the nth block, with zero-mean and variance s^2.

With the channel parameter estimated as $\hat{H}_m[n,k]$, the transmitted signal can be detected as $\hat{S}[n,k]$ by a maximal ratio combiner

$$\hat{S}[n,k] = \frac{\sum_m \hat{H}_m^*[n,k]R_m[n,k]}{\sum_m |\hat{H}_m[n,k]|^2} \tag{4}$$

Since the channel corresponding to each antenna is independent and has the same statistics, the estimator for each antenna works independently. Therefore, the subscript m is eliminated in the following sections.

2 Proposed Channel Estimate Method

The basic principle of the proposed channel estimate method is to improve the Discrete Fourier Transform(DFT)-based channel estimate by exploiting the structure of the channel impulse response from its noise version.

Unit-power pilot-symbol aiding, the Least Square(LS) channel estimate of the kth subcarrier can be obtained by

$$\hat{H}_{\text{LS}}[k] = \frac{R[k]S^*[k]}{|S[k]|^2} = H[k] + \tilde{H}[k] \tag{5}$$

where $\tilde{H}[k]$ denotes channel estimate error, superscript * denotes conjugate.

Let $\hat{h}_{\text{LS}}(l)$ denotes the lth estimated tap of channel impulse response

$$\hat{h}_{\text{LS}}(l) = \left[F_N^{-1}\left(\hat{H}_{\text{LS}}[k]\right)\right]_l = h(l) + \bar{w}(l) \qquad l = 0,\ 1,\ \cdots,\ N-1 \tag{6}$$

where $F_N^{-1}(\cdot)$ denotes the power-normalizing Inverse Fast Fourier Transform(IFFT) of size N and $\bar{w}(l)$ denotes channel estimate error. Since the channel length is L, the channel impulse response $h(l)$ can be described as

$$h(l) = \begin{cases} \left[F_N^{-1}\left(H[k]\right)\right]_l & l = 0,\ 1,\ \cdots,\ L-1 \\ 0 & \text{otherwise} \end{cases} \tag{7}$$

According to Eq.(7), all the channel information is contained in the first L taps and other taps only consist of noise. By ignoring those noise-only taps and consulting Eq.(2), we get the DFT-based channel estimate

$$\hat{h}_{\rm DFT}(l)=\begin{cases}a_1 g(l-\tau_1)+\bar{w}(l) & \lfloor\tau_1\rfloor-5\leqslant l\leqslant\lfloor\tau_1\rfloor+4 \\ \bar{w}(l) & \text{otherwise}\end{cases}\quad l=0,1,\cdots,L-1 \tag{8}$$

Ignoring those noise-only taps, and calculating the correlation of •$_{\rm DFT}(l)$ and the reference signal $g(l+\tau_x)$, we obtain

$$y(\tau_x)=\sum_{l=\lfloor\tau_1\rfloor-5}^{\lfloor\tau_1\rfloor+4}\hat{h}_{\rm MMSE}(l)g(l-\tau_x)=a_1\sum_{l=\lfloor\tau_1\rfloor-5}^{\lfloor\tau_1\rfloor+4}g(l-\tau_1)g(l-\tau_x)+\sum_{l=\lfloor\tau_1\rfloor-5}^{\lfloor\tau_1\rfloor+4}\bar{w}(l)g(l-\tau_x) \tag{9}$$

It is obviously that the absolute value of $y(\tau_x)$ attains its maximum if and only if $\tau_x=\tau_1$, that's the way τ_1 identified, and then by dividing $y(\tau_x)$ with $\sum_{l=\lfloor\tau_1\rfloor-5}^{\lfloor\tau_1\rfloor+4}g(l-\tau_1)g(l-\tau_x)$, we obtain the estimated

$$\hat{a}_1=y(\tau_1)\left(\sum_{l=\lfloor\tau_1\rfloor-5}^{\lfloor\tau_1\rfloor+4}|g(l-\tau_1)|^2\right)^{-1}=a_1+\left(\sum_{l=\lfloor\tau_1\rfloor-5}^{\lfloor\tau_1\rfloor+4}\bar{w}(l)g(l-\tau_1)\right)\left(\sum_{l=\lfloor\tau_1\rfloor-5}^{\lfloor\tau_1\rfloor+4}|g(l-\tau_1)|^2\right)^{-1} \tag{10}$$

According to Eq.(10), the estimated complex amplitude is blured by noise that has about the same statistical property as the noise contained in one tap, instead of ten taps, that's the reason the improved channel estimate method depresses the noise power greatly. The parameters of other paths can be identified in the same way and the channel impulse response is reconstructed when all the channel parameters identified.

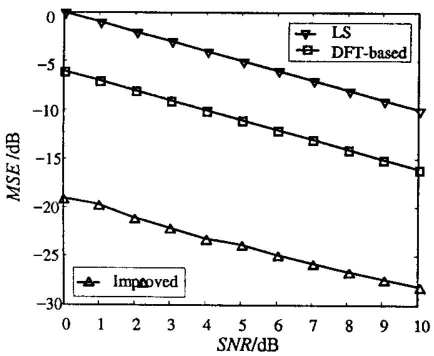
3 Simulation Results

3.1 System Parameters

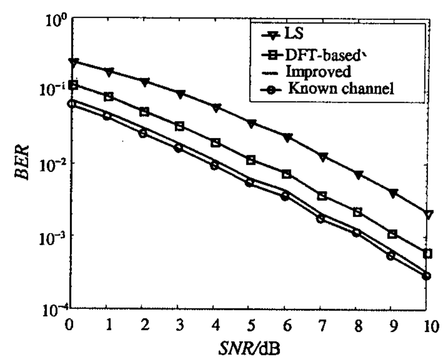
Slowly fading channel with 4 paths is considered, the delay of each path is uniformly distributed over the interval 0~6.4 μs. Operating at a bandwidth of 20 MHz, the OFDM system is divided into 512 tones. The OFDM symbol period is 32 μs, of which 6.4 μs constitute the cyclic prefix. Without error correcting, the QPSK modulated data is transmitted by one antenna. At the receiver, four antennas are set to combat fading; the received signal from each antenna is demodulated independently.

3.2 Performance Comparison

Fig. 1a and Fig. 1b give the simulation results of the comparison of the Mean Square Error (MSE) vs. Signal to Noise Power Ratio (SNR) and Bit Error Rate (BER) vs. SNR of three different channel estimate methods respectively.



(a) *MSE* vs. *SNR*



(b) *BER* vs. *SNR*

Fig. 1 Performance comparison of receiver diversity OFDM system with different channel estimate methods

Fig. 1a shows that the MSE of DFT-based channel estimate is about 6 dB lower than that of LS channel estimate, the reason is that N, the size of DFT, is 4 times the channel length L, and then the average noise power is reduced four times. Accordingly in Fig. 1b, the BER with DFT-based channel estimate is about 2~3 dB lower than that with LS channel estimate.

When improved channel estimate method applied, the MSE is about 10 dB lower than that of DFT-based channel estimate. The superiority is demonstrated more clearly in the BER vs. SNR figure. For the LS channel estimate, the required SNR for a 10^{-2} BER is 7.5 dB while it is about 5 dB for the DFT-based one and 4 dB for the improved one. It also can be seen that the BER performance of the system with the improved channel estimate is just a little worse than the BER performance of the system with known channel parameters.

4 Conclusions

In this paper, we proposed an improved channel estimate method for OFDM system. We analyze the characters of multipath path fading channel model firstly, and then we extract the channel information from its noisy version by calculating the correlation of the channel impulse response and the reference signal. Computer simulation shows that the proposed channel estimate method can enhance the accuracy of the channel estimation, and hence improve the BER performance of receiver diversity OFDM systems.

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编　辑　王　燕

·科研成果介绍·

Windows NT系统下实时动态模拟环境

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Windows NT系统下实时动态模拟环境是一个基于Windows NT的实时多任务应用软件的运行平台，通过使用NT的现有资源，在主模拟计算机中实现多任务的建立、调度管理以及各任务间的数据共享，并通过以太网实现主模拟计算机与外围计算机间的实时数据交换，数据通信方式包括单向广播式通信和点对点双向通信，该系统向用户提供了一个用户可自定义的图形用户界面，界面友善，操作方便，并具有对各类数据进行在线监视和修改的功能。

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