Influence on OFDM Channel Estimation by Modulations of Pilot Symbol

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Abstract　A frequency-domain channel estimation (CE) scheme for orthogonal frequency division multiplexing (OFDM) channel estimation which is based on a linear transformation is developed. The transmitted signal can be recovered efficiently by a linear transformation of the received signal. Firstly, two results on the generalized rotation matrix are deduced. Then based on the modulations of pilot symbols BPSK or QPSK, we achieve two channel estimation algorithms respectively. Simulations are performed at the condition that the channel is assumed to be Rayleigh fading and flat within one frame. Simulation results show that the BER and PER performance can be improved obviously when in-phase channel and quadrature-phase channel of each sub-carrier are inserted in the pilot symbols.

Key words　channel estimation;　OFDM;　Rayleigh fading channel;　rotation matrix

导频符号调制方式对OFDM信道估计的影响

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【摘要】引入了基于线性变换的正交频分复用信道的频域估计方法，通过对接收信号的线性变换达到数据的有效恢复。首先推导了关于推广后旋转矩阵的两个性质定理；然后根据所得的旋转矩阵的性质，给出了导频符号分别基于BPSK和QPSK调制的两种OFDM信道估计算法。在假设信道为瑞利衰落并且在一帧内保持不变的情况下，对基于这两种信道估计算法的系统进行了仿真比较。仿真结果显示，当各子载波的同相信道和正交相位信道同时插入信道估计符号时，OFDM系统的误码率和误包率都可以得到明显的改善。

关　键　词　信道估计;　正交频分复用;　Rayleigh衰落信道;　旋转矩阵

中图分类号　TN 911.2　　　　**文献标识码**　A

Multipath fading is always one of important characters in a wireless communication system. To combat the problems caused by the multipath fading environment, adaptive equalization technique[1-2] at the receiver is often adopted. However, achieving the equalization at several mega bits per second with compact and low-cost hardware is quite difficult in practice for broadband mobile communications[3-4]. So it is necessary to use parallel transmission. OFDM technique[5-6] is one of the selections, which renders complex equalizers unnecessary.

To achieve high-speed transfer rate, Channel estimation (CE) becomes especially important in OFDM systems. The CE algorithms in OFDM communication systems include blind, non-blind, and semi-blind estimations[7-8]. The non-blind estimation algorithms include the decision directed and the pilot symbol assisted[9-10]. The decision directed method uses all of the sub-carriers of the OFDM signal to estimate the channel, whereas the pilot symbol aided method uses the multiplexed pilot in the transmitted signal to estimate the channel.

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In this paper, a frequency-domain pilot symbol assisted CE scheme for OFDM system is developed. We achieve two channel estimation algorithms, which are based on inserting methods of pilot symbol. If only in-phase channel of sub-carrier is inserted with pilot data, the pilot symbols are modulated in BPSK. If both of in-phase and quadrature-phase channel of sub-carrier are inserted with pilot data, the pilot symbols are modulated in QPSK. We evaluate the bit error rate (BER) and packet error rate (PER) performance by simulation under Rayleigh fading channel. Simulations show that channel estimation, using the information both from in-phase and quadrature-phase channel of sub-carrier, can improve the performance of the system obviously.

1 OFDM System Model

The block diagram of an OFDM transmitter and a receiver are shown in Fig.1. In the transmitter, the transmitted high-speed data is first converted into parallel data.

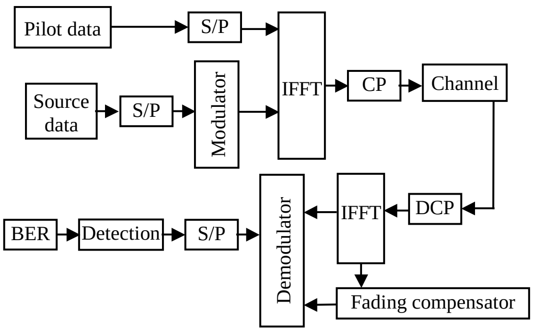

Fig.1 OFDM system model based on channel estimation

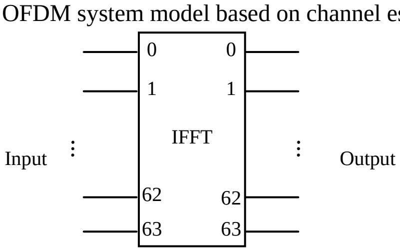

Fig.2 Input and output of IFFT

The output from S/P part is modulated into QPSK signals. The pilot data are modulated in BPSK or QPSK symbol in this paper, and input to the part of IFFT together with the data symbol. The amplitude and phase deviation of the pilot data after FFT can be used to estimate the channel. Fig.2 shows the signal mapping input and output of a 64-point IFFT circuit.

2 Channel Estimation Algorithms

The matrix notation of the OFDM system can be described as:

$$\boldsymbol{y} = \boldsymbol{X}\boldsymbol{h} + \boldsymbol{n} \tag{1}$$

where $\boldsymbol{y}$ is the received vector, $\boldsymbol{X}$ is a diagonal matrix containing the transmitted signaling points, $\boldsymbol{h}$ is a channel attenuation vector, and $\boldsymbol{n}$ is a vector of independent identically distributed (i.i.d.) complex zero-mean Gaussian noise with variance σ^2. The noise is assumed to be uncorrelated with the channel[5]. Channel model is a fading multipath channel model.

In order to estimate the channel from the inserted random pilot data, we consider the relationship between the original signal and received signal can be described by a linear transformation with the matrix $\boldsymbol{A}$, which can be described by:

$$\boldsymbol{A} = \begin{pmatrix} a & -b \\ b & a \end{pmatrix}$$

Matrix $\boldsymbol{A}$ is a generalized rotation matrix.

Lemma 1 If $a^2 + b^2 \neq 0$, then the inverse of matrix $\boldsymbol{A}$ is:

$$\boldsymbol{A}^{-1} = \frac{1}{a^2 + b^2} \begin{pmatrix} a & b \\ -b & a \end{pmatrix}$$

The proof of this lemma is obvious, so it is omitted.

Suppose $(x_0, y_0)^{\mathrm{T}}$ and $(x_1, y_1)^{\mathrm{T}}$ are original signal and receive signal respectively. Matrix $\boldsymbol{A}$ is the inverse of the fading matrix. Then:

$$\begin{pmatrix} x_0 \\ y_0 \end{pmatrix} = \boldsymbol{A} \begin{pmatrix} x_1 \\ y_1 \end{pmatrix} = \begin{pmatrix} x_1 & -y_1 \\ y_1 & x_1 \end{pmatrix} \begin{pmatrix} a \\ b \end{pmatrix} \tag{2}$$

That is:

$$\begin{pmatrix} a \\ b \end{pmatrix} = \frac{1}{x_1^{\ 2} + y_1^{\ 2}} \begin{pmatrix} x_1 & y_1 \\ -y_1 & x_1 \end{pmatrix} \begin{pmatrix} x_0 \\ y_0 \end{pmatrix}$$

So we get the following theorem.

Theorem 1 $(x_0, y_0)^{\mathrm{T}}$ and $(x_1, y_1)^{\mathrm{T}}$ are original signal and receive signal respectively. Matrix $\boldsymbol{A}$ is the inverse of the fading matrix. Then：

$$\begin{pmatrix} a \\ b \end{pmatrix} = \frac{1}{x_1^{\ 2} + y_1^{\ 2}} \begin{pmatrix} x_1 x_0 + y_0 y_1 \\ x_1 y_0 - x_0 y_1 \end{pmatrix} \tag{3}$$

and

$$\boldsymbol{A} = \frac{1}{x_1^{\ 2} + y_1^{\ 2}} \begin{pmatrix} x_1 x_0 + y_0 y_1 & x_0 y_1 - x_1 y_0 \\ x_1 y_0 - x_0 y_1 & x_1 x_0 + y_0 y_1 \end{pmatrix} \tag{4}$$

In each subcarrier, there are in-phase channel and quadrature-phase channel. If only the in-phase channel is used to carry the multiplexed pilot symbol (BPSK), then $y_0 = 0$. So:

$$\begin{pmatrix} a \\ b \end{pmatrix} = \frac{x_0}{x_1^2 + y_1^2} \begin{pmatrix} x_1 \\ -y_1 \end{pmatrix}$$

$$\boldsymbol{A} = \frac{x_0}{x_1^2 + y_1^2} \begin{pmatrix} x_1 & y_1 \\ -y_1 & x_1 \end{pmatrix}$$

If the channel is assumed to be flat within one frame, the linear transformation is:

$$\begin{pmatrix} u \\ v \end{pmatrix} = \boldsymbol{A} \begin{pmatrix} \zeta \\ \eta \end{pmatrix} = \frac{x_0}{x_1^2 + y_1^2} \begin{pmatrix} x_1 & y_1 \\ -y_1 & x_1 \end{pmatrix} \begin{pmatrix} \zeta \\ \eta \end{pmatrix} \quad (5)$$

Equ.(5) can be used to recover the data symbol, where $(u,v)^{\mathrm{T}}$ and $(\zeta,\eta)^{\mathrm{T}}$ are original signal and receive signal respectively.

If we use the in-phase channel and quadrature-phase channel to carry the CE information (QPSK), then the following linear transformation is used to recover the data symbol:

$$\begin{pmatrix} u \\ v \end{pmatrix} = \frac{1}{x_1^2 + y_1^2} \begin{pmatrix} x_1 x_0 + y_0 y_1 & x_0 y_1 - x_1 y_0 \\ x_1 y_0 - x_0 y_1 & x_1 x_0 + y_0 y_1 \end{pmatrix} \begin{pmatrix} \zeta \\ \eta \end{pmatrix} \quad (6)$$

where $(u,v)^{\mathrm{T}}$ and $(\zeta,\eta)^{\mathrm{T}}$ are original signal and receive signal respectively.

Theorem 1 describes the data recovering by a linear transformation in within one sub-carrier. When all sub-carriers are considered, we can achieve a generalized diagonal matrix.

Theorem 2 $(x_{i0}, y_{i0})^{\mathrm{T}}$ and $(x_{i1}, y_{i1})^{\mathrm{T}}$ are original signal and receive signal respectively of *i*th channel. Matrix $\boldsymbol{A}_i$ is the inverse of the fading matrix. Then the original signal of all channels can be recovered by：

$$(x_{i0}, y_{i0}, \cdots, x_{n0}, y_{n0})^{\mathrm{T}} = \boldsymbol{A}(x_{i1}, y_{i1}, \cdots, x_{n1}, y_{n1})^{\mathrm{T}} \quad (7)$$

where *n* is the number channels, and：

$$\boldsymbol{A} = \mathrm{diag}(\boldsymbol{A}_1, \boldsymbol{A}_2, \cdots, \boldsymbol{A}_n)$$

$$\boldsymbol{A}_i = \frac{1}{x_{i1}^2 + y_{i1}^2} \begin{pmatrix} x_{i1} x_{i0} + y_{i0} y_{i1} & x_{i0} y_{i1} - x_{i1} y_{i0} \\ x_{i1} y_{i0} - x_{i0} y_{i1} & x_{i1} x_{i0} + y_{i0} y_{i1} \end{pmatrix}$$

3 Simulations

We assume the output from the modulator is with 52 parallel QPSK symbols, and the 0th, 27th to 37th are set in null in the input mapping (Fig. 2). Pilot symbols are inserted in all sub-carriers. The BER and PER performance evaluation is simulated under Rayleigh fading channel, which is assumed flat within one frame.

In Fig. 1, if the pilot data are carried by in-phase channel, then CE symbol is modulated as a BPSK signal. If the pilot data are carried by in-phase channel and quadrature-phase channel, then CE symbol is modulated as a QPSK signal. In Fig. 3 and Fig. 4, BER and PER versus SNR are compared, where received symbol is compensated by Equ. (6) and (7).

In Fig. 3 and Fig. 4, CE BPSK Rayleigh fading channel means CE symbol is modulated in form of BPSK in Rayleigh fading channel. So dose CE QPSK Rayleigh fading channel. BPSK AWGN channel means this is a BPSK communication system in AWGN channel. The performance improvement is obvious when both in-phase channel and quadrature-phase channel used for CE symbol.

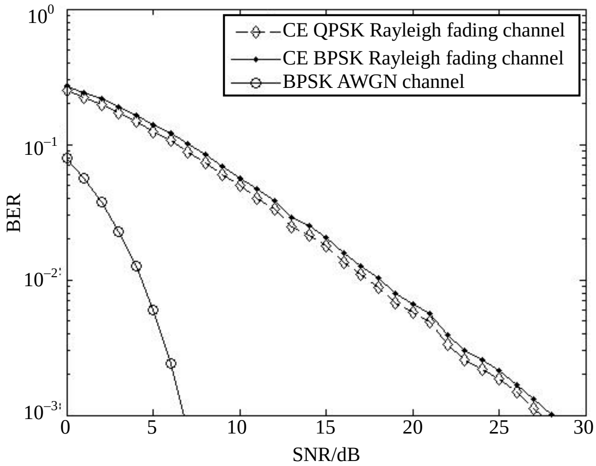

Fig. 3　BER versus SNR in two kinds of CE under Rayleigh fading channel

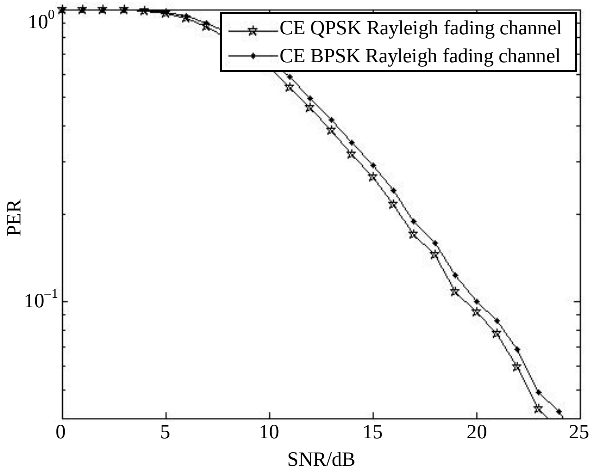

Fig. 4　PER versus SNR in two kinds of CE under Rayleigh fading channel

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