Research on Denoise Methods of Channel Estimation in OFDM System with High-speed Multipath Channels

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Abstract. To solve the problem of low accuracy of channel estimation in OFDM systems in the scenario of high-speed multipath channels, it is proposed in the paper that a noise reduction scheme of channel estimation is based on DFT (Discrete Fourier Transform) algorithm. By analyzing the algorithm principles, the mathematical model of the system is built, and the performance of the scheme is analyzed. Simulation results reveal that in high-speed scenario, the scheme has effectively achieved low bit error rate and low mean square error, thus having good application value.

1. Introduction
With the wide application of high-speed mobile terminals, requirements on data communication quality have been higher and higher. However, in the high-speed moving scenario, there are serious Doppler effect, multipath effect and fast frequency selective fading. These non-stationary time-varying characteristics of the mobile channel lead to ICI (inter-carrier Interference) and ISI (inter-symbol Interference). Therefore, accurate channel estimation is one of the key technologies to improve the quality of received signals. OFDM (Orthogonal Frequency Division Multiplexing), one of the multiple access technologies for 5G systems, has such advantages as high spectrum utilization, strong resistance to narrow-band interference, and multiple rates support. In the case of low speed, sub-carriers of OFDM system are quasi-orthogonal and transmit parallelly, and interference between sub-carriers can be ignored. However, in the high-speed mobile scenario, the increase of Doppler frequency shift results in the frequency offset of subcarriers, which destroys the orthogonality between subcarriers. The ICI leads to accuracy loss of channel estimation. Therefore, how to improve the accuracy of channel estimation with the interference elimination between subcarriers is an urgent problem to solve in high-speed mobile scenarios.

In this paper, DFT (Discrete Fourier Transform) algorithm is adopted to filter noise inner the data symbol in the high-speed and multi-path scenario, so as to improve the accuracy of channel estimation in OFDM system.

2. System Design
Channel estimation methods can be divided into three categories: non-blind channel estimation, semi-blind channel estimation and blind channel estimation. Non-blind channel estimation is mainly to send the specified training sequence or to insert the pilot symbol in the appropriate position at the sending end. The training sequence or pilot position is recovered at the receiving end. Such processes as filtering and transformation are applied to acquire the complete channel response. Although this channel estimation method has less transmission efficiency than that of blind channel
estimation, it has the advantages of easy implementation and fast convergence and is suitable for burst transmission system and continuous transmission system. Due to the high transmission rate and the application of multiple modulation and coherent demodulation in OFDM systems, the non-blind channel estimation algorithm based on pilot frequency is generally applied. Figure 1 shows the OFDM system model in this paper.

![Figure 1. System Model](image)

The paper focuses on the method to improve the accuracy of channel estimation in high-speed scenarios. Since the mobile platform is moving at high speed, Doppler effect is especially obvious. Considering that ground objects are mostly open areas and buildings are less shielded when moving at high speed, the dominant components in the received signal are direct waves, on which multipath components randomly arriving at different angles are superimposed. The channel fading characteristic obeys Rice distribution, and its probability density function is shown in equation (1), where $A$ is the peak of the main signal, and $I_0$ refers to the first kind of modified Bessel function of zero order.

$$p(r) = \frac{r}{\sigma^2} e^{-\frac{(r^2+\delta^2)}{2\sigma^2}} I_0\left(\frac{4r^2}{\sigma^2}\right)(A \geq 0, R \geq 0) \quad (1)$$

A multipath Rice channel with Doppler Frequency shift is adopted in the paper. The signal will produce amplitude attenuation, frequency offset and phase offset, resulting in reliability reduction of the system. The impulse response of the channel is shown in equation (2), where $N$ is the number of the paths, $a_k$ refers to the amplitude attenuation coefficient of the $K$th component, $t_k$ represents the delay caused by multipath and Doppler, and $\psi_k$ includes all the phase shifts of a multipath component within the $K$th increment delay, which obeys a uniform distribution of $[0, 2\pi]$.

$$h(t) = \sum_{k=0}^{N} a_k \delta(t-t_k) e^{-j\psi_k} \quad (2)$$

### 3. Algorithm

Compared to the blind estimation algorithm, the channel estimation algorithm based on pilot frequency can estimate the matrix parameters of the channel more accurately and reduce the computational complexity, thus receiving more wide application. The basic steps of channel estimation method based on pilot frequency are as follows: first, the channel impulse response of pilot position is obtained by inserting pilot symbol; then, the channel impulse response of data symbol position is estimated by interpolation algorithm; finally, the impulse response function of the whole channel is obtained.

#### 3.1. Pilot Structure

In OFDM system, pilot symbols can be inserted in both frequency domain and time domain. The common pilot structures include block-type structure, comb-type structure and grid-type structure.

In block-type pilot structure, pilots are interpolated into all subcarriers within an OFDM symbol (a block). Channel estimation based on block-type pilot structure only needs time domain interpolation.
with no frequency domain interpolation, so it has low computational cost, is sensitive to channel time selectivity, and is suitable for slow fading channel. In comb-type pilot structure, pilots are interpolated at all times on some subcarriers. Channel estimation based on comb-type pilot structure only needs frequency domain interpolation, but not time domain interpolation, so it is sensitive to channel frequency selectivity and suitable for fast fading channel.

In grid-type pilot structure, pilot signals are interpolated at equal intervals in both time and frequency domains. To restore the channel response without distortion, the time interval and frequency interval must satisfy the two-dimensional sampling theorem. $S_t$ and $S_f$ respectively represent the periods of the pilot symbol in time and infrequency. The arrangement of pilot symbols must satisfy the equation (3), where $\Delta f_m$ represents the maximum Doppler frequency shift and $\sigma_{\text{max}}$ stands for maximum delay propagation over multipath channel.

$$S_t \leq \frac{1}{\Delta f_m}, S_f \leq \frac{1}{\sigma_{\text{max}}} \tag{3}$$

![Figure 2. Grid-type Pilot Structure](image)

Channel estimation based on grid-type pilot structure requires two-dimensioning interpolation filtering time in both time domain and frequency domain, and has a large amount of computation. However, it can better track the time selection and frequency selection characteristics of the channel. Therefore, the grid-type pilot structure is adopted in the paper.

### 3.2. Channel Estimation

The commonly used channel estimation algorithms based on pilot frequency are frequency-domain least square (LS), minimum mean square error (MMSE) and linear minimum mean square error (LMMSE). LS means that the receiver uses the least square method to estimate the channel information when the received signal is transformed into the frequency-domain form by FFT.

According to the model of OFDM system, the expression of pilot signal at receiving end is shown in equation (4), where $H$ is channel response, $X_p$ refers to known pilot transmitted signal, $Y_p$ represents received pilot signal, and $W_p$ stands for noise superimposed on pilot sub-channels.

$$Y_p = X_p H + W_p \tag{4}$$

To obtain signal estimation $\hat{H}$, LS channel estimation needs to minimize the following cost functions, as shown in equation (5).

$$J(\hat{H}) = \left\| Y_p - X_p \hat{H} \right\|^2$$

$$= (Y_p - X_p \hat{H})^H(Y_p - X_p \hat{H})$$

$$= Y_p^H Y_p - Y_p^H X_p \hat{H} - X_p \hat{H}^H Y_p + X_p \hat{H}^H X_p \hat{H} \tag{5}$$
By minimization of cost functions, the LS channel estimation is obtained as shown in equation (6).

\[ H_{LS} = (X_p^H X_p)^{-1} X_p^H Y_p = X_p^{-1} Y_p \]  

(6)

The outstanding advantages of LS channel estimation algorithm are concise structure and small computation. Since channel noise is ignored in the estimation of LS estimation algorithm, the mean square Error (MSE) obtained by the LS channel estimation algorithm is large, the BER (Bit Error Ratio) is high, and the system performance is poor.

The core idea of MMSE channel estimation is to minimize the mean square error of channel estimation. The mean square error of channel estimation can be expressed as equation (7), where \( \hat{H} \) is obtained by weighting the estimated channel of LS, as shown in equation (8). K in equation (8) represents the weighting matrix.

\[ J(H) = \| H - \hat{H} \|^2 \]  

(7)

\[ \hat{H} = KX_p^H Y_p \]  

(8)

Since estimation error vector is orthogonal to \( X_p^H Y_p \), as is shown in equation, equation (10) is obtained.

\[ E\{ e(X_p^H Y_p)^H \} = E\{ (H - \hat{H})(X_p^H Y_p)^H \} = 0 \]  

(9)

\[ K = E\{ H(X_p^H Y_p)^H \} E\{ (X_p^H Y_p)(X_p^H Y_p)^H \}^{-1} \]  

(10)

Assume that \( H \) obeys Gaussian distribution and has no correlation with channel noise \( W_p \), MMSE estimation of \( H \) can be expressed as equation (11).

\[ \hat{H}_{MMSE} = KQ_{MMSE} F_p^H X_p^H Y_p \]  

(11)

\[ Q_{MMSE} = R_{hh}[ (F_p^H X_p^H X_p F)^{-1} \sigma_w^2 + R_{hh}]^{-1} (F_p^H X_p^H X_p F)^{-1} \]  

(12)

The MMSE channel estimation algorithm can well reflect the real-time performance of the channel and has a good performance in the mean square error. However, the method of two-dimensional filtering is more complex, requires the relevant information of the channel, and has a very large amount of calculation. If the Gaussian distribution is not obeyed, the mean square error of MMSE algorithm cannot achieve the minimum value.

LS channel estimation and MMSE channel estimation both have distinct characteristics, but neither considers the noise caused by ICI in high-speed scenes. Therefore, the paper focuses on how to reduce the influence of noise on OFDM symbols.

### 3.3. Denoise by DFT

The signals estimated by LS algorithm and MMSE algorithm has the energy concentrated in CP, while most of the noise is concentrated outside CP. Therefore, the fundamental principles of DFT denoising are as follows: first, the channel response at pilot frequency is completed by LS algorithm and MMSE algorithm, then, IDFT transform is implemented on the obtained channel response, and finally, the signal is denoised in the time domain with the noise sample point outside CP set to zero. Figure 3 shows the block diagram of DFT estimation algorithm.
According to principles of DFT algorithm, the pilot channel estimation expression can be obtained by zeroing the sample points outside CP, as shown in equation (13).

\[
\hat{h}_N(n) = \begin{cases} 
    h_p(n) + w_p(n), & 0 \leq n \leq M - 1 \\
    0, & M \leq n \leq N - 1
\end{cases}
\]  

(13)

Equation (14) is obtained by the DFT transform of \(\hat{h}_N(n)\).

\[
H_N(k) = \sum_{n=0}^{N-1} \hat{h}_N(n) \exp\left[-j \frac{2\pi}{N} nk\right]
\]  

(14)

4. Simulation Results & Their Analysis

Based on the characteristics of wireless channel in high-speed scenario, the OFDM channel estimation is denoised by DFT algorithm to further improve the system performance. Comparison and analysis of system performances are implemented by the design and simulation of the system. The simulation parameters of the system are shown in Table 1.

| Parameter                  | Value            |
|----------------------------|------------------|
| Numbers of Subcarriers, L  | 512              |
| Length of Cyclic Prefix, M | 8                |
| Pilot Interval             | 4                |
| Operating Frequency        | 2G               |
| Modulation Mode of Rf signals | QAM             |
| Wireless Channel           | Rician Channel   |
| Bandwidth of Subcarrier    | 15KHz            |
| Velocity                   | 370              |
| Pilot Scheme               | Grid-type        |

Figure 4 shows the MSE performance of different channel estimation algorithms in OFDM system without DFT algorithm processing, while Figure 5 shows the MSE performance of different channel estimation algorithms with DFT algorithm applied. It can be derived from Figure 4 that with the same parameters, MMSE algorithm obtains better MSE performance than LS algorithm, but with the increase of SNR, they have similar MSE performance.
A comparison of Figure 4 to Figure 5 shows that both LS and MME have obtained outstanding improvement in MSE performance by DFT denoising. When the SNR is less than 5dB, MMSE has better performance than LS. However, with the increase of noise, LS gets better performance than MMSE.

Figure 6 shows the BER performance of different channel estimation algorithms in OFDM system without DFT algorithm processing, while Figure 7 shows the BER performance of different channel estimation algorithms with DFT algorithm applied. It can be seen from Figure 6 that with the same parameters, BER performance of MMSE channel estimation algorithm, close to ideal estimation, is slightly better than that of LS algorithm.
Figure 6 BER Performance Comparison of Different Channel Estimation Algorithms without DFT Algorithm Processing

Figure 7 reveals that by DFT denoising, both LS and MMSE have received high improvement in BER performance, close to ideal estimation.

Figure 7 BER Performance Comparison of Different Channel Estimation Algorithms with DFT Algorithm Applied

5. Conclusion
According to the channel estimation theory, the OFDM system has been simulated and several algorithms are compared. Simulation results reveal that DFT denoising algorithm can effectively improve the accuracy of channel estimation in OFDM system. By comparison of several algorithms, it is suggested that the grid-type pilot pattern should be chosen for OFDM system in high-speed scenario, and LS algorithm should be selected as the channel estimation algorithm with DFT denoising algorithm applied. The scheme has good real-time performance and high reliability.

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