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Channel Estimation Algorithm Using an Improved Dft for Mimo-Ofdm Systems

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Abstract: *The Improved DFT-based Channel Estimation Algorithm for MIMO-OFDM System uses the symmetric property to extend the LS estimate in frequency domain, and calculates the changing rate of the leakage energy, and selects useful paths by the changing rate.*

The Discrete Fourier Transform (DFT) is used for spectral analysis, the $\{x_n\}$ *sequence usually represents a finite set of uniformly-spaced time-samples of some signal* $x(t)$*, where t represents time. The conversion from a very long (or infinite) sequence to a manageable size entails a type of distortion called leakage, which is manifested as a loss of detail in the DTFT. Choice of an appropriate sub-sequence length is the primary key to minimizing that effect. When the available data (and time to process it) is more than the amount needed to attain the desired frequency resolution, a standard technique is to perform multiple DFTs.*
Multiple Input Multiple Output (MIMO) - Orthogonal Frequency Division Multiplexing (OFDM) can not only effectively enhance the transmission rate and capacity of the wireless communication system but also effectively combat multipath fading and inter-symbol interference (ISI). MIMO-OFDM technology has become one of the most promising solutions in the high data rate wireless channel transmission. In the OFDM system with transmit diversity, when the receiver knows the channel information better, the space-time codes can be decoded effectively. In order to enhance frequency efficiency, the receiver also needs to know the channel information for coherent demodulation. So channel estimation is directly related to the system performance.

Least squares (LS) approach is the simplest channel estimation. This algorithm has lower complexity. However, it has larger mean square error (MSE) and easily influenced by noise and intercarrier interference. Another approach is also proposed by extending the LS estimate with a symmetric signal of its own. Based on these two methods, we propose a new method to solve the problem of energy leakage.
Keywords: *Channel Estimation, Energy Leakage, DFT- Discrete Fourier transform, MIMO- Multiple Input Multiple Output, OFDM-Orthogonal Frequency Division Multiplexing.*

I. Introduction

Existing Method:

The conventional discrete Fourier transform (DFT) is a specific kind of discrete transform, used in Fourier analysis. It transforms one function into another, which is called the frequency domain representation, or simply the DFT, of the original function (which is often a function in the time domain). But the DFT requires an input function that is discrete and whose non-zero values have a limited (finite) duration. Such inputs are often created by sampling a continuous function, like a person's voice. Unlike the discrete-time Fourier transform (DTFT), it only evaluates enough frequency components to reconstruct the finite segment that was analyzed. Using the DFT implies that the finite segment that is analyzed is one period of an infinitely extended periodic signal; if this is not actually true, a window function has to be used to reduce the artifacts in the spectrum. For the same reason, the inverse DFT cannot reproduce the entire time domain, unless the input happens to be periodic (forever). Therefore it is often said that the DFT is a transform for Fourier analysis of finite-domain discrete-time functions. The sinusoidal basis functions of the decomposition have the same properties. The conventional discrete Fourier transforms (DFT)-based approach will cause energy leakage in multipath channel with non-sample-spaced time delays.

Proposed Method:

DFT contains periodicity. If the original data sequence is not continuous, it will generate additional high-order component. In order to reduce this high-order component, we can use symmetry principle before IFFT. With this understanding, we will select paths effectively in order to reduce leakage power by calculating the changing rate of the leakage energy**.** The main advantage of this proposed method is that this improved method uses symmetric property to extend the LS estimate in frequency domain, and calculates the changing rate of the leakage energy, and selects useful paths by the changing rate.

MIMO-OFDM technology has become one of the most promising solutions in the high data rate wireless channel transmission. This technology can not only effectively enhance the transmission rate and capacity of the wireless communication system but also effectively combat multipath fading and inter-symbol interference (ISI)[1]. In the OFDM system with transmit diversity, when the receiver knows the channel information better, the space-time codes can be decoded effectively. In order to enhance frequency efficiency, the receiver also needs to know the channel information for coherent demodulation[2]. So channel estimation is directly related to the system performance.

By now, many channel estimation algorithms have been presented. Least squares (LS) approach is introduced in [3]. The LS estimation is the simplest channel estimation. This algorithm has lower complexity. However, it has larger mean square error (MSE) and easily influenced by noise and inter- carrier interference. Linear minimum mean square error (LMMSE) algorithm is introduced in [4]. LMMSE algorithm is a simplified algorithm of Minimum Mean Square Error (MMSE). Although they can achieve better performance than LS, they have higher computational-complexity and need to know the channel statistics which are usually unknown in real system. In [5] and [6], the algorithms of reducing the complexity of the LMMSE are proposed. But these two modified methods still require exact channel covariance matrices.

In this paper, we focus on DFT-based channel estimation method. This algorithm can make good compromise between performance and computational complexity[7]. Most of the published work on DFT-based channel estimation assumes each path delay is an integer multiple of the sampling interval in multipath channel. However, it is difficult to ensure this condition in real system because of the complexity and incomprehensibility of the transmission channel. In non- sample-spaced multipath channels, the channel impulse response will leak to all taps in the time domain. Reference[8] propose a method to reduce leakage power by calculating energy increasing rate. Another approach is also proposed by extending the LS estimate with a symmetric signal of its own in [9]. Based on these two methods, we propose a new method to solve the problem of energy leakage.

Software Required: MATLAB 7.4:

MATLAB is a high-level technical computing language and interactive environment for algorithm development, data visualization, data analysis, and numeric computation. Using the MATLAB product, you can solve technical computing problems faster than with traditional programming languages, such as C, C++, and FORTRAN.

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The outline of the paper is as follows. In Section II, the MIMO-OFDM system model is described. In Section III, we introduce LS and conventional DFT-based algorithms. The new method is explained in Section IV. Simulation results are presented in Section V. Finally Section VI provides our conclusions.

II. Mimo-Ofdm System Model

A. Multipath Channel Model

In multipath fading channel, the channel impulse response in time domain could be expressed as:

$$h(t) = \sum_{l=0}^{L-1} a_l \, \delta(t - \tau_l T_S) \qquad (1)$$

Where L is the number of multipath, a_l is the complex time varying channel coefficient of the l -th path, T_S is sampling interval, and $\tau_l T_S$ is the delay of the l –th path. When τ_l is an integer, the multipath channel is sample-spaced channel. Or the multipath channel is non-sample-spaced channels. From (1) the channel impulse response after sampling the frequency response of $h(t)$ is expressed as:

$$h_n = \frac{1}{N} \sum_{i=1}^{L} a_1 e^{-j\pi/N\,(n+(N-1)\tau_1)} \frac{\sin(\pi\tau_1)}{\sin \pi \left(\frac{1}{N}(\tau_1-n)\right)} \qquad (2)$$

The corresponding frequency response is expressed as:

$$H(k) = \sum_{i=1}^{L} h_n e^{(-j2\pi kl/N)} \qquad (3)$$

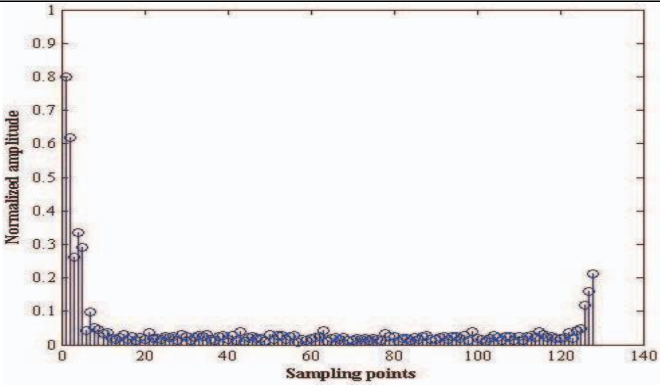

Figure 1. The channel impulse response in non-sample-spaced channel

From Figure 1 it can be seen that the energy leaks to all carriers at the condition of the channel is non-sampled-spaced channel.

B. MIMO-OFDM Model:

It is assumed that the system has N_T transmitter antennas and N_R receiver antennas. The total number of the subcarriers is N. At the sending end, the data stream is modulated by inverse fast Fourier transform (IFFT) and a guard interval is added for every OFDM symbol to eliminate ISI caused by multi-path fading channel. The receiver performs opposite operations.

The received signal can be expressed:

$$Y_j(k) = \sum_{i=1}^{N_T} X_i(k) H_{i,j}(k) + W_j(k) \quad 0 \le k \le N-1 \tag{4}$$

Where $j = (1,2,\ldots,N_R)$, k is the k-th subcarrier, $Y_j(k)$ is the signal of the j-th receive antenna in frequency domain, $X_i(k)$ is the signal of the i-th transmitter antenna, $H_{i,j}(k)$ is the discrete response of the channel on subcarrier k between the i-th transmitter antenna and the j-th receive antenna, and $W_j(k)$ is the complex Gaussian noise with zero-mean and variance n_0^2

III. Channel Estimation Algorithm

A. LS Channel Estimation

LS algorithm is the simplest channel estimation. It is assumed that H_{LS} is the estimate of the channel impulse response H. The LS estimate of the channel in frequency domain on subcarrier k can be obtained as:

$$\hat{H}_{LS}(k) = \frac{Y(k)}{X(k)} = H(k) + \frac{W(k)}{X(k)} \qquad 0 \le k \le N-1 \tag{5}$$

B. Conventional DFT-based Channel Estimation

In OFDM system, the length of the channel impulse response L is usually less than the length of the cyclic prefix L_g. Conventional DFT-based algorithm just takes advantage of this feature. It transforms the in-frequency channel estimation into in-time channel estimation , considers the part which is larger than L_g as noise, and then treats that part as zero in order to eliminate the impact of the noise. The algorithm can be summarized as follows:

- Step 1: Calculate the LS estimate $H_{LS}(k)$ in the usual LS manner.
- Step 2: Covert $\hat{H}_{LS}(k)$ to time domain:

$$\hat{h}_{LS}(n) = IFFT[\hat{H}_{LS}(k)] = h(n) + \tilde{w}(n) \qquad 0 \le n \le N-1 \tag{6}$$

where

$$\tilde{w}(n) = IFFT[W(k)/X(k)] \tag{7}$$

- Step 3: Eliminate the impact of the noise in time domain:

$$\hat{h}_{DFT}(n)=\begin{cases}\hat{h}_{LS}(n) & 0\le n\le L_g-1\\ 0 & L_g\le n\le N-1\end{cases} \quad (8)$$

- Step 4: Covert time-domain response to frequency response by fast Fourier transform (FFT):

$$\hat{H}_{DFT}(k)=FFT[\hat{h}_{DFT}(n)] \quad 0\le k\le N-1 \quad (9)$$

IV. An Improved Channel Estimation Method

DFT contains periodicity. If the original data sequence is not continuous, it will generate additional high-order component. In order to reduce these high-order component, we can use symmetry principle before IFFT. With this understanding, we will select paths effectively in order to reduce leakage power by calculating the changing rate of the leakage energy. The improved algorithm can be summarized as follows:

- Step 1: Calculate the LS estimate $\hat{H}_{LS}(k)$.
- Step 2: Extend $\hat{H}_{LS}(k)$ with a symmetric signal of its own:

$$\hat{H}_{symmetric}(k)=\begin{cases}\hat{H}_{LS}(k) & 0\le k\le N-1\\ \hat{H}_{LS}(2N-1-K) & N\le k\le 2N-1\end{cases} \quad (10)$$

- Step 3: Covert $\hat{H}_{symmetric}(k)$ to time domain by IFFT:

$$\hat{h}_{symmetric}(n)=IFFT[\hat{H}_{symmetric}(k)]=h(n)+\tilde{w}(n) \quad 0\le n\le 2N-1 \quad (11)$$

- Step 4: The energy of the channel impulse response can be expressed as:

$$E=\sum_{n=0}^{2N-1}\left|\hat{h}_{symmetric}(n)\right|^2 \quad (12)$$

From Figure 1, we can see the energy concentrates at the ends of the sequences after the energy leakage. That means the leakage energy concentrates in the middle of the sequences. So (9) can be written as:

$$E=\sum_{n=0}^{N-1}\left|\hat{h}_{symmetric}(n)\right|^2+\sum_{n=0}^{N-1}\left|\hat{h}_{symmetric}(2N-1-n)\right|^2 \quad (13)$$

$$E=\sum_{n=0}^{N-1}E(n)$$

Where

$$E(n)=\left|\hat{h}_{symmetric}(n)\right|^2+\left|\hat{h}_{symmetric}(2N-1-n)\right|^2 \quad (14)$$

$E(n)$ is the rgy of the n -th sampling point. $l_{leakage}$ is defined as the first path number of starting leaking ene and $E(l_{leakage})$ is defined as the leakage energy between the $l_{leakage}$ -th path and the $(2N-1-l_{leakage})$-th path. $E(l_{leakage})$ can be expressed as:

$$E(l_{leakage})=\sum_{n=l_{leakage}}^{N-1}E(n) \quad 0\le l_{leakage}\le N-1 \quad (15)$$

The changing rate of the leakage energy $P(l_{leakage})$ can be defined as:

$$P(l_{leakage})=\frac{E(l_{leakage})-E(l_{leakage}+1)}{E(l_{leakage})} \quad (16)$$

If $P(l_{leakage})$ is large, it shows that it is not the concentrated area of the leakage energy between the $l_{leakage}$ -th path and the $(2N-1-l_{leakage})$-th path. If $P(l_{leakage})$ is small, it shows that the change of the power leakage is not obvious. That means the energy of the $l_{leakage}$ -th path is small compared with the total leakage energy. We can treat it as zero. Then the channel response can be expressed as:

$$\tilde{h}_{DFT}(n) = \begin{cases} 0 & l_{leakage} \le n \le 2N-1-l_{leakage} \\ \hat{h}_{symmetric}(n) & other \end{cases} \qquad (17)$$

In (12), $\hat{h}$ symmetric (n)contains $\tilde{w}$ (n)except for h(n) . From (7), we can see that w~(n) is determined by W (k) and X (k) . W (k) is white noise, and its amplitude of the spectrum is constant. So the system uses the training sequences which have equal amplitude. Then the the changing rate of the leakage energy will not be affected by the change of the amplitude of X (k) .

- Step 5: After padding with zeros, convert $h_{DFT}(n)$ frequency domain by FFT:

$$\tilde{H}_{DFT}(k) = FFT[\tilde{h}_{DFT}(n)] \qquad 0 \le k \le 2N-1 \qquad (18)$$

- Step 6: According to the symmetric property, the corresponding frequency response is expressed as:

$$\hat{H}_{DFT}(k) = \frac{\tilde{H}_{DFT}(k) + \tilde{H}_{DFT}(2N-1-k)}{2} \qquad 0 \le k \le N-1 \qquad (19)$$

V. Simulation Results

In the simulations, we assume a MIMO-OFDM system with two transmitter antennas and two receiver antennas. The multi-path channel consists of 5 independent Rayleigh fading paths and the total number of sub-carriers is $N = 128$. The guard time interval is 16 sample periods. The symbols are modulated by 16QAM. The delay of the antenna 1 is delay1= 0ˈ0.4ˈ1.2ˈ2.1ˈ3.4∨ μs , and the delay of the antenna 2is delay2=∧0ˈ0.5ˈ1.5ˈ2.7ˈ4.3∨ μs . Table 1 shows the system introduction.

Table I. System Introduction

System	$l_{leakage}$	$P(l_{leakage})$**(%)**
LS-DFT1	32	4.95
LS-DFT2	50	0.38
LS-DFT3	100	0.19

Fig.2, 3 respectively shows the MSE and BER performance of the improved DFT-based channel estimation is better than

the LS estimate and the conventional DFT estimate method. From Fig.2, we can see that the MSE of the conventional DFT method appears error floor earlier than the improved method with $P(l_{leakage})$=4.95 and $l_{leakage}$ =32. And the performance of improved method are both better than LS estimation and conventional DFT-based channel estimation method. The improved method becomes better when $P(l_{leakage})$=0.38 and improved method achieves a satisfying tradeoff between $l_{leakage}$ =50. However, when $P(l_{leakage})$=0.19 and $l_{leakage}$ =100, the performance of the improved method degrades. From Fig.3, we also see it. This is because more noise exists with decrease of $P(l_{leakage})$. So wo should select proper $P(l_{leakage})$considering the existence of noise in order to achieve better performance.

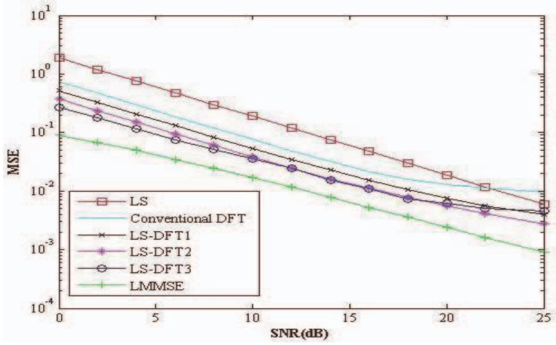

Figure 2. MSE performance of the improved method.

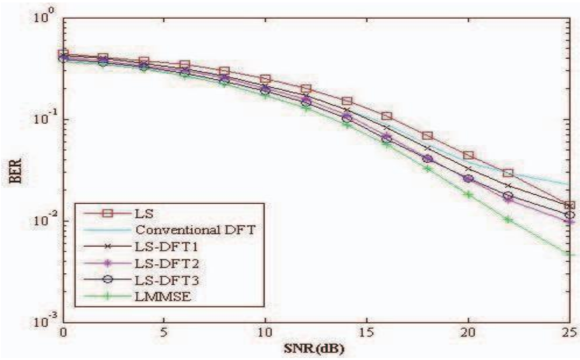

Figure 3. BER performance of the improved method

VI. Conclusion

In this paper, an improved DFT-based channel estimation method in non-sample-spaced multipath channel for MIMO- OFDM system is proposed. The improved method uses the symmetric property and calculates the changing rate of the leakage energy in order to select useful paths. Simulation results show that the improved method can reduce the leakage energy efficiently. And the MSE and BER performance of the improved method are both better than LS estimation and conventional DFT-based channel estimation method. The improved method achieves a satisfying tradeoff between complexity and performance.

VII. Acknowledgment

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