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Research paper

Investigations on wavelet and Fourier transform based channel estimation in MIMO-OFDM system

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Abstract

In this paper channel estimation methods for MIMO-OFDM system are investigated based on Fourier Transform and Wavelet Transform. The channel estimation algorithm based on Discrete Fourier Transform (DFT) cause energy leakage in multipath channel with non-sample-spaced time delays. Discrete Cosine Transform (DCT) based channel estimator can mitigate the drawback of Discrete Fourier Transform based channel estimator, when the non-sample spaced path delays are available in multipath fading channels. Wavelet based systems provide better spectral efficiency because of no cyclic prefix requirement, with narrow side lobes and also exhibit improved BER performance. Simulation results reveal that the DWT based transform outperforms the conventional DFT and DCT based channel estimator in terms of bit error rate and mean square error.

Keywords: *Discrete Fourier Transform (DFT), Discrete Cosine Transform (DCT), Discrete Wavelet Transform (DWT), Channel Estimation.*

1. introduction

The Discrete Wavelet Transform (DWT) is broadly considered as an efficient approach to replace FFT in the conventional OFDM systems due to its better time-frequency localization, bit error rate improvement, interference minimization, and improvement in bandwidth efficiency. The design of transmitter and receiver for wavelet modulation is presented in [1]. This wavelet modulation evaluates the bit error rate in presence of additive white Gaussian noise. Kucur *et al*. [2] proposed a multicarrier modulation based on time-frequency localization of the pulse shaping that reduces both narrowband interference and multipath channel interference. Marius Oltean *et al*.[3] analyzed the bit error rate performance of DWT based multicarrier modulation for frequency-selective and time-variant channel. Angrisani et al. [4] investigated the significant effect of presence of noise on the performance of OFDM receiver. DWT based OFDM has the ability to combat the narrow band interference as the wavelets possess high spectral containment properties and making the system more robust beside inter-carrier interference. Comparison between Fourier based and Wavelet based OFDM is presents in [5,6]. Khaizuran Abdullah *et al*. [7] conclude that to select a suitable wavelet method i.e, the new modulation scheme (wavelet packet modulation) which is used instead of the conventional OFDM. Mohammed Aboud Kadhim *et al*[8] propound that by reducing PAPR in DWT based OFDM systems we can use the traditional sinusoid carriers of the FFT based OFDM instead of using suitable wavelets. The simulation results showed that the Complementary Cumulative Distribution Function of PAPR for the DWT based OFDM signal achieved about 7dB improvement than the traditional OFDM signals at 10^{-3} of CCDF. Rohit Bodhe et al. [9] adopted DWT in place of FFT for frequency translation by using different modulation schemes i.e. 16-QAM, 32-QAM, 64-QAM and 128-QAM for both DWT and FFT based OFDM system model to achieve better performance in terms of Bit Error Rate for AWGN channel. It was found that all the wavelets perform better as compared to the IFFT-FFT implementation. El-Khamy et al. [10] proposed the use of discrete wavelet transform (DWT) in OFDM systems to mitigate the degrading effect of inter symbol interference successfully without using any cyclic prefix (CP). Therefore, bandwidth is conserved and the spectral efficiency is also improved. Anfal Ali Alansari [11] introduced the “Multiple Input Multiple Output Orthogonal Frequency Division Multiplexing” (MIMO-OFDM) system with Discrete Wavelet Transform (DWT) which offered new improvement performance results which have not been exist in either individual MIMO or OFDM. The performance results of the individual OFDM, MIMO and MIMO-OFDM systems are discussed and a comparison between these systems is done.

Somasekhar et al. [12] presented a pilot aided channel estimation for MIMO/ OFDM system in time-varying wireless channels. The performance analysis between Fourier BEM, DPSS models, Legendre and chebyshev polynomial based on Mean Square Error (MSE) is present.

Simulation results show that the DPSS-BEM model outperforms the Fourier Basis expansion model. Govinda Raju et al. [13] presented the Haar and Daubechies based orthonormal wavelets which have the capability of reconstructing the transmitted signal at the receiver and the effect of noise is minimized using wavelet denoising for different values of SNR on AWGN channel.

2. DFT and DCT based channel estimation in MIMO-OFDM

In OFDM systems, it is necessary to estimate the channel to obtain the channel state information (CSI), to overcome the distortion caused by fading.

Least Square (LS) method is widely used in channel estimation but it is more sensitive to noise respect to the other techniques.

Least Square (LS) Channel Estimation

The simplest algorithm in channel estimation is LS algorithm. The LS approximation in frequency domain can be obtained as:

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

Where $\hat{H}_{LS}$ is the estimate of the channel impulse response H, $X(k)$ is the transmitting antenna signal, $Y(k)$ is the receiving antenna signal, k is the no. of subcarriers and $W(k)$is the Gaussian noise.

In order to improve the performance of LS channel estimation, the DFT-based method has been proposed first as it can advantageously target both noise reduction and interpolation.

DFT-based channel estimation

Conventional DFT-based Channel Estimation transforms in-frequency channel estimation into in-time channel estimation and eliminates the influence of the noise as follows [14]

Case 1: Calculate LS estimate$\hat{H}_{LS}(k)$, similar to LS method

Case 2: The time domain of $\hat{H}_{LS}(k)$ is

$$IFFT\left[\hat{H}_{LS}(k)\right] = \hat{h}_{LS}(n) = h(n) + \widetilde{w}(n)$$

$$\text{Where } \widetilde{w}(n) = IFFT\left[\frac{W(k)}{X(k)}\right]$$

Case 3: Eliminate the influence of noise in time domain

$$\hat{h}_{DFT}(n) = \begin{cases} \hat{h}_{LS}(n) & 0 \le n \le L_g - 1 \\ 0 & L_g \le n \le N-1 \end{cases} \tag{2}$$

Case 4: Convert time domain response to frequency domain Response

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

In practice the performance of DFT is too slow and is not accurate in presence of error in signal. Direct computation of DFT is inefficient because it does not exploit the basic property of symmetric and periodicity. An Improved DFT based channel estimation algorithm can effectively reduce the leakage energy. In order to calculate the rate of change of leakage energy the enhanced method uses symmetric property. The symmetric signal can be expressed as

Case 1:

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

Case 2: Convert $\hat{H}_{symmetric}(k)$ to time domain

$$IFFT\left[\hat{H}_{symmetric}(k)\right] = \hat{h}_{symmetric}(n) = h(n) + \widetilde{w}(n)$$

$$0 \le n \le 2N-1$$

Case 3: The leakage energy $E(l_{leakage})$between $l_{leakage}$-th path and (2N-1-$l_{leakage}$)-th path can be expressed as [14]

$$E(l_{leakage}) = \sum_{n=l_{leakage}}^{N-1} E(n) \qquad 0 \le l_{leakage} \le N-1 \tag{3}$$

Where

$E(n) = \left|\hat{h}_{symmetric}(n)\right|^2 + \left|\hat{h}_{symmetric}(2N-1-n)\right|^2$is the energy of the n-th sampling point.

The rate of change of leakage energy P (l_{eakage}) is defined as

$$P(l_{leakage}) = \frac{E(l_{leakage}) - E(l_{leakage}+1)}{E(l_{leakage})} \tag{4}$$

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. Then the channel response can be expressed as:

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

Case 4: Convert $\hat{h}_{DFT}(n)$ to frequency domain

$$FFT\left[\hat{h}_{DFT}(n)\right] = \hat{H}_{DFT}(k) 0 \le k \le 2N-1$$

Case 5: According to the symmetric property, the corresponding frequency response is expressed as:

$$\hat{H}_{DFT}(k) = \frac{\widetilde{H}_{DFT}(k) + \widetilde{H}_{DFT}(2N-1-k)}{2}$$

$$0 \le k \le N-1$$

DCT based channel estimation

DCT based channel estimator can avoid defect in period boundaries partly but suffers from aliasing error. Aliasing effect and rudimental noise of conventional DFT and DCT channel estimation algorithms can overcome by considering the Truncated DCT channel estimation algorithm which is basing on mirror weighted DCT channel estimation. The method of mirror weighted original sequence is described as [15]

$$\hat{H}_{2M}(k) = \begin{cases} \hat{H}_P(k) & 0 \le k \le M-1 \\ 0 & k-M \\ \hat{H}_P(2M-k)e^{\frac{-j\pi(2M-k)}{M}} & M+1 \le k \le 2M-1 \end{cases} \tag{5}$$

3. DWT based channel estimation

The wavelet analysis consists of breaking up a signal into scaled and shifted versions of the original signal or mother wavelet. A series of wavelets generated from $\psi(x)$, is known as a "mother wavelet," which is restricted to a finite interval [16].Daughter wavelets, (x), are then calculated by translation (b) and contraction (a). An individual wavelet can be defined by

$$\psi^{a,b}(x) = |a|^{\frac{-1}{2}}\psi\left(\frac{x-b}{a}\right) \tag{6}$$

The DWT-OFDM symbol $S(t)$ can be represented as [1],

$$S(t) = \sum_{j \le J}\sum_k w_{j,k}(t)\psi_{j,k}(t) + \sum_k a_{J,k}\varphi_{J,k} \tag{7}$$

Orthogonality of these carriers depend on *k* and *j*. Where *k* isthe time location and *j* is the scale index. The symbol *S(t)* in (7) is similar to Inverse Discrete Wavelet Transform (IDWT) which is equal to weighted sum of wavelet and scale carriers. Next, the IDWT block processes the data and gives the output as,

$$d(k) = \sum_{m=0}^{\infty}\sum_{n=0}^{\infty} D_m^n 2^{\frac{m}{2}}\psi(2_k^m - n) \tag{8}$$

Where k is the number of subcarriers ($0 \le k \le N-1$), D_m^n are the wavelet coefficients, representing the signal in scale and position on time-axis and $\psi(t)$ is the wavelet function with compressed factor m times and shifted n times for each subcarrier [17].

Wavelet carriers in DWT-OFDM uses different types of scales (j) and positions on time-axis (k). Wavelet mother $\psi(t)$ is derived by translation and dilation of a unique function and is given by [18],

$$\psi_{j,k}(t) = 2^{-\frac{j}{2}}\psi(2^{-j}t - k) \tag{9}$$

The orthogonality of subcarriers depend upon scale index (j) and time location index (k). While compared to complex exponentials used in FFT based OFDM systems [19] it also reveals better time-frequency localization. According to (9) the condition of orthogonality is achieved only if it satisfies,

$$\langle \psi_{j,k}(t), \psi_{m,n}(t) \rangle = \begin{cases} 1 & if\ j = m, k = n \\ 0 & otherwise \end{cases} \quad (10)$$

A finite number of scales obtained through the scaling function $\varphi(t)$and is generated using (11) [20],

$$\varphi_{j,k}(t) = 2^{\frac{j}{2}}\varphi(2^j t - k) \quad (11)$$

Resolution depend on the values of j. More the value of j the resolution would be better. The functionφ (t) denotes the lower resolution and it can be represented by the weighted sum of shifted versions of some scaling functions at next higher resolution i.e.(2t), given by (12)

$$\varphi(t) = \sum_k h(k)\sqrt{2}\ \varphi(2t - k) \quad (12)$$

We are using another set of functions represented by $\psi(j,t)$ and this can be also represented in terms of the scaling function, and it also describers the important features of a signal in a better way which is given by (13) as follows,

$$\psi(t) = \sum_k g(k)\sqrt{2}\,\varphi(2t - k) \quad (13)$$

The set of (k) coefficients are known as Wavelet Function Coefficients. The wavelet basis function $\psi(t)$ is defined, in terms of the mother wavelet function, given as [20]:

$$\psi_{s\tau}(t) = \frac{1}{\sqrt{|s|}}\psi\left(\frac{t-\tau}{s}\right) \quad (14)$$

In equation (16), both s and τ are continuous variables.
The DWT of a signal $x(t)$ is set of coefficients $X_{DWT}(m,k)$ for m and k,as obtained from the inner product of the signal $x(t)$ and the wavelet function, $\psi_{m,k}$.
The discrete wavelet and inverse discrete representation is given by (15) and (16) respectively [9].

$$X_{DWT_k^m} = \int_{-\infty}^{\infty} x(t)\, 2^{\frac{m}{2}}\, \psi(2^m t - k)dt \quad (15)$$

$$X_{IDWT}(t) = \sum_{m=-\infty}^{\infty}\sum_{k=-\infty}^{\infty} X_k^m\, 2^{\frac{m}{2}}\, \psi(2^m t - k) \quad (16)$$

Where $\psi_{m,k}$, is the wavelet function [21]. Mallet's fast wavelet transform (FWT) provides a computationally efficient, practical, discrete time algorithm for computing DWT.
At the receiver the Discrete Wavelet Transform converts the time domain *x(n)*data into frequency domain data *X(k)* and then the channel $H_e(k)$ is estimated. For frequency domain channel estimation, MSE is usually considered as the performance measure of channel estimation and it is defined by

$$\text{MSE} = \left\{\left|H[K] - \hat{H}[K]\right|^2\right\} \quad (17)$$

Where $H[K]$ is the ideal channel and $\hat{H}[K]$ is the estimated channel.

4. Simulation results

In this paper, a MIMO-OFDM system can be considered with two transmit and two receiver antennas. The multi-path channel consists of 5 independent Rayleigh fading paths where the total number of sub-carriers is N=128 and the guard time interval is 16 sample periods. The symbols are modulated by 16QAM. Fig.1 shows the BER performance of LS, LMMSE, and DWT. It clearly shows that DWT is much better than the two previous LS and LMMSE channel estimators. This reflects the fact that the DWT is more significant than the LS and LMMSE algorithms. From Fig.2, we can see the MSE of LS, DFT, and DWT. From the above figure the MSE performance of DWT is better than the LS, LMMSE and conventional DFT. Fig.3 shows the MSE performance at different SNR values. From Fig.3 we can see that the MSE performance of DWT at SNR=10dB is approximately 10^{-3} and is superior to conventional methods.

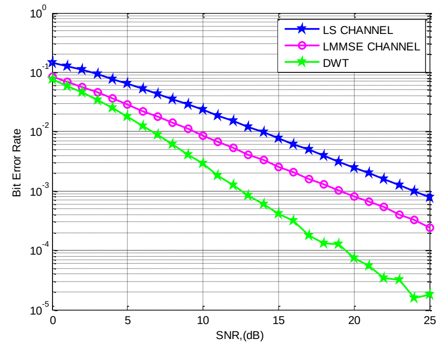

Fig.1. BER performance of LS, LMMSE, DWT

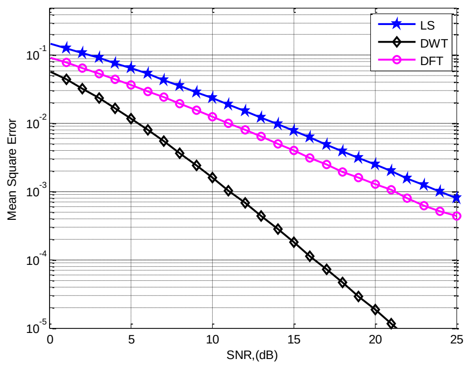

Fig.2. MSE Performance comparison with LS, DFT, DWT

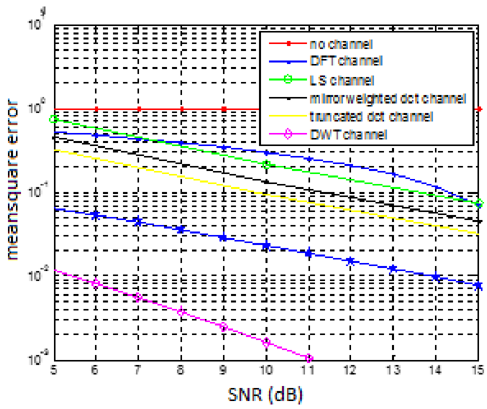

Fig.3. MSE Performance comparison with DFT, LS, Truncated DCT, DWT

5. Conclusion

This paper presented an enhanced DFT channel estimation using non-sample-spaced multipath channel to overcome the problem of conventional DFT method. Low-complexity truncated DCT channel estimator was also presented which is favorable for matrix-based channel estimator. Simulation results prove that an improvement of 3 dB is achieved at the BER of 10^{-2} using DWT based algorithm and MSE performance of DWT is around 10^{-3} at SNR of 10dB which is superior compared to conventional methods.

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