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Low-Complexity Wavelet Based Channel Estimation With Low Leakage For OFDM Systems

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Abstract: **In this paper, we describes, a low-complexity wavelet -based channel estimator with low leakage is proposed for OFDM systems using virtual subcarriers. In this paper, a new threshold based method using wavelet decomposition will be proposed which is based on an initial LS estimation technique. The reported simulation results show that the proposed method has better performance compared to the other methods such as Lee Method that has been published recently.. The performance and complexity of the proposed channel estimator are analyzed and verified by computer simulation. Simulation results show that the proposed estimator outperforms conventional estimators and provides near-optimal performance while keeping the low complexity comparable to the simple wavelet based channel estimator.**

Keywords: **Wavelet Transforms; OFDM; Low Leakage And Channel Estimation;**

I. INTRODUCTION

Although the linear minimum mean square error (LMMSE) estimator [1] is optimal in the sense of the mean square error (MSE) performance, the discrete Fourier transform wavelet-based estimator has been more preferred due to the comparable complexity-performance trade-off so that it has been widely used in practice for orthogonal frequency division multiplexing (OFDM) systems [2]. OFDM is a signaling technique that has been applied widely in wireless communication systems due to its ability to maintain effective transmission and highly efficient bandwidth utilization in the presence of various channel impairments which one of them is frequency selective fading. In OFDM systems the available spectrum are divided into many orthogonal sub-channels, which are instantaneously used to data transmission. Also, in this technique the inter-symbol interference (ISI) which is induced due to frequency selective channels can be reduced by adding the cyclic prefix (CP) [3].

In OFDM systems, channel estimation is necessary to obtain the channel state information (CSI), reducing the bit error rate and also to achieve a distortion less output data. There are various methods to channel estimation such as: with or without a need to parametric models, blind or pilot based methods, frequency and/or time domain analysis, adaptive or non adaptive techniques. Among these mentioned methods, channel estimation in OFDM systems is often done in frequency domain using pilot symbols or training data [4]. The least square and minimum mean-square error (MMSE) are conventional linear channel estimation techniques which are based on pilot arrangement. The LS method is less complicated and simple respect to other methods and consequently is used to channel estimation, but it has a serious drawback which is more sensitive to channel noise. MMSE estimator has better performance than LS method but suffers from a high computational complexity because it requires knowledge of the channel statistics and the signal-to-noise ratio (SNR) [5]. Some different methods have been developed to reduce the complexity and improve the performance of the MMSE estimation such as modified MMSE and singular value decomposition (SVD) [6-7].

1n 2006 Noh et al. proposed a method to decomposing the covariance matrix to the simple and low order sub matrix so that they can decrease the complexity of MMSE method [6]. Hsieh used a comb type pilot arrangement and second order interpolation method to channel estimation [7]. Coleri et al. compared the results of many interpolation techniques to channel estimation with Rayleigh fading such as linear, second order, cubic, low pass filtering and spline interpolation methods [8]. Edfors et al. modified the MMSE and LS methods with assumption that the channel model to be an FIR in which the impulse response duration can't greater than the Guard Interval of an OFDM symbol [9]. Dowler assumed that if the maximum delay caused by channel to be a known parameter so estimation based on DFT method can obtain better results [10]. Minn et al. improved the results of Dowler method by considering a sparse channel model [11]. In [12] Kang et al. proposed a DFT based channel estimation. In their method the effect of channel noise in outside of maximum channel delay are replaced with zero and finally a good estimation were resulted. In 2009 Lee et al. obtained an optimal threshold value based on wavelet decomposition and therefore they could improve the channel estimation [13].

In this paper, we propose a time-domain approach to channel estimation using wavelet decomposition.

In this approach, initial channel estimation is calculated by the LS estimator, and then channel coefficients in time-domain are obtained using IFFT transform. It is assumed that the maximum delay caused by channel at most is equal the length of cyclic prefix. In the next step wavelet transform is applied to the obtained coefficients in order to calculate a threshold value [14]. Finally, the estimated coefficients are de-noised and the good estimate is obtained using the calculated threshold.

II. SYSTEM DESIGN MODEL

2.1 OFDM Systems

OFDM technique converts a frequency selective channel into a number of frequency nonselective channels by dividing the available spectrum into a number of overlapping and orthogonal narrowband sub channels where each of them sends own data using a subcarrier. A block diagram of OFDM systems is shown in figure (1).

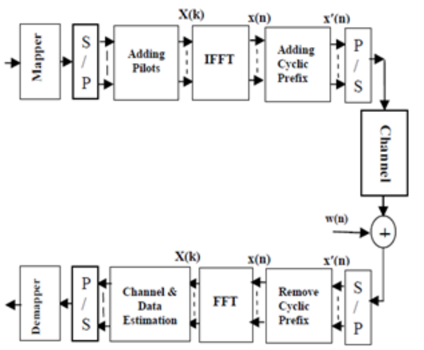

Figure 1. The OFDM System in base band model.

At first, in transmitter the binary inputs are grouped to get an *M*-ary symbol. According to a predefined baseband modulation such as QPSK and MQAM, the obtained symbols are modulated using a signal mapper subsystem. In the next step, an *S/P* sub-block converts the serial input symbols to a block data which can be considered as a vector *X*=[*X0*, *X*1 …, *XN-1*].

The vector size is '*N*' which determine the number of subcarriers in OFDM signal. Any subcarriers will be modulated by the obtained symbols in data vector using IFFT technique and consequently, the time domain of the *OFDM* signal are calculated which can be written as equation (1).

$$x(n) = \frac{1}{\sqrt{N}} \sum_{k=0}^{LN-1} X_K e^{j\frac{2\pi}{LN}kn} \quad 0 \le n \le LN-1 \qquad (1)$$

Where '*L*' is an oversampled factor which can be set to any number as: 2, 4, 8, 16. To prevent the effect of ISI in OFDM signals, a guard time which well known as cyclic prefix, must be add to the symbol. The equation (2) and figure (2) shows the adding process.

$$x'(n) = \begin{cases} x(N+n) & n = -N_c, -N_c+1, \ldots, -1 \\ x(n) & n = 0, 1, \ldots, N-1 \end{cases} \qquad (2)$$

Where '*Nc*' denotes the cyclic prefix length

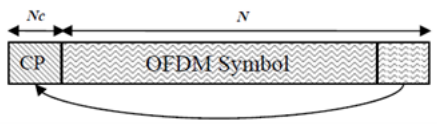

Figure 2. Cyclic Prefix adding process in OFDM symbol.

Finally, the obtained OFDM signal is converted to serial form and is transmitted to the receiver side through a frequency selective channel which is often considered as a Rayleigh fading model with additive white Gaussian noise (AWGN). The received signal in the output of the channel can be modeled as equation (3).

$$y'(n) = x'(n) \otimes h(n) + w(n) \quad 0 \le n \le N' \qquad (3)$$

Since LS estimator is much sensitive to noise, we introduce a time-domain method to channel estimation which its objective is improvement the performance of LS algorithm. In this paper it is assumed that the pilot spaces are related to the maximum delay caused by the channel. The estimated channel impulse response obtained by LS has most of its energy concentrated on a few first samples because in practice, the channel length is shorter than the IFFT size which can be determined by the cyclic prefix length. In this paper we will consider threshold based channel estimation in wavelet domain. Calculating of the threshold value is very important to noise reduction in channel estimation. According to [14], the calculated threshold value using wavelet decomposition can be obtained better results than other threshold based techniques.

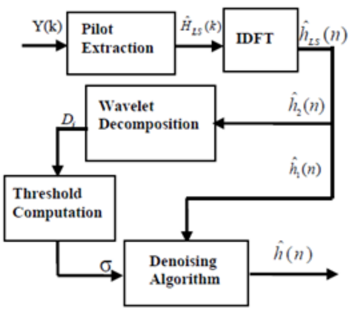

Figure 3. Block diagram of the proposed method

2.2 Channel Estimation

In any communication systems, channel estimation is a most important and challenging problem, especially in wireless communication systems. Usually, the transmitted signal can be degraded by many detrimental effects such as mobility of

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transmitter or receiver, scattering due to environmental objects, multipath and so on. These effects cause the signal to be spread in any transformed domains as time, frequency and space. To reducing these effects anyone must estimate the channel impulse response (CIR). Channel estimation has a long history in single carrier communication systems. In these systems, CIR is modeled as an unknown FIR filter whose coefficients are time varying and need to be estimated [16]. There are many channel estimation methods that can be used in multicarrier communication systems but the especial properties of multicarrier transmission systems give an additional perspective which forces to developing new techniques to channel estimation in wireless communication systems. In general, channel estimation methods based on OFDM systems can be categorized into two groups as blind and non-blind techniques. In the former, all of the techniques use the statistical behavior of the received signals and therefore, to obtain the accurate CIR a large amount data is required [17]. Finally, the complexity of computations is very high. In the later, to obtain a good estimation of channel, the transmitter sends a collection of data aided as pilots whose are previously known by the receiver. Often, most OFDM based systems as IEEE 802.11a and hyperLAN2 use pilots in frequency domain in order to sampling the faded channel in frequency domain.

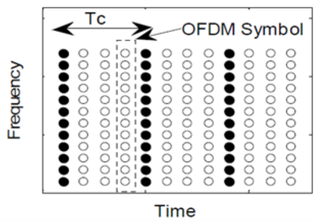


Figure 4. Block type arrangement of OFDM symbols.

2.3 Least Square Method

This method can be applied in both block and comb type. In later arrangement, in frequency domain, at first the channel output at pilot locations is extracted. In the next step channel estimation can be calculated using the extracted subcarriers which are known to the receiver. The corresponding equation can be written as the following equation.

$$\hat{H}_{LS}(k_p) = \frac{Y(k_p)}{X(k_p)} = H(k_p) + W'(k_p),\ k_p = 1,2,\dots,N_p$$

Where *W´*(*kp*)=*W*(*kp*)/*X*(*kp*) is the noise component at the estimated channel coefficients in frequency domain and '*kp*' denotes a subcarrier index at *pth* pilot. Then to obtaining the channel estimation at the data subcarriers, an interpolation technique is required. There are some interpolation techniques in [10] but linear interpolation is the simple one which can be written as equation.

$$\hat{H}(k) = [1-\frac{(k-k_p)}{L}]\hat{H}(k_p) + \frac{(k-k_p)}{L}\hat{H}(k_p+L).$$

2.4 Wavelet Decompositions

Wavelet transforms provide a framework where a signal is decomposed, with each level corresponding to a coarser resolution, or lower frequency band. There are two main groups of transforms, continuous and discrete. Continuous wavelet transform of the signal $x(t)$ can be expressed by :

$$x(a,b) = \frac{1}{\sqrt{a}}\int_{-\infty}^{+\infty} x(t)\psi^*(\frac{t-b}{a})dt \quad a>0,\ b\in\mathbb{R}.$$

Where '*a*' is called the scaling factor and also '*b*' denotes the translation factor and $\psi(t)$ is wavelet function. Although the continuous wavelet transform is simple to describe mathematically, both the signal and the wavelet function must have closed forms, which make it difficult or impractical to apply. The discrete wavelet is used instead so that if we choose the scale '*a*' and position '*b*' based on powers of two, the analysis will be much more efficient and accurate. Any finite energy analog signal $x(t)$ can be decomposed into a coarse approximation represented by scaling functions $\varphi(t)$ and details are represented by wavelet functions $\psi(t)$ as follows:

$$x(t) = \sum_{k=-\infty}^{+\infty} c_k\varphi(t-k) + \sum_{k=-\infty}^{+\infty}\sum_{j=0}^{+\infty} d_{j,k}\psi_{j,k}(t)$$

$$\psi_{j,k}(t) = 2^{j/2}\psi(2^j t-k).$$

Approximated and detailed coefficients can be obtained based on low-pass and high-pass filter respectively. These filter coefficients are calculable according to equation (11):

$$\varphi(t) = \sum_k h_0(k)\sqrt{2}\varphi(2t-k)$$

$$\psi(t) = \sum_k h_1(k)\sqrt{2}\psi(2t-k)$$

Where *h0*(*k*) and *h1*(*k*) are impulse response of low-pass and high-pass filters respectively. Based on these filters, each ideal signal can be expanded as coefficients wavelet. Figure (5) shows related decompositions in two levels.

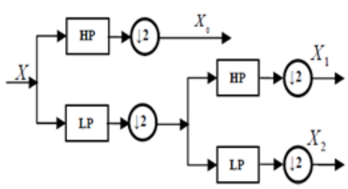
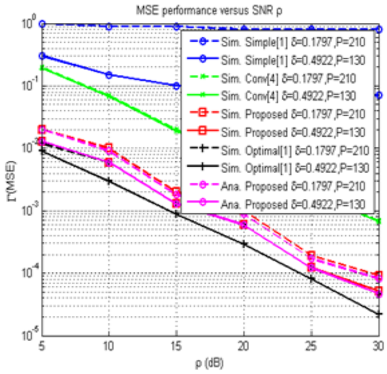
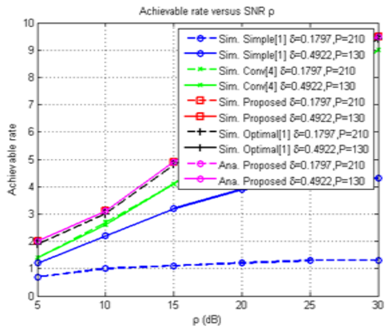


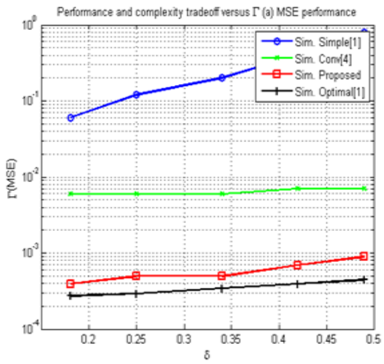
Figure 5. Wavelet decomposition in 2 levels

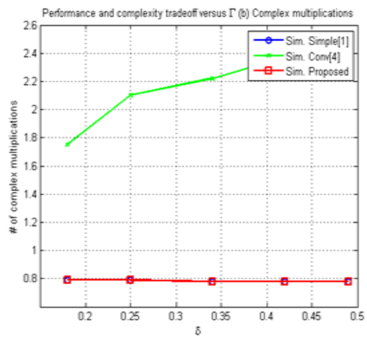
III. SIMULATION RESULTS

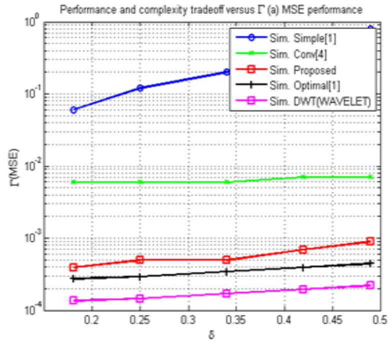
In order to evaluate the proposed method it is necessary that a simulation must be taken. In all simulations the block coding and inter leavers are not used and also in order to better evaluation of the proposed method the channel equalization are not considered.

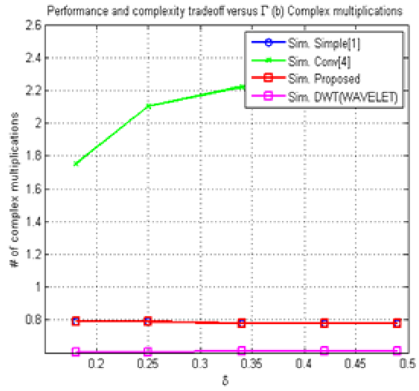












It is noted that the obtained result in the proposed method is better than Lee and LS methods in overall SNR conditions. It is shown that the proposed method has improvement of about 1-1.5dB compared to the Lee method. a low-complexity leakage suppression using a regularized TD post-processing. From the results, it is confirmed that the proposed estimator can provide near-optimal performance both in the sense of the MSE and the achievable rate while keeping low complexity similar to the simplest DFT-based channel estimator. Note that the proposed approach can be extended for practical cellular systems using orthogonal frequency division multiple access or single-carrier frequency division multiple access by employing a proper interference cancellation scheme. Thus, it would be fruitful to develop a practical channel estimator suitable for LTE or LTE-advanced systems as the future work.

IV. CONCLUSION

In this paper, a new method to estimating the faded channel based on wavelet decomposition is presented. In this method, a threshold based on wavelet decomposition is used in order to reduce the noise effect. It is assumed that the channel length is related to the maximum delay spread caused by multipath channel. This method is less sensitive to changes in modulation parameters and pilot spacing compared to Lee method that leads to improvement in channel estimation. It is shown that the proposed method has improvement of about 1-1.5dB compared to the Lee method.

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