On the Improved MB-OFDM System for Wireless Personal Area Networks

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***Abstract*—The IEEE 802.15.3a model for UWB channel models is introduced in this paper. The least-squares (LS) channel estimation on the basis of pilot and linearity insertion are described. Wavelet de-noising for semi-blind channel estimation of multiband Orthogonal Frequency Division Multiplexing (OFDM) based on WPANs UWB system was added. Compared with conventional method, the proposed framework can reduce the influence of noise.**

Keywords-Least-squares; Channel estimation; Wavelet de-noising; OFDM; Wireless Personal Area Networks

I. Introduction

Ultra wideband (UWB) is one of the key emerging technologies targeted particularly for short-range and low-power radio communication systems with devices having a small-to-medium form factor [1]. Several work regarding on-body UWB system modelling have been reported [2-6]: in [2], system-level analysis of UWB MB-OFDM radio system was performed by calculating the Bit Error Rate (BER) of several on-body radio links; Batra *et al.* [3] described the design of a UWB system optimized for very high bit-rate, low-cost, and low-power wireless networks for personal computing, consumer electronics, and mobile applications; Abbasi *et al.* [4] demonstrated that the BER is equal to or less than 0.1%, for 75% of stable and 61% of unstable transmitter locations respectively; in [5], Sudjai *et al.* investigated the performance of the space-time-frequency coded multiband orthogonal frequency division multiplexing UWB system over wireless personal area network (WPAN) channels. In the work presented above, various kinds of WPANs UWB systems were proposed, broadening the scope of selection for users; however, one should note that the BER performance still needs to be further improved. In this paper, we propose a wavelet de-noising method based system, which can improve the MB-OFDM system in terms of BER. It is worth noting that the modified S-V model [7], which can represent typical WPANs channels [2, 7-9], is used as the reference model in the evaluation process.

The paper is organized as follows: section 2 gives a brief introduction of IEEE 802.15.3a modified S-V channel model; section 3 proposes the improved MB-OFDM system for WBANs; conclusion is presented in section 4.

II. IEEE 802.15.3a Modified S-V Channel [7]

The IEEE 802.15.3a Multiband-OFDM (MB-OFDM) UWB system architecture was created by Simulink of Matlab®. The block diagram of the MB-OFDM system is illustrated in Fig. 1 [4]:

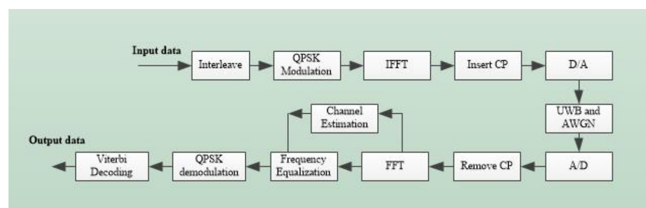

Figure 1. Baseband model of the MB-OFDM system

Channel impulse response (CIR) is generated by UWB channel model. The real-time data are received through each Rx position. In [7], it is mentioned that the CIR of WPANs can be replaced by the modified S-V model; therefore, in this article, four default and different channel information were used. Modified S-V model of channel impulse response can be represented as:

$$h(t) = \sum_{l=0}^{L}\sum_{k=0}^{K}\alpha_{k,l}\delta(t - T_l - \tau_{k,l}), \quad (1)$$

where $\alpha_{k,l}$ is the multipath gain coefficient, T_l is the delay of the l^{th} cluster, and $\tau_{k,l}$ is the delay of the k^{th} multipath component relative to the l^{th} cluster arrival time (T_l).

The model inherited the characteristics of S-V model; however, it is different from conventional model S-V. Because the multipath gain no longer conforms to the Rayleigh distribution and Logarithmic normal distribution. It is suggested in the system that the real baseband signal (see equation (1)) should be used.

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The modified model includes three parameters: the power delay profile, the RMS delay spread and the main multipath components. The channel delay spread can be measured through the power delay profile [10]:

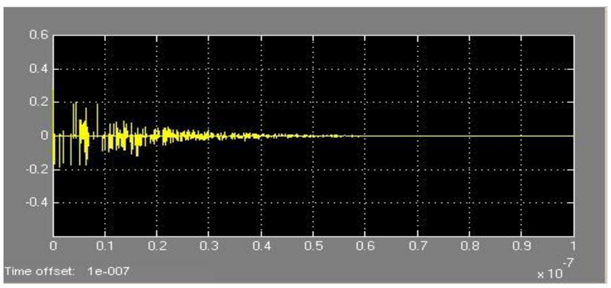
$$P(\tau)=\frac{|h(t)|^2}{\int_{-\infty}^{+\infty}|h(t)|^2\,dt}\,, \tag{2}$$

where $h(t)$ is the channel impulse response.

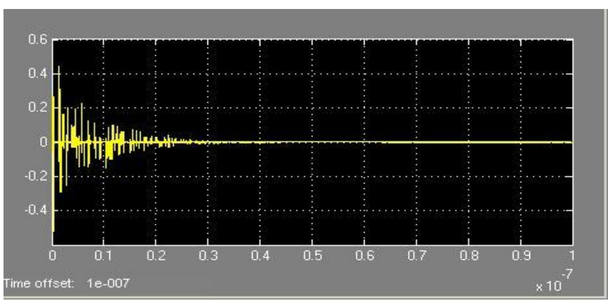
RMS delay spread is defined as follows [11]:

$$\tau_{RMS}=\left[\int(\tau-\tau_A-\tau_m)^2P(\tau)d\tau\right]^{1/2}. \tag{3}$$

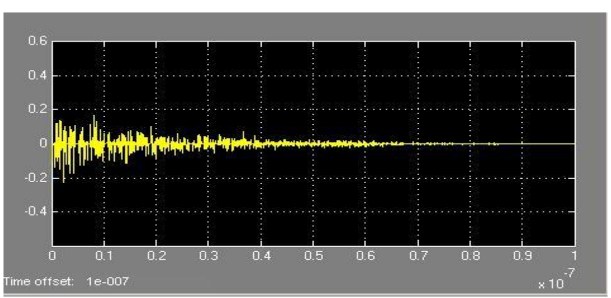
The number of multipath components is very important, which affects the design of RAKE receiver. We can use Matlab® to simulate the IEEE typical environment CM-1 ~ CM-4 based on the basic channel parameters. The channel impulse response is shown in Fig. 2.



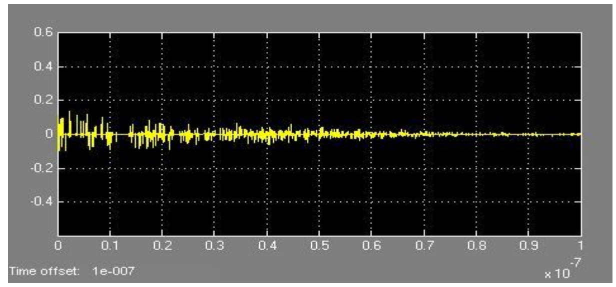
(a) CM-1Channel impulse response



(b) CM-2Channel impulse response



(c) CM-3Channel impulse response



(d) CM-4Channel impulse response

Figure 2. The average impulse response of the model IEEE 802.15.3a

III. IMPROVING THE MB-OFDM SYSTEM FOR WBANS

In the MB-OFDM systems, the channel estimation which is based on pilot frequency often use LS algorithm or MMSE algorithm. Compared with the LS algorithm, MMSE can achieve better effect, but has higher computational complexity. The LS algorithm is easy to calculate and has been widely used. Since the LS algorithm does not consider the effect of noise, its precision is lower. If the noise effect is eliminated, the accuracy of channel estimation can be improved. In this paper, LS algorithm, together with wavelet de-noising method, was used to analysis the channel estimation.

A. *The combination of LS Channel Estimation and linear interpolation*

At the pilot, assume Y_P is the received signal, X_P is the transmitted signal, W_P is the noise, H_P is the channel frequency response matrix at pilot sub-carriers, and can be obtained in equation (4):

$$Y_P=X_PH_P+W_P\,, \tag{4}$$

where P is the number of pilot subcarriers.

Then, H_P can be estimated from formula (4) using the cost function [12]:

$$\begin{aligned} f(\hat{H}_P)&=(Y_P-\hat{Y}_P)^H(Y_P-\hat{Y}_P)\\ &=(Y_P-X_P\hat{H}_P)^H(Y_P-X_P\hat{H}_P)\end{aligned}, \tag{5}$$

where $\hat{H}_P$ is the channel frequency response estimation at the pilot. Superscript $(\bullet)^H$ represents the associate matrix. Solving the partial derivative of $f(\hat{H}_P)$, it can be expressed as:

$$\frac{\partial f(\hat{H}_P)}{\partial\hat{H}_P}=X_P^H(\hat{H}_PX_P-Y_P)\,. \tag{6}$$

Then, the channel frequency response at the pilot can be obtained under LS criterion:

$$\hat{H}_{LS(P)} = \frac{Y_P}{X_P} = H_P + \frac{W_P}{X_P} . \quad (7)$$

Formula (7) means that the LS channel estimation only needs a matrix inversion and a matrix multiplication. Therefore, the pilot position of channel frequency response can be obtained. $\hat{H}_{LS(P)}$ is an approximation of H_P. If the noise reduces, BER can be improved. If the input X_P is normalized:

$$X_P(m) X_P^*(m) = 1 . \quad (8)$$

Through linear interpolation, we can get

$$\begin{aligned}\hat{H}_N(k) = & \left[(1-\frac{l}{L})\hat{H}_{LS(P)}(mL) + \frac{l}{L}\hat{H}_{LS(P)}(m+1)L \right] + \\ & X_P^*(m)\left\{ (1-\frac{l}{L})\left[W_N(mL)+I_N(mL)\right] + \right. , \\ & \left. \frac{l}{L}\left[W_N((m+1)L)+I_N((m+1)L)\right] \right\}\end{aligned} \quad (9)$$

where $0 \le m \le M-1$, $0 \le l \le L$, $mL < k < (m+1)L$. M is the number of pilot, L is the Pilot interval, N is the number of all subcarriers, $W_N(k)$ is k^{th} subcarrier noise, $ICI_N(k)$ is k^{th} subcarrier channel interference, $H_N(k)$ is the k^{th} subcarrier of noise frequency response. Literature [13] shows that $\left[W_N(mL)+I_N(mL)\right]$ obey zero mean Gaussian distribution [14]. Formula (9) and Formula (7) fit the signal de-noising model. Thus, the wavelet de-noising method can be used to remove the noise; as a result, the accuracy of estimation can be improved.

B. Wavelet De-noising

The whole channel frequency response can be obtained through linear interpolation. The high frequency part should be de-noised and reconfigured to achieve a better channel estimation result. Block diagram of channel estimation based on wavelet de-noising system is illustrated in Fig. 3:

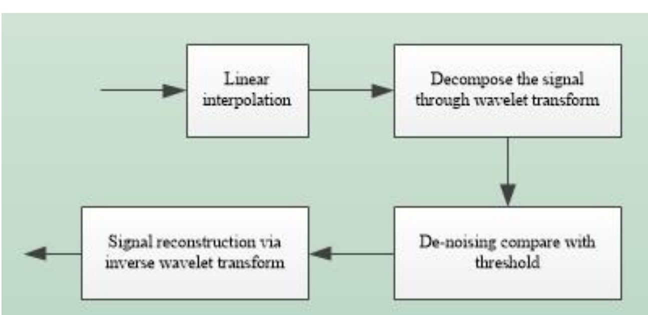


Figure 3. Channel estimation based on wavelet de-noising

Given a signal $f(t) \in L^2(R)$, we have [15]

$$W_f(a,b) = \int_{-\infty}^{+\infty} f(x)\psi_{a,b}(x)dx , \quad (10)$$

where $\psi_{a,b}(t) = \frac{1}{\sqrt{a}}\psi\left(\frac{t-b}{a}\right)$ is the wavelet function. a is the scale factor, b is the translation factor. They are defined as $a = 2^j$, $b = k2^j$, $f(t)$ can be expressed as $f(t) = \sum_j \sum_k c_{j,k}\psi_{j,k}(t)$. $c_{j,k}$ is the wavelet coefficient. Discrete wavelet transform formula can be obtained [16]:

$$c_{j,k} = \sum_n c_{j-1,n} h(n-2k) , \quad (11)$$

$$d_{j,k} = \sum_n c_{j-1,n} g(n-2k) , \quad (12)$$

$c_{0,n}$ is the discrete version of $f(t)$. The reconstruction formula for $f(n)$ is:

$$f(n) = \sum_{j=1}^{J}\sum_{k\in Z} d_{j,k}\tilde{g}_j(n-2k) + \sum_{k\in Z} c_{J,k}\tilde{h}_j(n-2^j k) , \quad (13)$$

where $\tilde{h}(n)$ and $\tilde{g}(n)$ are the reconstructed wavelet filter banks.

Channel transmission often has noise, and it usually consists of two parts—the useful signal and the noise. Usually the noise can be characterized by threshold and it can be obtained through experience. Then, the signal can be obtained through inverse wavelet transform; thus, the goal of de-noising can be achieved; as a result, the noise is reduced. $\hat{H}_{LS(k)}$ is channel estimation value that can be obtained by LS method through the linear interpolation. The channel estimation value at receiving terminal is:

$$\hat{H}_{LS(k)} = H_k + \frac{W_k}{X_k} . \quad (14)$$

In (14), the k^{th} channel estimation at the carrier frequency is composed of two items. One is the real response of the channel H_k, the other is the interference W_k / X_k. When the SNR is low, the influence of the noise will increase, then the value W_k / X_k will become greater. At this point, the channel estimation value $\hat{H}_{LS(k)}$ would have larger deviation compared with the real value H_k. In this case, we can adopt the method of wavelet de-noising to suppress the noise; hence, the noise effect can be reduced.

Ⅳ. CONCLUSION

This paper proposes the wavelet de-noising based MB-OFDM channel estimation algorithm.

Firstly, after LS algorithm we can obtain channel response at the pilot. Then we use linear interpolation. Using wavelet transform and threshold to handle the noise in the multipath fading channel. So this method reduces the ICI and AWGN. Finally, we can get an ideal BER. It can be combined with

WBANs system so that we have better performance.

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