Two-Stage Channel Estimation using LS approach for MB-OFDM UWB System

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Abstract— In this paper a two-stage channel estimation technique for high rate ultra-wideband communication system is proposed. In the preamble-stage, channel estimation is done using least square approach followed by frequency-domain smoothing operation. Channel estimated at this stage is then windowed by a rectangular window whose length is optimized by the Hannan–Quinn criteria. The channel estimated from the previous stage is further refined by applying time- and frequency-redundancy in a decision-directed manner followed by smoothing and windowing. Link level simulation shows that the two-stage method with fixed window size provides a good estimation performance close to that of the minimum-mean-square-estimation (MMSE) scheme with significant reduction in computational cost.

Key words: Channel Estimation, MB-OFDM, UWB systems, Hannan-Quinn Criteria, LS approach

I. INTRODUCTION

In wireless communications, Channel State Information (CSI) refers to known channel properties of a communication link. This information describes how a signal is transmitted from the transmitter to the receiver and represents the combined effect of scattering, fading and power decay with distance. This method is called Channel Estimation. Multiband orthogonal frequency division multiplexing(MB-OFDM) ultra-wideband (UWB) is a radio technology for short range wireless communications with high data rate [1]. For an error free data decoding, efficient channel estimation with low computational complexity at receiving side is necessary. There exist a number of channel estimation techniques for UWB communications [2]. However, these methods estimate channels only at preamble stage. The possibility of further performance improvement by using channel measurements at payload stage is not considered. The two-stage method proposes a simple channel estimation technique for MB-OFDMUWB system that offers considerable estimation performance with low computational cost.

II. SYSTEM AND SIGNAL MODEL

If the channel and noise distributions are unknown, then the least-square estimator is used. The method of least squares is about estimating parameters by minimizing the squared discrepancies between observed data, and their expected values. According to the standard ECMA-368 [3], there are six OFDM symbols dedicated for channel estimation in each packet layer convergence protocol (PLCP) protocol data unit(PPDU). This is basically a transmission frame structure of preamble, header, and payload. The payload consists of Nsym OFDM data symbols, where Nsym is an integer multiple of 6. We use six dedicated training symbols for primary channel estimation. Payload OFDM symbols are grouped each of which contains 12 OFDM symbols. OFDM symbols in each group are used in decision-directed manner for final channel estimation for that group. We describe the channel estimation procedure for the first OFDM- symbols group (OSG); the same process is done for the subsequent groups. The set of data subcarriers and set of pilot subcarriers in an OFDM symbols are denoted by Z.

Also, we assume the L-tap UWB channel impulse response (CIR) on sub-band q represented by $h^q = [h^q(0), h^q(1), \ldots, h^q(L-1)]^T$ whose corresponding channel frequency response (CFR) is denoted by $H^q = [H^q(0), H^q(1), \ldots, H^q(N-1)]^T$ where N = 128 is the fast Fourier transform (FFT) size i.e., number of subcarriers in each OFDM symbols. Assuming perfect synchronization and performing the necessary receiving operations and signal processing, the frequency domain samples of the n^{th} received OFDM symbol for the q^{th} sub-band $Y^q_n = [Y^q(0), Y^q_n(1), \ldots, Y^q(N-1)]^T$ is given by $Y^q_n(k) = X^q_n(k)H(k) + W^q_n(k)$ $k \in \{0, 1, \ldots, N-1\}$ where $X^q_n = [X^q_n(0), X^q_n(1), \ldots, X^q_n(N-1)]^T$ is the n^{th} transmitted OFDM symbol using q^{th} sub-band, and $W^q_n(k)$ is the channel noise at the k^{th} subcarrier in the q^{th} sub-band and is modeled as complex Gaussian random variable with mean zero and variance σ^2_w. $X^q_n(k)$ represents the n^{th} symbol transmitted at the k^{th} subcarrier using qth sub-band. We transmit the same information across two consecutive PLCP service data unit (PSDU) OFDM symbols to introduce the time-domain spreading. And, within each OFDM symbol, frequency-spreading is introduced i.e., the same informationis transmitted on two different subcarriers. Time-spreading in first OSG for sub-band 1 can be achieved as

$$X^1_n(k) = X^1_v(k),\ n \in (\pi_{11},\ v \in (\pi_{21} \cup \pi_{31});\ |n - v| = 1 \quad (1)$$

$$X^1_n(k) = [X^1_n(N-k)]^*,\ k \in Z \text{ and } k \leq (N/2) n \in (\pi_1 \cup \pi_2 \cup \pi_3) \quad (2)$$

where $[Q]^*$denotes the complex conjugate of Q. It is clearthat there are 2 training symbols and 4 payload symbols for channel estimation on each sub-band during each OSG. For simplicity, we show the analysis for sub-band 1 and omit the symbol q. The channel estimation strategy is the same for other bands too.

III. PROPOSED METHOD

Starting with the preamble-stage, in step 1, we obtain an initial CFR estimation $\hat{H}_1(k)$, performing simple least square (LS) approach as

$$\hat{H}_1(k) = \frac{1}{\theta_1}\sum \frac{Y_n(k)}{X_n(k)} = \frac{1}{\theta_1}\sum_{n\in\Gamma_1} Y_n(k)[X_n(k)]^* \quad (3)$$

The estimation using this is usually thought to have residual error. Therefore, we perform step 2 and step 3 to reduce this error. In step 2, we relate a straight forward frequency-domain smoothing operation on $\hat{H}_1(k)$ and obtain

$\hat{H}_2(k)$. The reason why this frequency-smoothing is used can be realized by verifying the relation between the channel coherent bandwidth and the subcarrier spacing. In third step, we perform windowing operation on estimated channel at step 2. There are few Discrete Fourier Transform (DFT)-based channel estimation methods for MB-OFDM systems with time-domain windowing [4]. However, they just directly assume the length of windowand set the value of zero for the samples outside the windowlength. This causes performance degradation in MMSE sense[5]. Now, we find a rectangular window whose length is optimizedusing Hannan-Quinn criteria (HQC) [6].

The estimatedCIR from step 2 denoted by $\hat{h}_2$ can be obtained as $\hat{h}_2$ is given by

$$\hat{h}_2 = F^H \hat{H}_2 \quad (4)$$

where F is the N × N DFT matrix whose (m, n) element is given by

$$F_{m,n} = \frac{1}{\sqrt{N}} \exp(-\frac{j2\pi mn}{N}) \text{ with } 0 \le m,n \le N-1$$

Let us define autocorrelation function of CIR at step 2 as

$$\phi = \frac{1}{3}\sum_{q=1}^{3} \hat{h}_2^q \left(\hat{h}_2^q\right)^H \quad (5)$$

Taking the diagonal elements and sorting these elements with descending approach, we form the new vector as

$$\phi' = [\phi_0, \phi_1, \ldots, \phi_{N-1}]^T \quad (6)$$

Define the feat function (FF) as

$$FF(l) = f_1(l) - f_2(l) + f_3(l),\ l = 0, 1, \ldots, N-1 \quad (7)$$

The normalized FF (NFF) is obtained by

$$NFF(l) = \frac{FF(l)}{\max(FF(l))} \quad (8)$$

where max(FF(l)) is the maximum element in FF. Therefore,the estimated length of rectangular window becomes

$$\hat{L} = \min_{\arg l} NFF(l),\ l = 0, 1, \ldots, N-1 \quad (9)$$

Now, the windowed CIR is

$$\hat{h}_3 = \begin{cases} \hat{h}_{2(n)} & ; n \le \hat{L} \\ 0 & else \end{cases} \quad (10)$$

Thus, the estimated channel at step 3 can be obtained as

$$\widehat{H_3} = F\hat{h}_3 \quad (11)$$

$\widehat{H_3}$ can also be achieved in the frequency-domain by adopting the DFT-based MMSE approach on $\widehat{H_2}$

In payload stage, we first detect the OFDM symbols within the OSG using the estimated channel ˆH3 obtained from the preamble stage. Then, we obtain a refined estimated CFR in decision-directedapproach [7]. In detecting the OSG symbol on sub-band 1, we first compute

$$\hat{X}_n(k) = \frac{Y_n(k)}{\widehat{H_3^2}(k)},\ n \in \pi_{11};\ k \in Z \quad (12)$$

$$\hat{X}_v(k) = \frac{Y_v(k)}{\widehat{H_3^2}(k)},\ v \in (\pi_{21} \cup \pi_{31});\ k \in Z \quad (13)$$

Therefore, using time- and frequency-redundancy introduced in the transmitted signal by (2) and (3), we get the estimators for $\theta_n(k)$ and $\vartheta_n(k)$. The detection performance in low-signal to noise ratio (SNR)region can be increased by using a CFR-weighted detection scheme.

With the detected OSG, we find the decision-directed estimated channel. In the following two steps, we repeat the same operations as we did in step 2 and step 3 during preamble stage. Finally, we do a weighted average to get the decisive estimated channel.

IV. PERFORMANCE EVALUATION

To assess the performance of the proposed technique, we execute computer simulation using MATLAB. We evaluate both the normalized mean square error (NMSE) and the computational complexity performances. We consider CM1 and CM4 as the target channel models and use the mandatory band group 1 with preamble1 and time-frequency code (TFC) 1. CM1 represents line-of-sight (LOS) scenario, whereas CM4 represents non-line-of-sight (NLOS) scenario. Different timing-related parameters such as values of sampling frequency, and FFT size are taken according to the standard ECMA-368 [3]. With this simulation setup, we achieve the results. The two-stage method outperforms LS approach across the entire range of SNR in both CM1 and CM4 channels. This is largely due to the contribution of channel refinement at payload stage; the deviation of estimated CIR at preamble stage is rectified taking instantaneous channel fluctuations during symbol decoding into considerations. Significant credit goes to grabbing channel variations in both time and frequency domain during symbol detection in decision-directed phase.

The two-stage method with fixed windowing offers 1 dB performance improvement over LS estimation. A further 0.5 dB improvement at low SNRs by two-stage method has been obtained due to the use of optimized-windowing. The net contribution of the 1.5 dB NMSE performance improvement by our proposed method over LS estimation is thus the ultimate consequence of introducing diversity at second stage, and the use of optimized-windowing. Since interference due to inapt windowing causes deterioration of signal strength at low SNR and no longer dominates the signal at high SNR, the performances of two-stage scheme with optimized windowing coincide with that of two-stage method with fixed length windowing beyond the SNR of 15dB. The proposed technique exhibits almost similar performances to that of MMSE method in both CM1 and CM4 environments. MMSE technique in general outperforms the LS approach by 3dB.

V. CONCLUSION

We have proposed a simple two-stage channel estimation technique for MB-OFDM UWB systems. This method provides a good estimation performance, since it considers channel fluctuations by using time- and frequency diversity at preamble stage and eliminates interference caused by inapt windowing with the help of optimized-windowing. Since its NMSE performance is close to that of MMSE scheme with significant reduction in implementation complexity, the proposed method can be utilized in practical high rate UWB system.

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