ISTANBUL UNIVERSITY –
JOURNAL OF ELECTRICAL & ELECTRONICS ENGINEERING

YEAR : 2005 (1333-1340)
VOLUME : 5
NUMBER : 1

THE ADAPTIVE CHANNEL ESTIMATION FOR STBC-OFDM SYSTEMS

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ABSTRACT

In this paper, we propose adaptive channel estimation methods based on LMS and RLS for orthogonal STBC-OFDM systems with three transmit antennas. The performance of the proposed algorithms is obtained in the frequency selective channels using Hiperlan/2 characteristics.

Keywords: *Space-time block coded OFDM, adaptive channel estimation*

1. INTRODUCTION

In order to provide the users mobile multimedia services such as high speed mobile internet access at better quality of services, at higher data rates and higher mobility, the wireless communication systems should improve link reliability and spectral efficiency in frequency selective fading channels [1]. Multiple-input multiple-output (MIMO) communication systems that use multiple transmit and multiple receive antennas, increase the data rate without expanding the bandwidth [2], increase the diversity and improve the performance against fading channels using space-time codes. The orthogonal frequency division multiplexing (OFDM) technique which transforms a frequency selective channel into parallel flat fading subchannels [3] is a potential candidate for high data rate wireless transmission. Therefore, in frequency selective fading channels, MIMO codes can be combined with OFDM in the time dimension as space-time block coded (STBC)-OFDM [4] and SFBC-OFDM in frequency domain [5] for the next generation wireless communication systems.

It is proven by the Hurwitz-Radon theorem that orthogonal STBC which can provide full diversity and full rate and can be decoded by simple linear decoder, does not exist for systems with more than two transmit antennas over complex constellations [6]. For any number of transmit antennas, the generalized design issues for STBC has been presented in [7][8]. These orthogonal codes achieve transmission rate 1 for real constellations, transmission rate 1 for complex constellations with two transmit antennas and transmission rates 1/2 and 3/4 for complex constellations with more than two transmit antennas. For these codes, since the orthogonal structures are used, a maximum likelihood (ML) decoding becomes a linear processing at the receiver. In this paper, for orthogonal STBC systems with three transmit antennas, we use the code matrix which provides

Received Date : 16.09.2004
Accepted Date: 14.01.2005

full diversity gain with linear operations at the receiver side at transmission rate of 3/4 [9].

The performance of the communication systems relies on the knowledge of channel state information (CSI) at the receiver side. Therefore, the efficient algorithms should be used to estimate channel parameters. Since STBC systems are designed assuming that the channel coefficients are perfectly known at the receiver side, the estimation of channel coefficient that approaches the ideal case is very important in term of performance. In [10] and [11], adaptive channel estimation algorithms based on least mean square (LMS), recursive least square (RLS) and Kalman filtering [12] have been examined for STBC in time varying flat fading channels. In [13], the channel tracking and equalization based on LMS, RLS and Kalman filtering have been proposed for MIMO systems in time varying frequency selective channels. For MIMO-OFDM systems, the channel tracking and equalization method based on Kalman filtering has been proposed in [14] in time varying channels. In this method, tracking and equalization of MIMO channel matrix has been performed in time and frequency domain respectively to reduce computational complexity. In addition, the Kalman filter technique for pilot symbol assisted MIMO-OFDM channel tracking has been examined for the time varying channels in [15]. The comparison of time and frequency domain channel tracking algorithms based on Kalman filtering has been examined in [16] for MIMO-OFDM systems. In this paper, we propose adaptive channel estimation algorithms based on LMS and RLS in frequency domain for STBC-OFDM systems with three transmit antennas in frequency selective channels.

In section 2, we will explain the STBC-OFDM system model with three transmit antennas. In section 3, we will propose the adaptive channel estimation algorithms based on LMS and RLS. Finally, in section 4, we will give the simulation results compared to perfect CSI results using Hiperlan/2 characteristics.

2. SYSTEM MODEL FOR STBC-OFDM

In order to obtain third order diversity gain in frequency selective fading channels, STBC with rate 3/4 for three transmit antennas are combined with OFDM as shown in Figure 1 [4]. The STBC encoder for three transmit antennas is used the G_3 code matrix presented in Equation (1). Since three symbols are transmitted using four time interval, the rate of the code is 3/4.

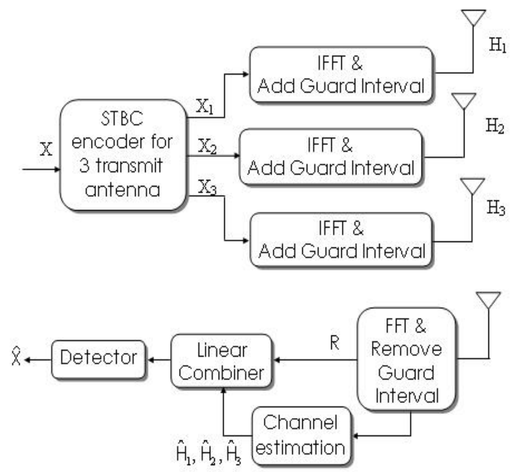

Figure 1: Transmitter and receiver scheme of STBC-OFDM with three transmit antenna

$$G_3 = \begin{bmatrix} s_1 & s_2 & s_3 \\ -s_2^* & s_1^* & 0 \\ s_3^* & 0 & -s_1^* \\ 0 & s_3^* & -s_2^* \end{bmatrix} \tag{1}$$

As shown in Figure 1, the outputs of STBC X_1, X_2 and X_3 are transmitted though the multipath fading channel after applying inverse fast Fourier Transform (IFFT) and adding guard interval. The transmitted symbols belonging k th subcarrier and three adjacent OFDM symbols $X_{1,k}(3n), X_{2,k}(3n+1)$ and $X_{3,k}(3n+2)$ are represented in matrix form as given in Equation (2). For $k = 1, 2, ..., K$ each row of the matrix is transmitted from the three antennas $(\ell = 1, 2, 3)$ simultaneously.

$$\text{Antenna} \rightarrow \quad \text{Time} \downarrow \begin{bmatrix} X_k(3n) & X_k(3n+1) & X_k(3n+2) \\ -X_k^*(3n+1) & X_k^*(3n) & 0 \\ X_k^*(3n+2) & 0 & -X_k^*(3n) \\ 0 & X_k^*(3n+2) & -X_k^*(3n+1) \end{bmatrix} \tag{2}$$

The subcarrier channel vector between the ℓ th transmit and receive antenna for n th OFDM symbol vector are denoted by $H_\ell(n) = \left[H_{\ell,1}(n) \quad H_{\ell,2}(n) \quad \ldots \quad H_{\ell,K}(n) \right]$. If we assume that the channel coefficients do not change during the four OFDM symbol transmission $H_{\ell,k}(4n) = H_{\ell,k}(4n+1) = H_{\ell,k}(4n+2) = H_{\ell,k}(4n+3)$, we represent the system model given in Equation (3).

$$R_k(n) = \mathcal{H}_k(n) X_k(n) + N_k(n) \qquad (3)$$

where $R_k(n) = \left[R_k(4n) \quad R_k^*(4n+1) \quad R_k^*(4n+2) \quad R_k^*(4n+3) \right]^T$ is the received vector for each subcarrier, $X_k(n) = \left[X_k(3n) \quad X_k(3n+1) \quad X_k(3n+2) \right]^T$ is the transmitted symbols, $N_k(n) = \left[N_k(4n) \quad N_k^*(4n+1) \quad N_k^*(4n+2) \quad N_k^*(4n+3) \right]^T$ is the additive white Gaussian noise vector whose elements are zero mean and σ^2 variance and $\mathcal{H}_k(n)$ is the channel transfer matrix as given in Equation (4).

$$\mathcal{H}_k(n) = \begin{bmatrix} H_{1,k}(4n) & H_{2,k}(4n) & H_{3,k}(4n) \\ H_{2,k}^*(4n) & -H_{1,k}^*(4n) & 0 \\ -H_{3,k}^*(4n) & 0 & H_{1,k}^*(4n) \\ 0 & -H_{3,k}^*(4n) & H_{2,k}^*(4n) \end{bmatrix} \qquad (4)$$

Assuming the channel transfer matrix has been estimated, the reconstructed symbol vector is obtained multiplying the received vector with $\hat{\mathcal{H}}_k^H(n)$ which is transpose-conjugate of channel transfer matrix.

$$\hat{X}_k(n) = \hat{\mathcal{H}}_k^H(n) \mathcal{H}_k(n) X_k(n) + \hat{\mathcal{H}}_k^H(n) N_k(n) \qquad (5)$$

3. THE PROPOSED ADAPTIVE CHANNEL ESTIMATION METHOD

We propose an adaptive channel estimation based on LMS and RLS algorithms in frequency domain. The channel coefficients are estimated using N_p pilot OFDM symbols in training mode as is given in Figure 2.

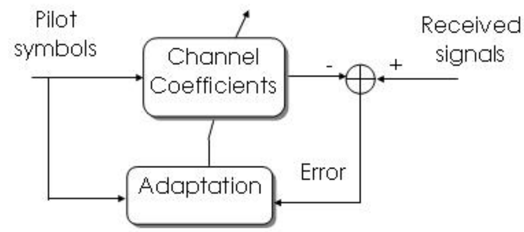

Figure 2. The adaptive filter structure

After estimating the channel coefficients, the reconstructed symbols are used as pilot symbols in tracking mode to track the channel coefficients during the transmission.

The filter coefficients are adapted by using RLS algorithm which has small converge time than LMS)algorithm [12]. For each subcarrier, the channel transfer matrix of STBC-OFDM with three transmit antennas given in Equation (4) is estimated using LMS and RLS adaptation algorithms.

For four time interval, the pilot OFDM symbols that belongs to kth subcarrier are defined as

$$\begin{aligned} S_{4n,k} &= \left[X_k(3n) \quad X_k(3n+1) \quad X_k(3n+2) \right]^T \\ S_{4n+1,k} &= \left[-X_k^*(3n+1) \quad X_k^*(3n) \quad 0 \right]^T \\ S_{4n+2,k} &= \left[X_k^*(3n+2) \quad 0 \quad -X_k^*(3n) \right]^T \\ S_{4n+3,k} &= \left[0 \quad X_k^*(3n+2) \quad -X_k^*(3n+1) \right]^T \end{aligned} \qquad (6)$$

Using the pilot OFDM symbols in Equation (6), the adaptive algorithm is summarized as follows:

LMS algorithm for $n = 2,3,\ldots,N_p$

$$\begin{aligned} E_{n,k} &= R_{n,k} - S_{n,k}^T \hat{H}_k(n-1) \\ \hat{H}_k(n) &= \hat{H}_k(n-1) + \mu E_{n,k} S_{n,k}^* \end{aligned} \qquad (7)$$

RLS algorithm for $n = 2,3,\ldots,N_p$

$$\begin{aligned} E_{n,k} &= R_{n,k} - S_{n,k}^T \hat{H}_k(n-1) \\ K &= P_k S_{n,k} (\lambda + S_{n,k}^H P S_{n,k})^{-1} \\ P_k &= (P_k - K S_{n,k}^H P_k) / \lambda \\ \hat{H}_k(n) &= \hat{H}_k(n-1) + E_{n,k} P_k S_{n,k}^* \end{aligned} \qquad (8)$$

where μ is the step size for LMS, λ is the forgotten factor for RLS and $E_{n,k}$ is the error vector for each step. $S_{n,k}$ pilot symbols are chosen from Equation (6) according to n value. Here, the estimated channel vector belonging to kth subcarrier is defined as $\hat{H}_k(n) = \left[\hat{H}_{1,k}(n) \quad \hat{H}_{2,k}(n) \quad \hat{H}_{3,k}(n)\right]^T$.

4. SIMULATION RESULTS

The simulation results are obtained using Hiperlan/2 specifications as given in Table 1 [17] and Channel model A characteristics which corresponds to a typical office environment and its power delay profiles are given in Table 2 [18]. Classical Jakes' Doppler spectrum [19] choosing the Doppler frequency 15Hz are used and Rayleigh fading statistics are assumed for all taps. Therefore, each tap has a complex gain with Rayleigh amplitude and uniformly distributed phase.

The Hiperlan/2 standard provides the data rate from 6Mbps to 54Mbps according to type of modulation and channel encoder. We choose QPSK modulation scheme without channel coding for simulation results.

In Figure 3, the absolute value of channel transfer function is plotted versus subcarriers and OFDM frames. Notice that, the channel transfer function changes between subcarriers in single OFDM frame while the whole function changes very slowly from frame to frame due to the fact that a low Doppler frequency is chosen.

In order to compare the convergence properties of LMS and RLS algorithms, we draw the instantaneous mean squared error versus number of step as shown in Figure 4 for 30dB signal-to-noise ratio (SNR) at the transmitter side. According to Figure 4, RLS algorithm has better convergence properties compared to LMS algorithm.

Therefore, we choose RLS algorithm by using 12 pilot OFDM symbols following 88 data OFDM symbols. Each data OFDM symbol includes 52 data symbols instead of 4 pilot and 48 data symbol as in Hiperlan/2 characteristics. Thus, the reduction effect of pilot symbols in data rate is tolerated using only data symbols after pilot symbols. Again 12 OFDM symbols are used as retraining sequence after each 88 transmitted OFDM symbols in order to avoid divergence since the channel is a slowly time varying channel.

Table 1. Hiperlan/2 System Parameters

Bandwidth	20MHz
Total OFDM symbol duration	4μs
Guard Interval duration	0.8μs
Sampling time	50ns
The number of used subcarrier	52
The number of data subcarrier	48
The number of pilot subcarrier	4
FFT size (K)	64
The spacing of subcarrier	0.3125MHz

Table 2. Power delay profile for Channel Model A of Hiperlan/2 standard

Path	Delay (ns)	Power (dB)	Path	Delay (ns)	Power (dB)
1	*0*	*0.0*	*10*	*90*	*-7.8*
2	*10*	*-0.9*	*11*	*110*	*-4.7*
3	*20*	*-1.7*	*12*	*140*	*-7.3*
4	*30*	*-2.6*	*13*	*170*	*-9.9*
5	*40*	*-3.5*	*14*	*200*	*-12.5*
6	*50*	*-4.3*	*15*	*240*	*-13.7*
7	*60*	*-5.2*	*16*	*290*	*-18.0*
8	*70*	*-6.1*	*17*	*340*	*-22.4*
9	*80*	*-6.9*	*18*	*390*	*-26.7*

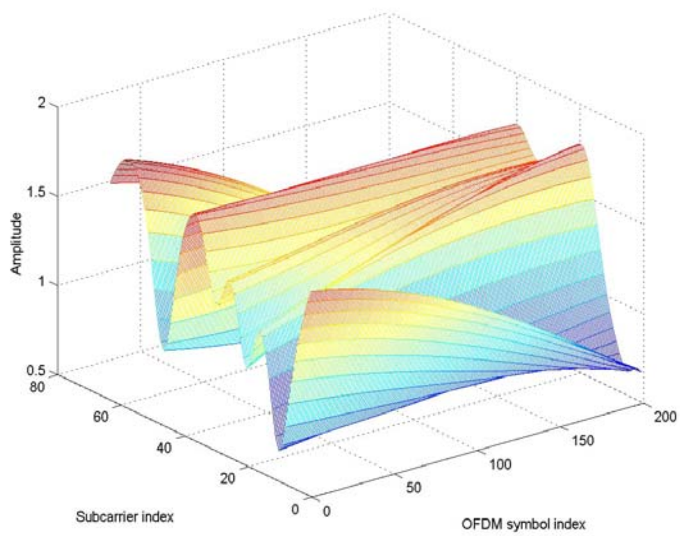

Figure 3. Channel Transfer Function for Hiperlan/2 at v=50m/sec

In order to compare the estimated channel coefficients with actual values, we draw the amplitude and phase values of complex channel coefficients for each antenna and for all subcarriers as illustrated in Figure 5 and Figure 6, respectively. According to curves, it can be observed that the estimated channel coefficients approach the actual values in reasonable degree .

We obtain the simulation results for STBC-OFDM with three transmit and one receive antenna using Hiperlan/2 characteristics as shown in Figure 7. We compare the BER performance that are obtained assuming the channel coefficients are perfectly known at the receiver (ideal case) with the BER performance that are obtained estimating the channel coefficients using RLS algorithm. According to results, the BER performance of the scheme with the RLS equalizer approaches to perfect CSI model with a difference of 2 dB at BER=10^{-4}. Moreover, STBC-OFDM with three transmit and one receive antenna gives approximately 8dB diversity gain at BER=10^{-3} compared to only OFDM case.

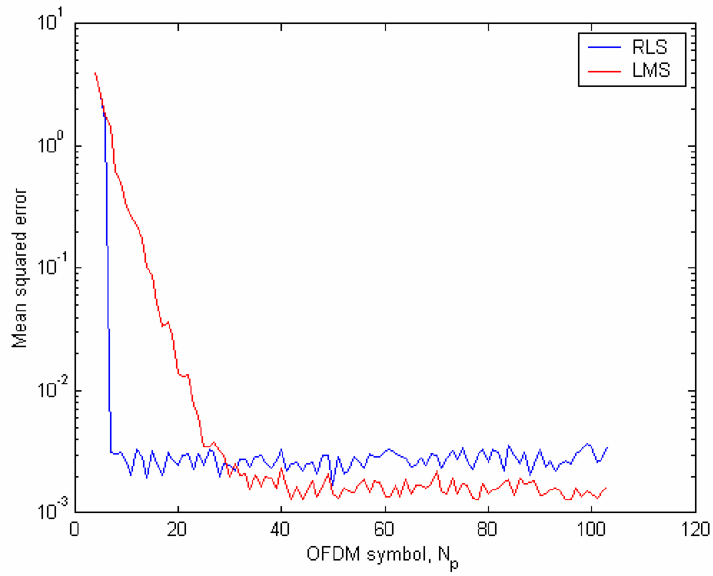

Figure 4. The mean squared error

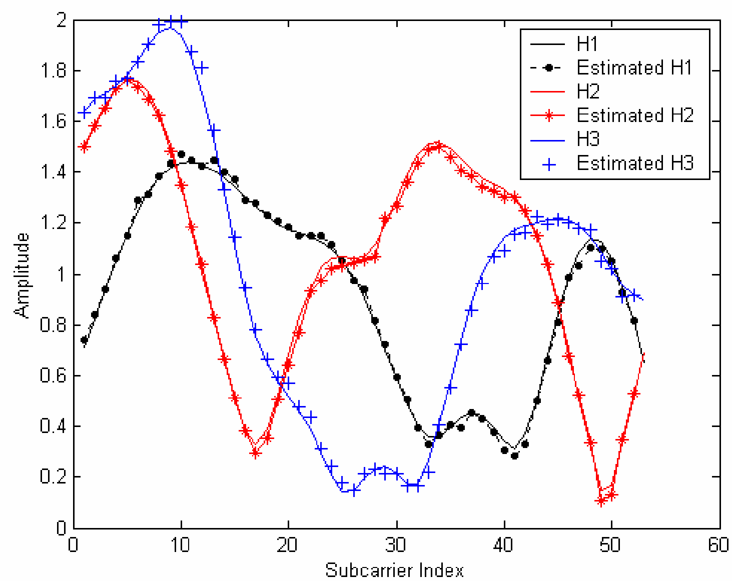

Figure 5. Amplitude values of estimated and actual channel coefficients for each transmit antenna for all subcarriers

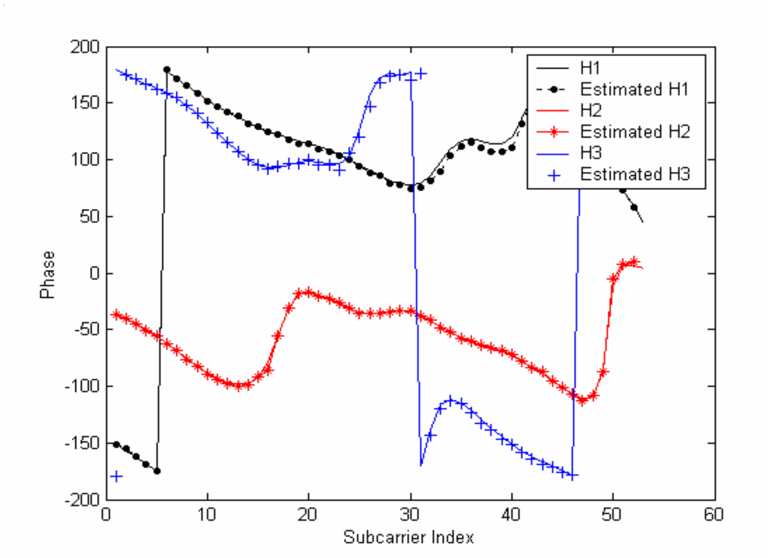

Figure 6. Phase values of estimated and actual channel coefficients for each transmit antenna for all subcarriers

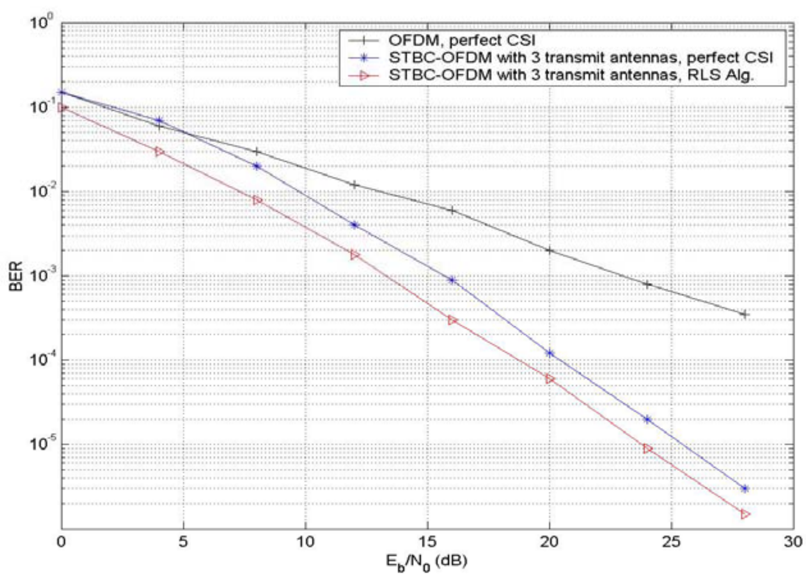

Figure 7. The BER performance for STBC-OFDM system with three transmit and one receive antenna for Hiperlan/2

5. CONCLUSION

In this paper, we have proposed adaptive channel estimation based on LMS and RLS algorithms in frequency domain. We have shown that the BER results that are obtained using proposed RLS algorithm approach the BER results assuming the channel coefficients are perfectly known at thee transmitter side with a reasonable degree.

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